U.S. Department
of Transportation

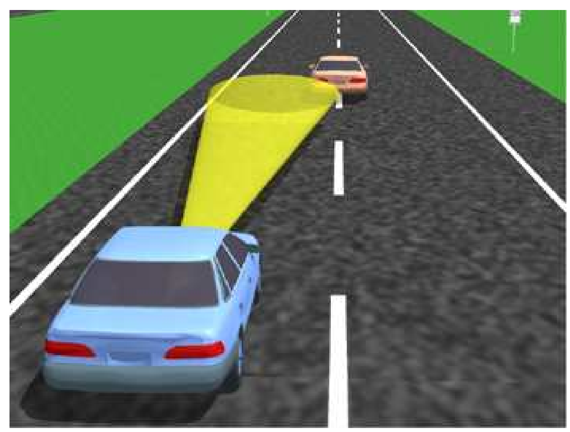
**National Highway
Traffic Safety
Administration**

People Saving People
www.nhtsa.dot.gov

DOT-VNTSC-NHTSA-06-01
DOT HS 810 569

March 2006

Evaluation of an Automotive Rear-End Collision Avoidance System



Research and Innovative
Technology Administration

Volpe National Transportation Systems Center
Cambridge, MA 02142-1093

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
January 2006

3. REPORT TYPE AND DATES COVERED
Final Report
June 1999 – January 2006

4. TITLE AND SUBTITLE
Evaluation of an Automotive Rear-End Collision Avoidance System

5. FUNDING NUMBERS

6. AUTHOR(S)
Wassim G. Najm, Mary D. Stearns, Heidi Howarth, Jonathan Koopmann, and John Hitz

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Research and Innovative Technology Administration
Advanced Safety Technology Division
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

8. PERFORMING ORGANIZATION REPORT NUMBER
DOT-VNTSC-NHTSA-06-01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
National Highway Traffic Safety Administration

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DOT HS 810 569

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report presents the results of an independent evaluation of the Automotive Collision Avoidance System (ACAS). The ACAS integrates forward collision warning (FCW) and adaptive cruise control (ACC) functions for light-vehicle applications. The FCW detects, assesses, and alerts the driver of a potential hazard in the forward region of the vehicle. The ACC provides automatic brake and throttle actuation in order to maintain speed and longitudinal headway control. Through the integration of these two functions, ACAS is intended to improve automotive safety by assisting drivers to avoid rear-end crashes. To accomplish this goal, the ACAS must also prove useful and acceptable to drivers.

The Volpe National Transportation Systems Center conducted the independent evaluation of the ACAS based on data collected from a field operational test (FOT) and from an independent system characterization test. The goals of the independent evaluation were to: characterize ACAS performance and capability; achieve a detailed understanding of ACAS safety benefits; and determine driver acceptance of ACAS. Data was collected from the ACAS FOT that employed 10 vehicles using a total of 66 drivers that included three age groups (younger, middle-age, and older) with equal numbers of male and female drivers.

14. SUBJECT TERMS
Automotive collision avoidance, forward collision warning, adaptive cruise control, field operational test, automotive safety, rear-end crash avoidance

15. NUMBER OF PAGES
423

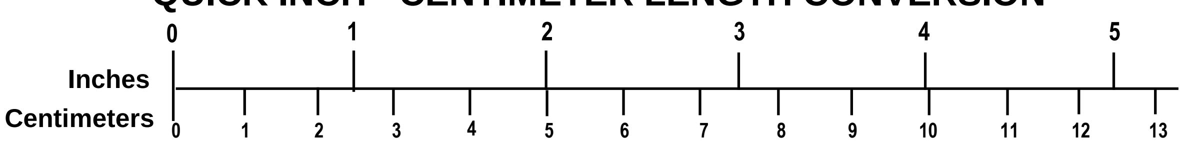
16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

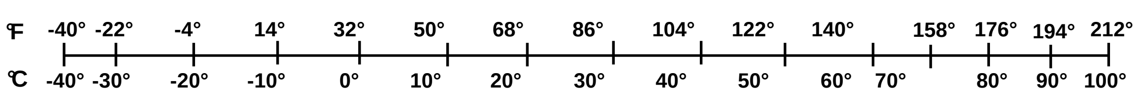
METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC		METRIC TO ENGLISH	
LENGTH (APPROXIMATE)		**LENGTH** (APPROXIMATE)	
1 inch (in)	= 2.5 centimeters (cm)	1 millimeter (mm)	= 0.04 inch (in)
1 foot (ft)	= 30 centimeters (cm)	1 centimeter (cm)	= 0.4 inch (in)
1 yard (yd)	= 0.9 meter (m)	1 meter (m)	= 3.3 feet (ft)
1 mile (mi)	= 1.6 kilometers (km)	1 meter (m)	= 1.1 yards (yd)
		1 kilometer (km)	= 0.6 mile (mi)
AREA (APPROXIMATE)		**AREA** (APPROXIMATE)	
1 square inch (sq in, in^2)	= 6.5 square centimeters (cm^2)	1 square centimeter (cm^2)	= 0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2)	= 0.09 square meter (m^2)	1 square meter (m^2)	= 1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2)	= 0.8 square meter (m^2)	1 square kilometer (km^2)	= 0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)	10,000 square meters (m^2)	= 1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)		
MASS - WEIGHT (APPROXIMATE)		**MASS - WEIGHT** (APPROXIMATE)	
1 ounce (oz)	= 28 grams (gm)	1 gram (gm)	= 0.036 ounce (oz)
1 pound (lb)	= 0.45 kilogram (kg)	1 kilogram (kg)	= 2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)	1 tonne (t)	= 1,000 kilograms (kg)
			= 1.1 short tons
VOLUME (APPROXIMATE)		**VOLUME** (APPROXIMATE)	
1 teaspoon (tsp)	= 5 milliliters (ml)	1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 tablespoon (tbsp)	= 15 milliliters (ml)	1 liter (l)	= 2.1 pints (pt)
1 fluid ounce (fl oz)	= 30 milliliters (ml)	1 liter (l)	= 1.06 quarts (qt)
1 cup (c)	= 0.24 liter (l)	1 liter (l)	= 0.26 gallon (gal)
1 pint (pt)	= 0.47 liter (l)		
1 quart (qt)	= 0.96 liter (l)		
1 gallon (gal)	= 3.8 liters (l)		
1 cubic foot (cu ft, ft^3)	= 0.03 cubic meter (m^3)	1 cubic meter (m^3)	= 36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)	1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)		**TEMPERATURE** (EXACT)	
[(x-32)(5/9)] °F	= y °C	[(9/5) y + 32] °C	= x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

PREFACE

The Volpe National Transportation Systems Center (Volpe Center) of the U.S. Department of Transportation's (U.S. DOT) Research and Innovative Technology Administration, in conjunction with the National Highway Traffic Safety Administration (NHTSA), is conducting independent evaluations of various crash avoidance systems in support of the U.S. DOT's Intelligent Vehicle Initiative (IVI). The IVI focuses on solving traffic safety problems through the development and deployment of vehicle-based and vehicle-infrastructure cooperative crash countermeasures that address rear-end, roadway departure, lane change, crossing paths, driver impairment, reduced visibility, vehicle instability, pedestrian, and pedalcyclist crashes. The purpose of the independent evaluations is to assess the impact of crash avoidance systems on factors, such as safety benefits and driver acceptance, which influence the decision of government officials and private industry to accelerate the deployment of these systems in the U.S. vehicle fleet and infrastructure. Crash avoidance prototypes or production-intent systems have been built and undergone field operational tests for four vehicle platforms including light vehicles (passenger cars, sport utility vehicles, vans, minivans, and pickup trucks), commercial vehicles (medium and heavy trucks), transit vehicles (buses, but not school buses), and specialty vehicles (police, fire, ambulance, snow plows, and other roadway maintenance vehicles).

This report presents the results of an independent evaluation by the Volpe Center to estimate the safety benefits, determine driver acceptance, and characterize the capability of an automotive rear-end crash avoidance system built by General Motors and Delphi Electronics for light-vehicle applications. This was a part of the Automotive Collision Avoidance System Field Operational Test (ACAS FOT) program sponsored by NHTSA. According to the 2002 National Automotive Sampling System/General Estimates System crash database, light vehicles were involved in approximately 1.8 million police-reported rear-end crashes in the United States or about 29 percent of all light-vehicle crashes. These rear-end crashes resulted in about 850,000 injured people.

The authors of this report are *Wassim Najm, Mary Stearns*, *Heidi Howarth*, *Jonathan Koopmann*, and *John Hitz*.

The authors acknowledge the technical contribution and support of many individuals in different organizations. Appreciations are due to *Jack Ference*, program manager, and to *Dr. August Burgett* and Dr. *David L. Smith* of NHTSA for their support and technical guidance. Also acknowledged are the following Volpe Center staff people who contributed to many aspects of the independent evaluation:

- *Frank Foderaro*: database and software management as well as data query
- *Andy Lam*: data processing and conflict identification algorithms
- *Marco daSilva*: Monte Carlo computer simulation models
- *Sara Secunda*: GPS/GIS vehicle location algorithm
- *Bruce Wilson*: data processing and conflict identification algorithms
- *Linda Boyle*: driver acceptance framework and survey composition

- *Jonathan Tam*: analysis of video episodes
- *Paul Schimek*: evaluation planning

The authors also acknowledge *Raman Sampath* and *Balaji Gopalan* of Computer Sciences Corporation for their diligent efforts in building and maintaining the database, developing the multimedia data analysis tool, programming various algorithms, and performing data query. Researchers at the University of Michigan Transportation Research Institute were very helpful and cooperative in transferring FOT data, explaining data anomalies, providing video processing and time synchronization routines, accommodating Volpe Center staff for subject debriefings and focus groups, responding quickly to inquiries, supporting the system characterization test, and sharing their overall expertise in running FOTs. The technical staffs at General Motors and Delphi Electronics were also helpful in explaining various aspects of system operation. Finally, *Cassandra Oxley* of Chenega Advanced Solutions and Engineering (CASE, LLC) is appreciated for editing this report.

LIST OF ACRONYMS

ACAS	Automotive Collision Avoidance System
ACC	Adaptive Cruise Control
ANOVA	Analysis of Variance
BTS	Bureau of Transportation Statistics
CAMP	Crash Avoidance Metrics Partnership
CCC	Conventional Cruise Control
CDS	Crashworthiness Data System
CIPS	Closest In-Path Stationary
CIPV	Closest In-Path Moving Vehicle
DARPA	Defense Advanced Research Projects Agency
DAS	Data Acquisition System
DCS	Delphi Chassis Systems
DES	Delphi Electronics and Safety
DGPS	Differential Global Positioning System
DVI	Driver-Vehicle Interface
$E(S_i)$	ACAS effectiveness in scenario S_i
EE	Exposure Effectiveness
EP	Prevention Effectiveness
ER	Exposure Ratio
FCW	Forward Crash Warning
FHWA	Federal Highway Administration
FOT	Field Operational Test
GES	General Estimates System
GIS	Geographical Information System
GM	General Motors
HRL	Hughes Research Laboratory
HUD	Head-Up Display
ICC	Intelligent Cruise Control
IV	Independent Variable
IVI	Intelligent Vehicle Initiative
LTAP	Left Turn Across Path
LVA	Lead Vehicle Accelerating
LVD	Lead Vehicle Decelerating
LVM	Lead Vehicle Moving at Slower Constant Speed
LVS	Lead Vehicle Stopped

MANOVA	Multivariate Analysis of Variance
MOP	Measure of Performance
NHTS	National Household Travel Survey
NHTSA	National Highway Traffic Safety Administration
N_{wo}	Annual number of rear-end crashes prior to ACAS deployment
OEM	Original Equipment Manufacturer
PR	Prevention Ratio
$P_w(C)$	Probability of a crash type C with ACAS assistance
$P_w(C\|S)$	Probability of a crash of type C with ACAS assistance given that driving conflict S has been encountered
$P_w(S)$	Probability of an encounter with driving conflict S with ACAS assistance
$P_{wo}(C)$	Probability of a crash type C without ACAS assistance
$P_{wo}(C\|S)$	Probability of a crash of type C without ACAS assistance given that driving conflict S has been encountered
$P_{wo}(S)$	Probability of an encounter with driving conflict S without ACAS assistance
$P_{wo}(S_i\|C)$	Probability of an encounter with driving conflict scenario S_i prior to a crash given that a rear-end crash has happened *without* ACAS assistance
RITA	Research and Innovative Technology Administration
SE	System Effectiveness
TAM	Technology Acceptance Model
TH	Time Headway
TTC	Time-To-Collision
U.S. DOT	United States Department Of Transportation
UMTRI	University of Michigan Transportation Research Institute
VDT	Vehicle Distance Traveled

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This report presents the results of an independent evaluation by the Volpe Center to assess an automotive rear-end crash avoidance system built by General Motors and Delphi Electronics for light-vehicle applications. According to the 2002 National Automotive Sampling System/ General Estimates System (NASS/GES) crash database, light vehicles (e.g., passenger cars, vans, minivans, sport utility vehicles, and light trucks) were involved in approximately 1.8 million police-reported rear-end crashes in the United States or about 29 percent of all light-vehicle crashes. These rear-end crashes resulted in about 850,000 injured people.

System Description

This rear-end crash avoidance system is known as the Automotive Collision Avoidance System (ACAS), which consists of both forward crash warning (FCW) and adaptive cruise control (ACC) functions. The FCW detects, assesses, and alerts the driver of a potential hazard in the forward region of the host vehicle. The FCW is automatically functional when the host vehicle speed exceeds 25 mph (40 km/h), and becomes inactive when the speed falls below 20 mph (32 km/h). The ACC uses automatic brake and throttle to maintain speed and longitudinal headway control. The maximum braking authority of ACC is 0.3g. Cautionary alerts are visually presented to the driver by means of a color head-up display (HUD). The driver can control the sensitivity of visual cautionary alerts in six settings. Crash imminent alerts consist of both a flashing visual display (HUD) and an auditory alert from a speaker embedded in the dashboard, which occur simultaneously. The timing of the flashing visual display and the auditory tone are not adjustable. The driver can set the gap headway of ACC in six steps between 1 and 2 seconds. The ACC possesses a warning capability that takes into account the braking that ACC can provide (up to 0.3 g). In integrating FCW and ACC functions, the ACAS is intended to improve automotive safety by assisting drivers to avoid rear-end crashes.

Description of Field Operational Test

The ACAS underwent a field operational test (FOT) that was conducted with 10 equipped vehicles from March 2003 to November 2004. Ninety-six subjects were selected from the State of Michigan as FOT participants, 66 of which were exposed to the final version of the ACAS that was evaluated in this report. They were split equally by gender and three age groups: younger (20 to 30 years old), middle-age (40 to 50 years old), and older (60 to 70 years old). Each subject drove the ACAS-equipped vehicle as his or her own personal car for a test period of four weeks, unsupervised and unrestricted. The first week was dedicated to collecting baseline driving data, i.e., *without* the assistance of the ACAS. During this week, FOT subjects drove with manual control and also had the option of using conventional cruise control (CCC). During the remaining three weeks, driving was performed *with* the assistance of the ACAS. In that period, subjects drove the FOT vehicles with either manual control or manual control augmented with the FCW function, and they also had the option of engaging ACC. It should be noted that FOT subjects could not disable the FCW function during ACAS-enabled test period. Two hours of training were provided for FOT participants prior to starting the FOT.

Independent Evaluation Goals

Goals of the independent evaluation of ACAS were to:

- characterize ACAS performance and capability;
- achieve a detailed understanding of ACAS safety benefits; and
- determine driver acceptance of ACAS.

The independent evaluation sought to address these three goals to support the decision process in the deployment of crash avoidance systems. The FOT generated objective data gathered by on-board data acquisition systems and subjective data obtained from test subject interviews, surveys, and focus group sessions. The Volpe Center independently conducted a system characterization test to acquire additional data on the performance of ACAS sensors and automatic controls from controlled, predetermined on-road routes.

Independent Evaluation Results

System Exposure

FOT participants (66 subjects) drove a total of about 163,000 km during the FOT – 64,000 km with FCW and 44,000 km with ACC. ACC use was about 1.8 times greater than CCC in terms of vehicle distance traveled (VDT). The older population used ACC most often. About 85 percent of the distance traveled was accumulated at vehicle speeds greater than or equal to 35 mph. About 55 percent of the distance traveled was on freeways.

System Capability

The system capability analysis examined the operational performance of ACAS by addressing its major components individually: sensor suite, alert logic, automatic controls, and driver-vehicle interface (DVI). FOT participants received 0.62 crash-imminent alerts per 100 km traveled overall – 56 percent of the alerts were due to in-path targets and the remaining 44 percent were caused by out-of-path targets. The highest rate of crash-imminent alerts was issued at vehicle speeds between 25 and 35 mph, amounting to 2.18 alerts per 100 km traveled. In an analysis of recorded facial images, the driver appeared to be distracted in 38 percent of all crash-imminent alert episodes. The eyes of the driver were off the road ahead for at least 1.5 seconds prior to the alert in 3 percent of all crash-imminent alert episodes. The independent evaluation judged 28 or about 3 percent of all crash-imminent alerts as "true" alerts to a potential impending rear-end collision. Thus, the rate of true alerts was about 1.8 crash-imminent alerts per 10,000 km traveled. Based on a sample of "closing" events, the analysis of ACC autobraking in response to a lead vehicle decelerating ahead showed that ACC was slow to disengage the automatic brakes after the ACAS-equipped vehicle is no longer closing in on the lead vehicle; the median time delay for ACC to release the brakes in this situation was about 2 seconds. Based on survey data, acceleration authority and deceleration authority of the ACC were rated at an average of 4.46 and 3.85, respectively (1= too fast and 7= too slow). The majority of FOT subjects rated very favorably the capability of the DVI in conveying clear information.

Safety Impact

The safety benefits analysis assessed the safety impact of ACAS in three areas using FOT objective data: exposure and response to driving conflicts at four different intensity levels, involvement in severe near-crashes, and unintended consequences. This safety analysis focused on ACAS as an integrated package of FCW and ACC, and did not attempt to separate ACC and FCW effects because the two functions were coupled in the FOT vehicle and will typically be bundled together in production vehicles. Separate analyses of FCW and ACC functions were conducted by the University of Michigan Transportation Research Institute and General Motors. Subjects experimented with the ACAS during the first few days the system was enabled, attempting to trigger crash-imminent alerts. To offset the influence of ACAS experimentation, the safety impact was assessed by comparing driver performance between the ACAS-Disabled test period and the second half of the traveled distance during the ACAS-Enabled test period. The ACAS reduced exposure to all driving conflicts leading to rear-end crashes by 8-23 percent under the following conditions: daylight, clear weather, moderate traffic, freeways, or vehicle speeds greater than or equal to 35 mph. Moreover, it was estimated that ACAS reduced exposure to lead-vehicle-decelerating conflicts by 11-26 percent at speeds greater than or equal to 35 mph. There was also a 29-46 percent reduction in exposure to lead-vehicle-stopped conflicts at speeds between 25 and 35 mph, and 14-27 percent reduction at speeds greater than or equal to 35 mph. There were very few differences in driver response initiation and response intensity between *with* and *without* the assistance of ACAS conditions once a driving conflict was encountered.

ACAS, as an integrated system of FCW and ACC functions, has the potential to prevent about 10 percent of all rear-end crashes based on projections that combine FOT data with GES crash statistics. The 95 percent confidence lower and upper bounds of system effectiveness are respectively 3 and 17 percent, resulting in a reduction of approximately 133,000 and 687,000 rear-end crashes in the United States annually. These projections of safety benefits are conservative estimates and a “best guess” given the nature of data collected during this FOT. About 63 percent of these predicted safety benefits are attributed to a decrease in exposure to driving conflicts at speeds greater than or equal to 35 mph. In this speed range, FOT subjects traveled about 54 and 42 percent of all VDT in the ACAS-Enabled test period respectively with FCW and ACC.

ACAS also reduced the exposure to severe near-crashes during the FOT by 10-20 percent. Severe near-crashes were defined by a minimum time-to-collision of less than 3 seconds and a peak deceleration level by the host vehicle of over 0.3g. Analysis of video episodes triggered by crash-imminent alerts showed that the system might have prevented a crash, near-crash, or heavy braking by the host vehicle in 28 episodes. No unintended negative consequences were observed by examining travel speed, time headway, distraction, and eyes-off-the-road. Long-term, positive or negative, safety effects were not evaluated due to the nature of the FOT.

Driver Acceptance

The driver acceptance analysis addressed the following five objectives based on survey and numerical data: ease of use, ease of learning, perceived value, advocacy, and driving performance. Driver acceptance findings suggest a mixed response to the FCW system by FOT participants as a group. Just under half of the drivers said that they "probably" or "definitely" would consider purchasing FCW and three-fifths of the older drivers said they would "probably" or "definitely" purchase FCW. Using a more refined technique to estimate the FCW purchase likelihood, results show that just over one-quarter of the drivers actually would purchase FCW assuming 100 percent system availability and 100 percent feature awareness. The data also indicate that, when FCW alerted drivers to actual threats, their opinion of the FCW system was more positive. However, drivers did not experience many actual threats. The more tentative opinions may result from receiving false alerts that were deemed excessive, and/or recurring. About 41 percent of the subjects stated that they would have used an on-off switch to turn off FCW crash alerts, if it had been available.

In general, drivers viewed ACC very positively despite expressing concerns about its ungainly acceleration and braking, as well as some degree of uncertainty about brake light activation to alert vehicles behind. The purchase likelihood of ACC was estimated at 44 percent, assuming 100 percent system availability and 100 percent feature awareness.

Lessons Learned and Recommendations

System Design

Generally speaking, the FCW function of ACAS incorporates state-of-the-art sensor technologies for short-term deployment plans (1–2 years). However, improved signal processing and threat assessment algorithms would enhance FCW alert efficacy by better recognition of slower lead vehicles transitioning from the path of the host vehicle to out of its path. This event generated numerous unnecessary crash-imminent alerts during the FOT, and even forced the ACC to automatically brake in response to lead vehicles exiting the freeway. Stationary out-of-path targets were the greatest source of false crash-imminent alerts. The disregard of stationary (never before seen moving) objects by the threat assessment algorithm would increase system credibility and driver acceptance since false alarms to these objects would be removed.

The analysis of crash-imminent alerts also showed that increasing the threshold to activate FCW over 25 mph would not make any significant impact on false and nuisance alerts (> 50% reduction). To boost driver acceptance of FCW at the expense of some limited safety benefits, it is recognized that a trade-off must be made between alert rates and the speed threshold and sensitivity of FCW. The ACAS incorporated many subsystems to identify the path of the host vehicle, and track and select targets at long ranges in the path of the host vehicle. One of these subsystems is GPS/GIS mapping to help identify the path of the host vehicle and make in-path target selection; though it is not clear that this feature had a significant impact on crash-imminent alerts. It is recommended that human factors tests be conducted to obtain user feedback on the usability of some of the HUD icons presented to FOT subjects by the ACAS. This recommendation is based on qualitative comments made by FOT subjects during debriefings and focus group meetings. It should be noted that only the cautionary and crash-imminent alert icons of FCW were tested prior to building the pilot vehicle for the FOT. Survey and subjective data from FOT subjects and system characterization test data suggest that even better acceptance of ACC would be achieved with improved automatic acceleration and deceleration characteristics.

The results of the independent evaluation suggest marginal acceptance of FCW and better acceptance of ACC as well as some positive safety indicators (e.g., less exposure to driving conflicts and severe near-crashes with ACAS) that warrant deployment at least at low-level market penetration.

Additional research may be necessary to reduce false and nuisance alerts of FCW and to enhance the timing of crash-imminent alerts for mid-term deployment plans (2–5 years). Proceeding with further FCW enhancement activities may depend on successful results (driver satisfaction, units sold, and positive safety impact) from short-term deployment and good market penetration levels. The recognition of the driver state would improve FCW alert timing, ranging from low complexity to identify the location of driver face (facing forward or sideways), medium complexity to track the eyes of the driver, to high complexity to measure the cognitive load of the driver. This research could build on current efforts undertaken in the SAVE-IT program. Another FCW improvement might be using digital image processing of the forward scene to discern objects that the radar is tracking, which might reduce the rates of crash-imminent alerts due to stationary out-of-path targets.

Vehicle to vehicle communication could improve the forward-looking sensing capability of FCW for long-term deployment plans (greater than 5 years). This research would build upon prior work in vehicle safety communications by the Crash Avoidance Metrics Partnership, and would call upon lead vehicles to transmit information about their state to following vehicles, given wider deployment of FCW in the vehicle fleet. The transmission of relevant information about the lead vehicle such as its dynamic state (stopped in traffic, moving at constant speed, decelerating, or accelerating), brake initiation, and value of its acceleration/deceleration might improve the timing of crash-imminent alerts, thus reducing the rates of “too late” alerts (increasing crash prevention potential) as well as “too early” alerts (decreasing nuisance alert rate). It should be noted that this current ACAS estimates the value of lead vehicle acceleration/deceleration in support of the timing algorithm. Proceeding with such system improvement activity might depend on significant market penetration rates of FCW in the vehicle fleet during the next five to 10 years.

FOT Design

Future FOTs of crash avoidance systems should involve as many subjects as possible given the limited number of instrumented or equipped vehicles and FOT duration. The use of more subjects (greater than 66 participants) might improve the estimates of distributions for the different measures of performance and might increase exposure to the various driving conditions. Given the scope of this type of FOTs, using 120 subjects would be feasible if each subject had an instrumented vehicle for a test period of three weeks; the FOT scope would then amount to 360 car-weeks. This scope is less than the ACAS FOT that totaled 369 car-weeks from testing the three versions of ACAS algorithms. The three-week test period might be sufficient based on the conflict exposure results of the ACAS FOT, using the defined measures of low-and high-intensity conflict and near-crashes adopted in this evaluation. One week would be dedicated to baseline data collection and two weeks would be allocated to driving with enabled crash countermeasure systems. One week with the system enabled would be devoted to subjects becoming familiar with the system. To limit the experimentation and learning period of the system to less than one week, it is recommended that subjects be trained for a time period slightly longer than in the ACAS FOT (extended two to four hours of driving accompanied by a researcher). Driver performance with the system would be observed in the second week of the system-enabled period. The analysis would then compare driver performance without the system in the first baseline week to driver performance with the system in the third week. In contrast, increased exposure (e.g., having some FOT subjects experience the system for a prolonged period of time, such as six to eight weeks) would serve to increase the number of close calls and raise the likelihood of the driver experiencing a crash-imminent alert perceived as “highly valuable”. This alternative would significantly decrease the number of FOT subjects (≈ 40) given the scope of this type of FOTs, unless more resources were dedicated to expanding the FOT. Moreover, it is uncertain whether the prolonged exposure time (≤ 8 weeks) would result in more close calls.

Based on driving exposure results of the ACAS FOT, future FOT subject recruits should be high-mileage drivers since the test period is relatively short given the cost of instrumented vehicles. The more mileage accumulated the more exposure to driving conflicts, which affects the analysis of safety impact. This recommendation, however, would reduce the generalizability of the findings since it would exclude a portion of the general public who drive less mileage, such as the older population. This trade off should be further examined. To ensure that they accumulate as much mileage as possible, subjects should be tracked and pulled out of the FOT if they do not use the equipped vehicle, realizing that this action would add a cost to the logistics of running the FOT. Subjects should remain in the three age groups representing the younger driver between 20 and 30 years old, the middle-age drivers between 40 and 50 years old, and the older between 60 and 70 years old. It would also be helpful to recruit FOT subjects who usually have travel patterns under driving conditions that are targeted by the crash countermeasure systems. For instance, rear-end crash countermeasures address conditions of moderate to heavy traffic and more following vehicle situations while on the other hand, lane departure warning systems target drivers who are most likely tired (nighttime conditions) or inattentive on long trips typically with a low level of traffic. In addition, subjects “at risk” should be recruited based on information derived from crash data or studies about drivers of higher involvement in crashes targeted by the countermeasures (e.g., younger drivers with many traffic violations).

Crash countermeasure functions dealing with similar dynamic scenarios should be treated in separate vehicles in the FOT if the objectives of the FOT were to evaluate each function individually. It was difficult to isolate the effects of ACC from FCW in the ACAS FOT since these two functions were integrated by design.

Additional tests are recommended to supplement the data collected from the FOT. Due to the limitations of data used in the analysis of safety benefits, a test track or driving simulator experiment to gauge the response of subjects to severe driving conflicts or near-crashes with and without assistance by the crash countermeasures would be needed. This type of experiment would generate data about the swiftness of reaction and intensity of response to these severe events, which feed into the safety benefits estimation equation. This was a weakness in the ACAS FOT as subjects rarely encountered events of severe nature under similar initial conditions. This experiment could be a part of the design and development cycle to improve system performance. To avoid a false start of the FOT that led subsequently to three phases of testing in the ACAS FOT, it is recommended that a small FOT be conducted with few subjects prior to the regular FOT in a similar test period to try out all the data collection instruments and logistics, a dress rehearsal for the FOT. In addition, the independent evaluation should plan on a longer duration of the system characterization test to collect data under different driving conditions (i.e., in rain or snow or different traffic conditions).

The analysis of unintended consequences in this FOT was limited to short-term exposure with the system. Short-term test periods (few weeks) do not yield comprehensive information on driver adaptation with the system, thus risk compensation behavior would not be easy to detect. Results of the safety assessment don't convey in any way the long-term, positive, or negative, safety effects of ACAS. Perhaps few FOT subjects could be selected to drive a test vehicle for a longer time period to assess long-term effects of system use. Longer exposure periods (months or years) could be accommodated if the subjects' own vehicles were equipped with less expensive crash countermeasure and data acquisition systems, which would of course yield better data to examine driver adaptation and potential safety benefits. A higher degree of system acceptance might be achieved if drivers were able to experience the full capability of the crash countermeasure system in a near-crash event. The low acceptance rate of FCW was due perhaps to many subjects not experiencing true alerts to hazardous or imminent rear-end crash events during the ACAS FOT. Longer exposure (months-years) with the system might improve the acceptance of FCW.

FOT subjects quickly became familiar with the operation of a new vehicle (2002 Buick LeSabre in the ACAS FOT) based on the number of conflicts or near-crashes encountered per distance traveled. However, a past study indicates that drivers might learn quickly to operate a new vehicle in normal driving situations but might take longer to appreciate its capability in intense evasive maneuvers. Thus, it is recommended that subjects experience heavy braking or steering maneuvers during the training stage of the FOT to become acclimated to the new vehicle.

To gain a better understanding of the potential safety benefits that can be accrued from ACAS use, it is recommended that the FCW threat assessment algorithm be applied to real-world rear-end crashes already recorded in a naturalistic driving study. The ACAS issues crash-imminent alerts that were sometimes deemed "too late" by FOT subjects. This is done by design to minimize the rate of nuisance alerts. The application of the algorithm to rear-end crash data would help estimate how many of these rear-end crashes the ACAS may have prevented.

FOT Data Analysis

Based on the results of data analysis to assess the safety impact of ACAS, it is recommended that improved filtering processes be applied to identify driving conflicts and near-crashes, and filter out low risk conflicts. The analysis of the ACAS FOT numerical data limited the conflict duration to at least one second to capture meaningful driving events of the host vehicle closing in on a lead vehicle. Perhaps a longer minimum duration would have filtered out events in which the lead vehicle was cutting in or out of the host vehicle's path. Moreover, counting a driving conflict in the ACAS FOT once the peak deceleration surpassed the 0.1g threshold resulted in many driving conflicts and near-crashes where the driver responded with very low average braking levels. An additional filter might assign a certain time duration in which the peak deceleration must remain over 0.1g. Low-risk conflicts with very low deceleration levels dilute the response with and without ACAS assistance, which affects the comparison between the baseline and treatment conditions. In addition, including too many conflicts of low-risk nature adds to the complexity of the analysis.

Visual filtering steps could also be used to filter out low-risk conflicts from numerical FOT data, which would add more labor effort to sort conflicts out. In addition, continuous recording of the forward scene would be needed at higher frame rates of at least 2 Hz or 2 images per second instead of 1 image per second in the ACAS FOT (other than triggered events); this would add to the amount of stored data. Finally, this evaluation used Monte Carlo simulations to estimate the probability of a crash given an encounter with a specific driving conflict. Use of direct mathematical techniques to estimate the probability of a crash is recommended, such as the application of crash prevention boundary techniques or statistical distributions from extreme value theory.

1. INTRODUCTION

1.1 BACKGROUND

This report presents the results of an independent evaluation of the Automotive Collision Avoidance System. The ACAS integrates Forward Collision Warning and Adaptive Cruise Control functions for light vehicles (e.g., passenger cars, vans, minivans, sport utility vehicles, and light trucks). The FCW detects, assesses, and alerts the driver of a potential hazard in the forward region of the vehicle. The ACC provides automatic brake and throttle actuation in order to maintain speed and longitudinal headway control. Through the integration of these two functions, the ACAS is intended to improve automotive safety by assisting drivers to avoid rear-end crashes. To accomplish this goal, the ACAS must also prove useful and acceptable to drivers.

NHTSA explores new automotive technologies to help achieve its mission of saving lives, preventing injuries, and reducing health care and other economic costs associated with motor vehicle crashes. As part of this research effort, NHTSA entered into a two-phased cooperative agreement, signed in June 1999 with General Motors Corporation to develop and test ACAS (Colgin, 1999).

In the first phase, GM developed ACAS in partnership with Delphi Electronics and Safety, Delphi Chassis Systems, and Hughes Research Laboratory. NHTSA, GM, DES, and DCS each supported the project by providing funds. GM and DES (formerly Delphi-Delco Electronics Systems) were the founding members of the Automotive Collision Avoidance System Development Consortium that completed a cooperative agreement with NHTSA and the Defense Advanced Research Projects Agency in 1998 as part of the Technology Reinvestment Project (Intelligent Transportation Systems Joint Program Office, 2000) (Delphi-Delco Electronic Systems, 2000). The goals of that initial development effort were to accelerate the deployment of near-term crash warning systems, to advance the development of promising but immature enabling technologies, and to reduce manufacturing costs of key system components.

The second phase of the cooperative agreement between NHTSA and GM involved an extensive field operational test of 10 GM-built passenger vehicles equipped with ACAS. The University of Michigan Transportation Research Institute, under contract to GM, provided extensive support in the development and conduct of the FOT. The ACAS FOT was conducted between March 2003 and November 2004. UMTRI, under a previous agreement with NHTSA, conducted a similar FOT of the Intelligent Cruise Control system that ended in 1998 (Fancher et al., 1998). The ICC is similar to ACC except speed control is achieved via throttle modulation and downshift, without the use of automatic braking. The Volpe National Transportation Systems Center of the U.S. DOT's Research and Innovative Technology Administration, under agreement with NHTSA, provided an independent evaluation of ICC and prepared a final evaluation report that assessed the safety impact, performance, and user acceptance of such a system (Koziol et al., 1999). The Volpe Center, again under agreement with NHTSA, has performed a similar independent evaluation of ACAS, taking full advantage of the knowledge and expertise gained in the prior ICC evaluation. This report documents the results of the Volpe Center's independent evaluation of ACAS.

1.2 FIELD OPERATIONAL TEST OVERVIEW

Generally, an FOT and an evaluation are conducted before a system is deployed to project or confirm that the system will have, or has achieved, the required operational capabilities and characteristics when placed in service (Stevens, 1986 and Reynolds, 1996). The FOT and evaluation are normally conducted in the intended operational environment, under realistic operating conditions on a production-representative system by typical users. The FOT and evaluation measure the acceptability to the user and project potential impacts on safety, mobility, and the environment.

The ACAS FOT was conducted by UMTRI on 10 vehicles from March 2003 to November 2004 (University of Michigan Transportation Research Institute and General Motors, 2005). The FOT took place primarily in Michigan, although some driving extended beyond this range. The original FOT plan specified a total of 78 drivers to participate in the FOT. Early results from the FOT, however, required some modification to the FOT to correct for deficiencies in ACAS. Drivers of the initial system expressed an unacceptable level of dissatisfaction with the number of false alarms or "nuisance alerts" produced by the system. To improve performance of the system, the original Algorithm A was replaced with two subsequent revisions, Algorithm B and Algorithm C. A total of 30 drivers were involved with testing Algorithms A and B before the final Algorithm C was implemented. Algorithm C was tested using a total of 66 drivers. Thus, a total of 96 subjects were eventually employed in the FOT to test the three versions of the warning algorithm. The independent evaluation is based on Algorithm C since it represents the final, improved ACAS.

The FOT subject pool included three age groups (younger, middle-age, and older) with equal numbers of male and female drivers. Table 1-1 shows the breakdown of subjects according to their age and gender.

Table 1-1. FOT Subject Pool

Subjects						Total Subjects
Younger (20-30)		Middle-Age (40-50)		Older (60-70)		
Male	Female	Male	Female	Male	Female	
11	11	11	11	11	11	66

Each of the 66 FOT subjects drove the ACAS-equipped vehicle (host vehicle) as their personal cars for a test period of four weeks, unsupervised and unrestricted. For each subject, the first week of driving was dedicated to collecting baseline driving data, i.e., *without* the assistance of the ACAS (system not available). In the first week, FOT subjects drove with manual control and also had the option of using conventional cruise control (CCC). During the next three weeks, driving was performed *with* the assistance of the ACAS. During that period, subjects drove the FOT vehicles with either manual control or manual control augmented with the FCW function, and they also had the option of engaging ACC. It should be noted that drivers could not turn off the FCW function during the FOT. Prior to starting the test, FOT participants were introduced to the ACAS-equipped vehicle as well as the FCW and ACC functions and controls via a 17-minute training video. The participants were then given a hands-on overview of the vehicle and ACAS. The driver vehicle interface was demonstrated to afford each participant the opportunity to observe the FCW warning icons and ACAS-state messages before experiencing them in real traffic. Afterwards, a researcher from UMTRI accompanied the participant on a 20-minute test drive and included both local roads and expressways so drivers were exposed to the FCW as well as being able to engage the ACC on the expressway.

Drivers' experiences were captured by means of objective data collected by the on-board data acquisition system and subjective data obtained from post-FOT surveys as well as focus groups. The DAS collected and stored objective numerical data, video clips, and audio recordings. Numerical data were continuously gathered from various sensors at a 0.1 seconds time interval when the FOT vehicle was in use. A microphone captured audio recordings to recover the driver's immediate reaction to a warning or the lack thereof if the driver manually turned on the microphone. Crash imminent alerts issued by the ACAS triggered the recording of 10-Hz 8-second video clips (from five seconds prior to the alert to three seconds after) showing the forward scene of the host vehicle and the face of its driver. Exposure video was also recorded to capture one snapshot of the forward scene every second and 4-second 5-Hz video of the driver face at five-minute intervals.

In addition to the FOT, additional data were collected from the system verification test as discussed in Section 3, System Capability.

1.3 AUTOMOTIVE REAR-END CRASH AVOIDANCE SYSTEM

The ACAS consists of both FCW and ACC functions. This section provides an overview of the characteristics and functions of these two systems that are most significant to the ACAS evaluation (see Table 1-2). The reader is referred to the final ACAS FOT program report for a more comprehensive description of the ACAS (General Motors, 2005). A suite of sensors supports the functions of the two systems and comprises a combination of vehicle original equipment manufacturer (OEM) sensors with forward-looking radar, forward-looking camera, differential global positioning system (DGPS) with map matching, and a yaw-rate sensor. Table 1-3 provides a list of the OEM vehicle sensors, switches, and controls. The radar measures range, range-rate, and azimuth angle to a maximum of 15 targets from 1 to 150 meters (3 to 492 feet) with a sampling frequency of 10 Hz. The maximum horizontal field of view of the radar is 15° with an azimuth angle accuracy of 0.5°, azimuth discrimination (between two targets traveling at the same speed) is 2°, and the vertical beam width is 4.1°. The GPS/map and forward-looking camera systems determine the lane geometry ahead of the ACAS vehicle from 15 to 75 m (49 to 246 ft). In general, the GPS/map is relied upon for longer-range shape, while the camera lane tracker is used for shorter-range details such as host vehicle heading and lateral position within the lane and the local curvature. The system presents visual information to the driver by means of a color head-up display. The HUD projects an image on the windshield, which subtends a visual angle of 1.5° vertical and 3.0° horizontal. The apparent size of the image is approximately 3”×5” at the instrument panel or windshield; however, the virtual image appears at the front bumper and looks much larger.

1.3.1 Forward Collision Warning Function

The FCW function provides visual cautionary alerts when following within a driver-adjustable headway time, when following very closely (tailgating), or when approaching a vehicle too rapidly (closing). Cautionary alerts are presented visually to the driver in a graded scale by vehicle icons on the HUD. For closing situations, FCW issues a final imminent alert that consists of both a flashing visual display (HUD) and an auditory warning (vehicle speaker). In contrast to cautionary alerts, the timing of the imminent alert is not adjustable by the driver. These alerts assist drivers in avoiding or reducing the severity of rear-end crashes. FCW is enabled when the vehicle ignition is turned on, and cannot be disabled by the driver. This function does not activate until the speed of the host vehicle exceeds 25 mph (40 km/h) and will remain active until the vehicle slows to below 20 mph (32 km/h). The range of the warning function is set to a maximum of 100 m (328 ft) and is limited on curves with a radius of curvature below 500 meters (1,640 feet). The driver can adjust the sensitivity of the visual cautionary alerts with a six-setting sensitivity adjustment control. The factors that determine when to issue a crash-imminent alert include, but not limited to, range and range rate between the host and lead vehicles, host vehicle speed, lead vehicle acceleration, and host vehicle brake pedal press. The HUD provides a graded visual display that reflects the degree of the closing gap between the host vehicle and the lead vehicle based on the FCW sensitivity setting. The most sensitive setting of FCW produces the most cautionary alerts because FCW responds to the host vehicle closing in on obstacles ahead at farther distances with lower range rates.

1.3.2 Adaptive Cruise Control Function

The ACC function maintains both a selected cruise speed (speed control mode) when there is no lead vehicle limiting its forward motion, and a selected headway (headway control mode) with a lead vehicle that is traveling slower than the selected cruise speed. The driver is provided with the following ACC control switches:

- Cruise on-off
- Set/coast (decrease set speed in 1-mph steps)
- Resume/accelerate (increase set speed in 1-mph steps)
- Gap up (1-2 seconds in 0.2-second increments)
- Gap down (1-2 seconds in 0.2-second increments)

The headway adjustment control consists of six discrete steps that vary from a minimum of one to a maximum of two seconds. This same control also sets the desired cautionary alert timing of the FCW function when ACC is not engaged. The ACC is engaged by the driver and becomes active when the speed of the host vehicle exceeds 25 mph. At first ACC engagement at the start of the second week, the initial headway setting is set to the maximum value. In headway control mode, the ACC can slow the host vehicle by throttle application or brake to pace a lead vehicle

Table 1-2. Characteristics of ACAS

	Rear-End Crash Warning (FCW)	Adaptive Cruise Control (ACC)
Functions	FCW provides drivers of the ACAS vehicle with alerts and advisory displays that assist them in avoiding or reducing the severity of crashes between the front of their vehicle and the rear of a lead moving or stationary vehicle (rear-end crashes).	ACC maintains both a *selected cruise speed* when there is no lead vehicle limiting its forward motion and a *selected headway* with a lead vehicle that is traveling slower than the selected cruise speed.
Modes	• FCW is in "enable" mode when vehicle ignition is turned on. • FCW turns ON when host vehicle speed exceeds 25 mph and turns OFF when the speed falls below 20 mph. • Driver can't disable FCW. • Other conditions controlling FCW "enable" and "disable" modes are specified by system designers. • Range of warning function is 100 m. • FCW incorporates a head-up display that shows the headway-following distance in terms of vehicle icons on the windshield to help drivers maintain driver-preferred headways.	• ACC has a speed control mode and a headway control mode when active above 25 mph. • ACC in headway control can slow the host vehicle to pace a lead vehicle moving slower than the set speed. Once vehicle speed is below 20 mph, the driver is alerted to take manual control of the vehicle. • ACC accelerates the host vehicle when the driver manually accelerates above 25 mph and initiates the *resume function* or the *set speed function*. • ACC does not respond to stopped vehicles ahead by automatically applying the brakes – unless the stopped vehicle was at one time being tracked as a moving vehicle. • When ACC active, warning algorithm takes into account the braking that ACC can provide (maximum braking is 0.3 g). An imminent alert is issued if ACC maximum braking of 0.3g level is reached.
Controls	• Driver can adjust FCW sensitivity (cautionary alert range) using the same ACC headway setting control. • Driver can <u>not</u> adjust the timing of the crash-imminent alert (contrary to cautionary alerts) • Driver cannot disable system with the sensitivity adjustment control.	• Standard cruise controls and a headway selection switch. • Six headway settings from 1.0 sec to 2.0 sec in 0.2-sec increments. • ACC may be over-throttled by the accelerator pedal. • ACC goes to *standby* mode by manual braking.
Displays	Color Head-Up Display (HUD)	
	• *Crash warning display*: provides cautionary visual and crash-imminent visual and auditory alerts. • *Following distance display*: provides a visual indicator that supports the driver in maintaining a safe distance behind lead vehicles. • FCW Operational/Failed message • Beyond operational conditions message • Cautionary alert sensitivity setting	• ACC on-off • Set speed • Current speed • Gap setting • ACC operational/failed message • Tracking/not tracking a lead vehicle
Sensors	• Radar (tracks up to 15 targets from a range of 1 - 150 m) • Forward-looking camera • Differential GPS and map-matching • Yaw-rate • Vehicle OEM sensors	

moving slower than the set speed. Once vehicle speed falls below 20 mph, the driver is alerted to take manual control of the vehicle. The ACC does not respond to stopped vehicles ahead – unless the stopped vehicle was initially being tracked as a moving vehicle. The maximum automatic braking capability of the ACC is limited to 0.3g (2.9 m/s^2). The brake lights of the host vehicle turn on when vehicle brakes are automatically applied. The ACC goes into a standby mode when the brakes are manually applied. The ACC automatically accelerates the host vehicle when the driver manually accelerates above 25 mph and initiates the resume function or the set speed function. The ACC function issues an imminent warning if the maximum automatic braking of 0.3g level is reached. When ACC is engaged, the driver does not receive visual cautionary alerts.

Table 1-3. OEM Vehicle Sensors, Switches, and Controls

- Brake pedal switch	- Windshield wiper setting
- Extended brake switch	- Road surface roughness
- Brake pressure	- Compass heading
- Lateral acceleration	- Rain
- Steering wheel angle	- Outside temperature
- Yaw rate	- HVAC controls
- Wheel speeds	- Audio controls
- Throttle position	- Headlight switch position
- Turn signal status	- PRNDL

1.4 INDEPENDENT EVALUATION

The Volpe Center conducted the independent evaluation of the ACAS based on data collected from the FOT and from an independent system characterization test. The independent evaluation had the following three major goals:

1. Characterize ACAS performance and capability.
2. Achieve a detailed understanding of ACAS safety benefits.
3. Determine driver acceptance of ACAS.

The independent evaluation sought to address these three goals to support the decision process in the deployment of crash avoidance systems. The FOT generated objective data gathered by on-board data acquisition systems and subjective data obtained from test subject interviews, surveys, and focus group sessions. The system characterization test acquired data on the performance of ACAS sensors from controlled, predetermined on-road routes. Next, the goals and concomitant objectives of the independent evaluation are delineated. This is followed by a description of the numerical data processing, data analysis tools, and analysis databases.

1.4.1 Evaluation Goals and Objectives

1.4.1.1 System Capability

The system capability goal addresses ACAS performance by examining its individual components including the sensor suite (objective 1), alert logic (objective 2), ACC controls (objective 3), and driver-vehicle interface (objective 4). The sensor suite objective focuses on the ability of the forward-looking sensing component to differentiate in-path and out-of-path targets, and to maintain in-path target tracking by looking at intermittent and lost targets. The alert logic objective assesses the efficacy of ACAS to warn the driver of driving conflicts that may lead to rear-end crashes, and determines the nuisance level from alerts triggered by out-of-path targets and warnings considered unnecessary by FOT subjects. The analysis of the sensor suite and alert logic objectives was based on the individual examination of video episodes triggered by the crash-imminent alert, characterization test data, and FOT surveys. The ACC controls objective concentrates on the ability of ACC to maintain set headways and to perform vehicle acceleration and deceleration under dynamic conditions, using data from the system characterization test and FOT surveys. The driver-vehicle interface objective looks into the visibility, audibility, and readability of the displays as experienced by the FOT subjects based exclusively on survey data.

1.4.1.2 Safety Benefits

The safety benefits goal assesses the safety impact of ACAS in three areas using FOT objective data: driving conflicts (objective 1), severe near-crashes (objective 2), and unintended consequences (objective 3). The driving conflicts objective examines both the exposure and response of FOT subjects to the most common scenarios leading to rear-end crashes, which involve the host vehicle closing in on a lead vehicle either stopped, moving at slower constant speed, decelerating, or accelerating. This objective estimates ACAS effectiveness in reducing driver exposure to driving conflicts under different driving conditions including ambient light, weather, road type, traffic state, and travel speed. In addition, ACAS effectiveness in reducing the probability of a rear-end crash is also estimated based on Monte Carlo simulations for each of the common pre-crash scenarios, using representative data of the initiation and intensity of driver response to these driving conflicts. The severe near-crash objective examines driver exposure and response to severe near-crashes with and without the assistance of ACAS, based on numerical data and video episodes triggered by crash-imminent alerts. The unintended consequences objective explores whether or not ACAS might have an impact on safety either in a positive or negative manner by examining increased inattention by FOT subjects (distraction or eyes-off-the-road) using video episodes, and change in normal driving performance using numerical data of time headway, vehicle lane position, and travel speed with and without ACAS.

1.4.1.3 Driver Acceptance

The driver acceptance goal addresses the following five objectives based on survey and numerical data: ease of use, ease of learning, perceived value, advocacy, and driving performance. The ease of use objective examines whether drivers find FCW and ACC easy to use in a variety of driving conditions. The ease of learning objective examines whether drivers are able to learn, in a timely and effective manner, enough about ACAS functions to accept the system. The perceived value objective explores whether drivers perceive that using FCW and ACC increase their safety and/or driving skills. The advocacy objective looks at whether sustained exposure to and use of FCW and ACC results in drivers' interest in acquiring and/or endorsing FCW and ACC. The driving performance objective examines whether FCW and ACC use leads to lasting changes in driving behavior.

1.4.2 Data Processing

The FOT generated a massive amount of objective data, totaling about 120 GB of numerical data and 230 GB of video data. The identification of specific driving scenarios and assignment of concomitant safety hazard levels from this huge data set poses an immense challenge. Figure 1-1 illustrates the framework that was used to process and analyze the FOT data (Najm et al., December 2003). This framework consists of four data transition steps that transform the raw data into aggregated data of significant conflict and near-crash events so as to facilitate data query and analysis. The first step employs numerical data processing algorithms to smooth and parse raw FOT data of naturalistic driving into low-risk, conflict, and near-crash events. The second step identifies significant epochs in the conflict and near-crash events from parsed data by using a multi-media data analysis tool. The third step codes significant conflict and near-crash events into discrete variable database. The last step queries the database using SQL or SAS programs to aggregate data from conflict and near-crash events in a manner that facilitates finding answers to the evaluation questions.

Figure 1-2 provides the block diagram of the process that implements the first transition step of the data processing framework. The circular blocks refer to the input data that were drawn from the radar (target or lead vehicle information), in-vehicle sensors, and the geographical information system (GIS) database. The rectangular blocks point to the algorithms and their respective data summary tables that were created and added to the independent evaluation database. The dotted boundary lines of the rectangular blocks refer to tables containing 10-Hz numerical data, while the solid boundary lines represent tables with transitional data. The contents of each of these tables are described below:

- *Host vehicle maneuver*: going straight, negotiating a curve, turning, and changing lanes.
- *Host vehicle state*: stopped, constant speed, decelerating, and accelerating.
- *Driving state*: none, following, closing, and separating (between host and lead vehicles).
- *Lead vehicle state*: none, stopped, constant speed, decelerating, and accelerating.
- *Lead vehicle category*: same as lead vehicle state, but in transitional format.
- *Lead vehicle event*: same as lead vehicle category, except that driving state is closing.
- *Driver/vehicle response*: none, slowdown, slowdown and lane change, slowdown and turn, brake, brake and lane change, brake and turn, autobrake, autobrake and lane change, autobrake and turn, lane change, and turn.

In addition to the tables listed above, the following transitional tables were created to identify the driving environment and driving mode of the host vehicle:

- *Ambient light*: light and dark.
- *Weather*: clear, rain, and snow.
- *Road type*: freeway and non-freeway.
- *Traffic or level of service*: low, moderate, and heavy.

1.4.3 Data Analysis Tools

To support the independent evaluation, the Volpe Center developed the following data analysis tools:

- Computer Simulation - Monte Carlo models are used to estimate the ability of ACAS to prevent rear-end crashes, given that a rear-end conflict has occurred.

- GPS/GIS Location Algorithm – This algorithm geographically locates the FOT vehicles during testing so as to identify characteristics of the roadways they are driving on.
- Traffic State Identification Algorithm - This algorithm identifies the state of traffic in terms of the level of service on roadways that the host vehicles are driving on during the FOT.
- Multimedia Analysis Software - A software program was developed to integrate numerical data with video clips in order to analyze alert-triggered episodes captured during the FOT. Figure 1-3 provides a snapshot of the multi-media data analysis tool that was developed to analyze video data in support of the data processing framework. This tool synchronizes two sets of video (forward scene and driver face) and two sets of numerical data (in-vehicle sensors and radar). A window was also created in the middle of the screen to simulate the HUD and warning icons. Moreover, a data logger was built in Access for the analysts to record their observations. This tool was exclusively employed to analyze all 10-Hz video episodes triggered by crash-imminent alerts. This activity resulted in the formation of the episode database described below.
- Databases - A main FOT database was built and maintained to store and manage the data collected from the FOT and additional evaluation tests. The data consist of objective data (e.g., numerical and video data) as well as subjective data (e.g., surveys). The data processing of the 350 GB FOT database also produced a few summary databases that were queried to address the goals and objectives of the independent evaluation. These include:

    - *Conflicts-Brake* database of driving conflicts and near-crashes associated with brake-only driver/vehicle response. It encompasses data on driver, trip, driving mode, conflict type and intensity level, FCW sensitivity and ACC gap settings, road type, ambient light, weather, traffic, host vehicle speed and acceleration, response data such as initiation time and intensity, minimum time-to-collision and minimum deceleration during the event, and kinematic data such as range, range rate, lead vehicle deceleration, and time-to-collision.
    - *Conflicts-Steer* database similar to the conflicts-brake database above, except events associated with steering and steering-braking responses are included.
    - *ACAS Setting* database on distance traveled with each setting and setting changes in driving modes, road type, and traffic states.
    - *HUD* database on HUD brightness and position control setting changes in driving modes, road type, ambient light, and weather conditions.
    - *Performance* database on time headway, speed ratio (vehicle speed/speed limit), and lane position of host vehicle in cruise mode in driving modes, road type, and traffic states.
    - *Episode* database from alert video episodes consisting of a wide range of variables about the conditions of the driver, traffic, environment, and alerts.

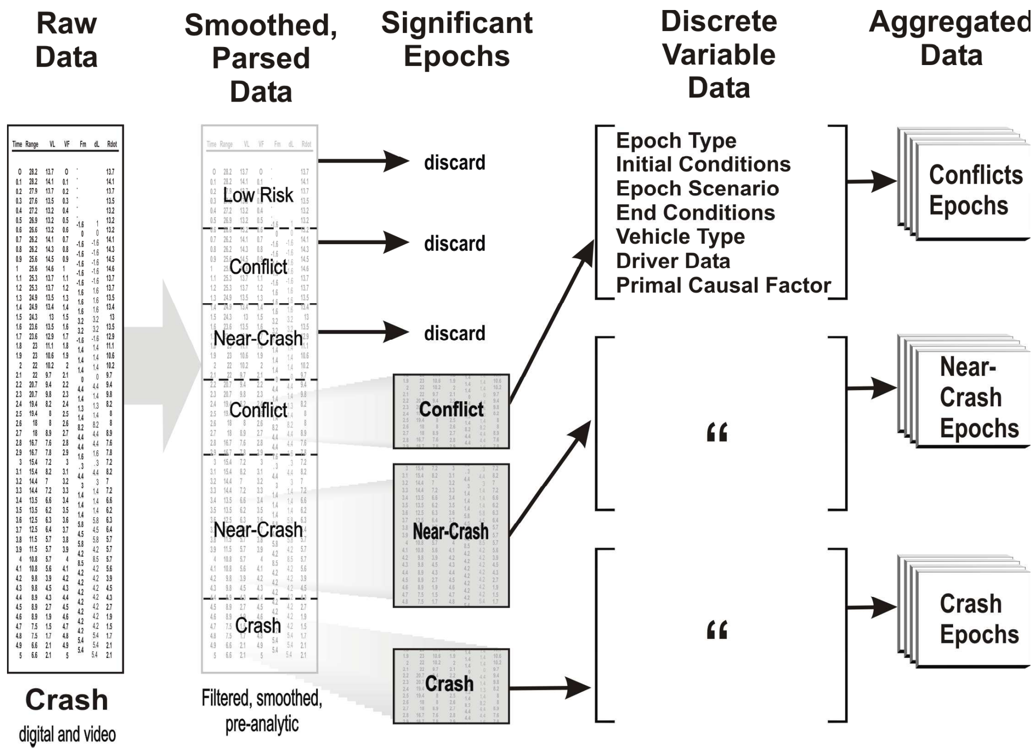


Figure 1-1. ACAS FOT Data Processing Framework

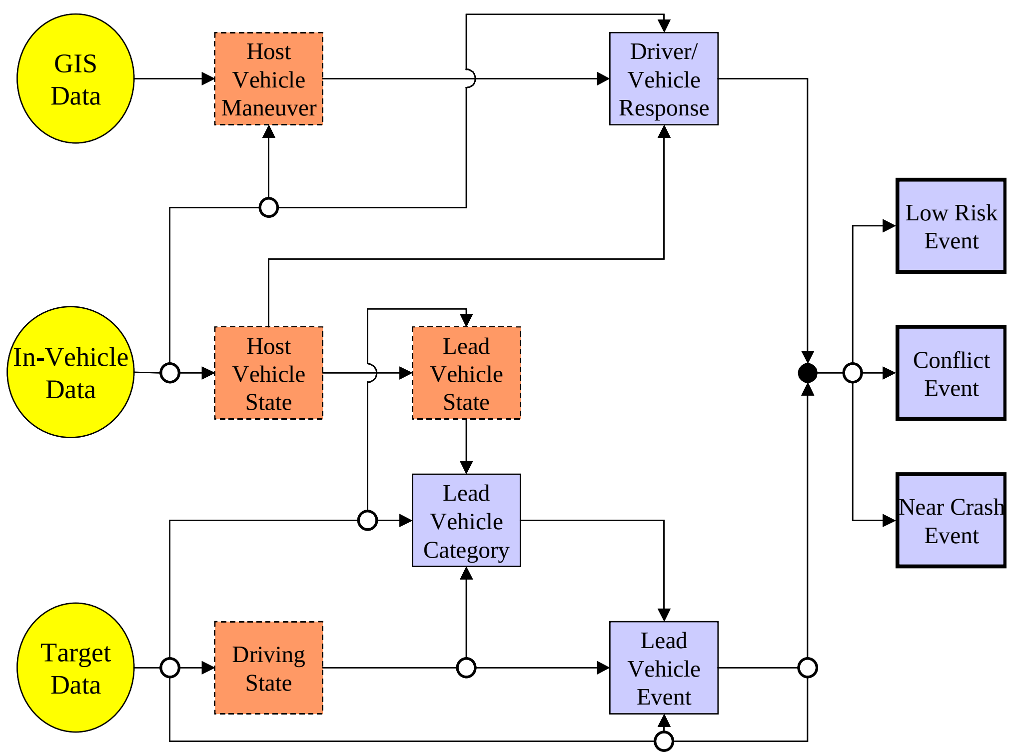


Figure 1-2. Block Diagram of Raw Data Processing

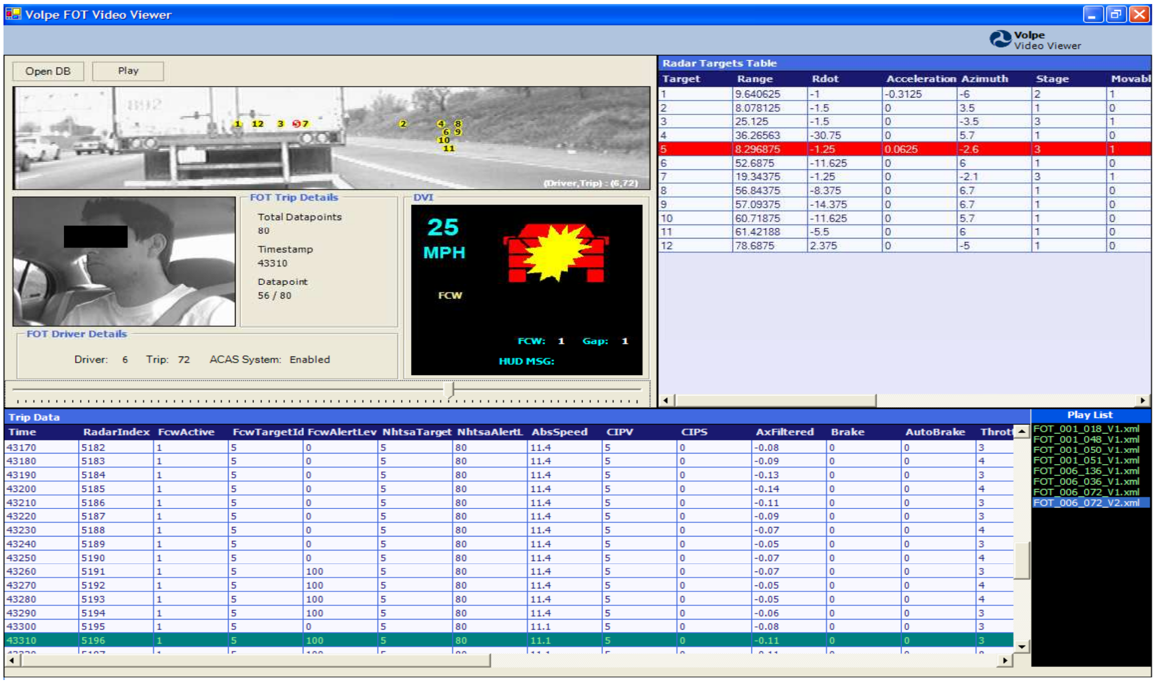


Figure 1-3. Multi-Media Data Analysis Tool

2. ACAS EXPOSURE

2.1 INTRODUCTION

An important element of the evaluation is an examination of driver exposure to key factors that might influence safety performance and user acceptance of ACAS. The exposure assessment determines where and under what conditions participants of the FOT used the ACAS-equipped vehicles, both when ACAS was disabled (week 1) and when it was enabled (weeks 2, 3, and 4). These exposure results will provide a detailed description of the FOT driving environment that will assist in the interpretation of safety and user acceptance results. Furthermore, these results will help in determining if:

- the quantity of data describing exposure to key factors is sufficient for valid analysis,
- exposure to key factors is sufficiently representative between data sets (e.g., driving with and without ACAS) so that valid comparisons between those sets can be made, and
- differences in exposure to key factors are affecting results rather than ACAS itself.

The key exposure factors analyzed include the following (more detailed definitions of these factors will be provided in the subsections below):

- Road Type: Freeways and non-freeways
- ACAS Status: ACAS-Disabled and ACAS-Enabled
- Driving Mode: Manual 1 and CCC during the ACAS-disabled test period and Manual 2, FCW, and ACC during the ACAS-enabled test period
- Driver Age: Younger, middle age, and older
- Driver Gender: Female and male
- Weather: Clear and adverse
- Ambient Light: Light and dark
- Traffic Level: Low, moderate, and heavy
- Vehicle Speed: Less than 25 mph (40 km/h), 25 mph to 35 mph (56 km/h), and greater than or equal to 35 mph
- ACAS Usage Patterns: Level of ACC Use, FCW Sensitivity Settings, and ACC Gap Settings

It should be noted that the “ACAS Status” factor refers to whether ACAS is enabled or disabled, whereas the “Driving Mode” factor points to the specific driving status selected within ACAS-Disabled (i.e., Manual 1 or CCC) or ACAS-Enabled (i.e., FCW, ACC, or Manual 2). The exposure results presented below are based on the data obtained from 66 subjects (numbers 31 through 96) who were assigned to ACAS Algorithm C vehicles during the FOT.

2.2 EXPOSURE BY ACAS STATUS, DRIVING MODE, AND VEHICLE SPEED

The FOT subjects drove a total of about 163,000 km during the FOT. Due to data collection problems, some of the data acquired for this total distance traveled were not valid for purposes of the evaluation. Two of the main reasons for invalid data were failure of the DAS to collect data for one entire trip and the "frozen" sensor phenomenon during part of a trip. Thus, the analysis was conducted on data collected only for trips that were classified as "valid." A trip starts with vehicle ignition turned on and ends with ignition turned off. In a few trips, the DAS failed to boot up and record data for the whole trip. During some trips, recorded values of some sensor parameters were frozen (not updated) for a brief period of time.

Based on valid trip data, FOT subjects drove a total of about 158,000 Km, which represents about 97 percent of the vehicle distance traveled (VDT) for the entire FOT. The ACAS-Disabled test period covers all driving during the first week of the FOT when the ACAS system was not available to the driver. The ACAS-Enabled test period covers all driving during the second, third, and fourth weeks of the FOT when the ACAS system was available to the driver. The distribution of VDT is about 36,000 km (23%) for the ACAS-Disabled test period and 122,000 km (77%) for the ACAS-Enabled test period. Thus, considering that the duration of the ACAS-Enabled test period is three times that of the ACAS-Disabled test period, the level of driving (VDT per week) during the two test periods is almost equivalent.

The number of valid trips made by FOT participants was 1,965 and 6,155 trips for the ACAS-Disabled and ACAS-Enabled test periods, respectively. The average distance of these trips was 18.4 km and 19.8 km respectively for the ACAS-Disabled and ACAS-Enabled test periods. The average trip frequency (trips/week) and the average distance of these trips are equivalent between these two test periods.

The distribution of VDT among the driving modes is expressed below both as distance (rounded to the nearest 1,000) and percent of total FOT kilometers driven:

- Manual 1: 29,000 km or 18 percent of total VDT
- CCC: 7,000 km or 5 percent of total VDT
- Manual 2: 13,000 km or 8 percent of total VDT
- FCW: 64,000 km or 41 percent of total VDT
- ACC: 44,000 km or 28 percent of total VDT

Manual 1 includes "manual" driving during the ACAS-Disabled test period when CCC was not being used. CCC driving mode encompasses all CCC engagement during the ACAS-Disabled test period. On the other hand, Manual 2 includes manual driving during the ACAS-Enabled test period when FCW function was not available and ACC was not engaged. FCW driving mode includes all driving during the ACAS-Enabled test period when FCW function was active and ACC was not engaged. It should be noted that FCW function becomes active when host vehicle speed reaches 25 mph (40 km/h) and becomes inactive when host vehicle speed falls below 20 mph (32 km/h). Moreover, FCW is suspended during braking by the host vehicle. ACC driving mode comprises all distances traveled during the ACAS-Enabled test period when ACC was engaged.

Figure 2-1 shows the distribution of VDT by driving mode for the ACAS-Disabled and ACAS-Enabled test periods separately. In comparing these two periods, it should be noted that Manual 1 driving is roughly equivalent to the sum of Manual 2 and FCW driving since FCW is involuntarily active for all driving above 25 mph. Within this context, the two periods are similar; however, it can be seen that ACC is engaged more extensively than CCC in their respective test periods. Overall, the ACC usage rate is 76 percent greater than CCC or, stated differently, ACC is used about 1.8 times more than CCC. By comparison, the usage rate of the intelligent cruise control (ICC) system that was tested in the mid 1990's was about 1.5 times more than CCC (Fancher et al., 1998) (Koziol et al., 1999). It is noteworthy that the ICC system did not possess any automatic braking control authority, but maintained a selected distance to the vehicle ahead using throttle and downshift controls.

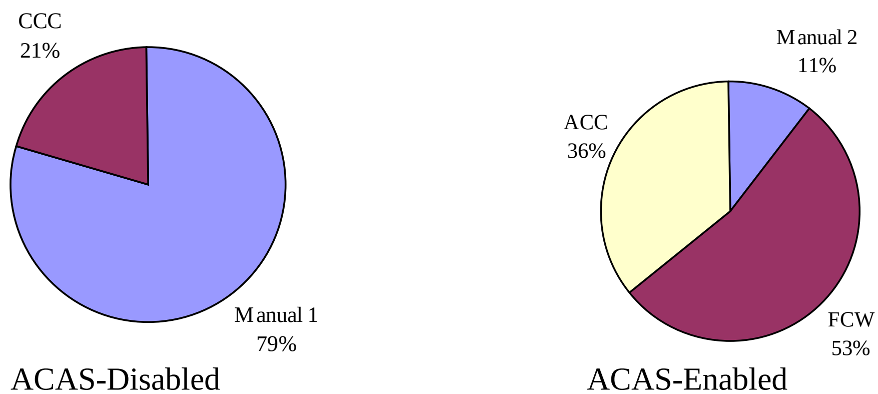


Figure 2-1. Percent Distance Traveled of Driving Modes by ACAS Status

Figure 2-2, Figure 2-3, and Figure 2-4 show the distribution of VDT by driving mode and vehicle speed range. These particular speed ranges are of interest since ACAS function is dependent on speed and the safety impact analyses correspondingly considered these speed ranges. Below 25 mph (40 km/h), the dominant driving mode is Manual 1 during the ACAS-Disabled test period and Manual 2 during the ACAS-Enabled test period with the minor exception that FCW is sometimes active for a small portion of driving between 20 and 25 mph. Above 35 mph (56 km/h), driving with ACAS-Disabled is split between Manual 1 (76%) and CCC (24%). On the other hand, driving with ACAS enabled is split predominately between FCW (54%) and ACC (42%). A small amount of Manual 2 use is seen above 35 mph reflecting brief periods of ACAS suppression. ACC, as well as CCC, are engaged almost exclusively at speeds above 35 mph. For speeds between 25 mph and 35 mph, Manual 1 remains the most used driving mode during the ACAS-Disabled test period while a mix of Manual 2 (26%) and FCW (73%) driving modes dominates the distance traveled during the ACAS-Enabled test period. Overall, about 84 percent and 87 percent of all VDT respectively during the ACAS-Disabled and ACAS-Enabled test periods were accumulated at vehicle speeds greater than or equal to 35 mph.

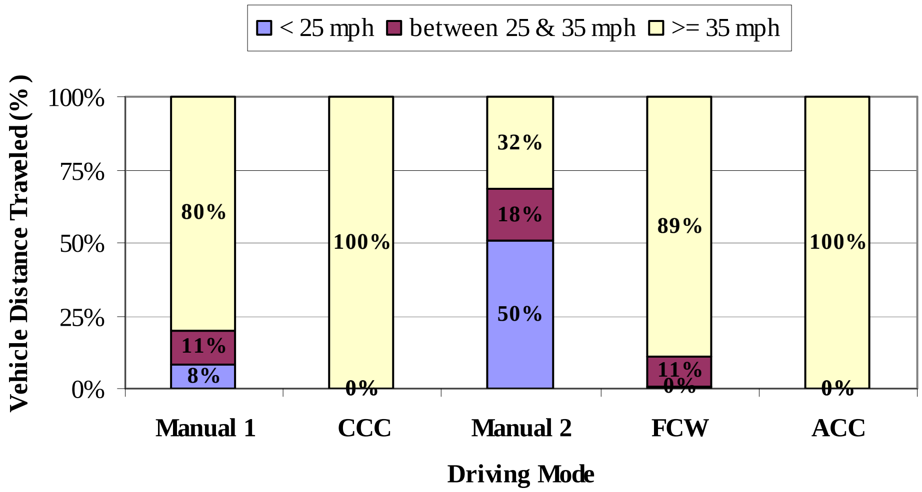


Figure 2-2. Distribution of Vehicle Distance Traveled by Driving Mode and Speed Range

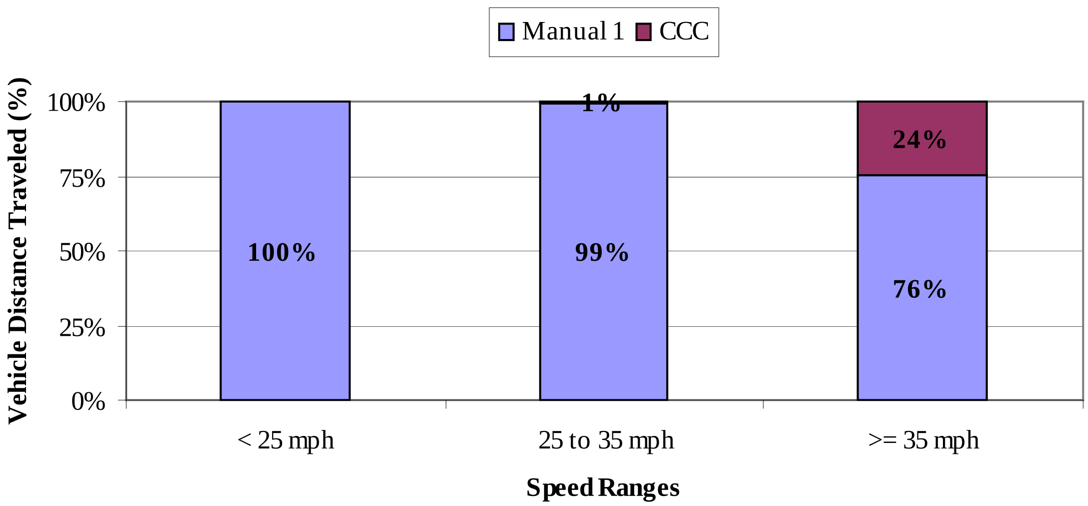


Figure 2-3. Distribution of VDT by ACAS-Disabled Driving Mode and Speed Range

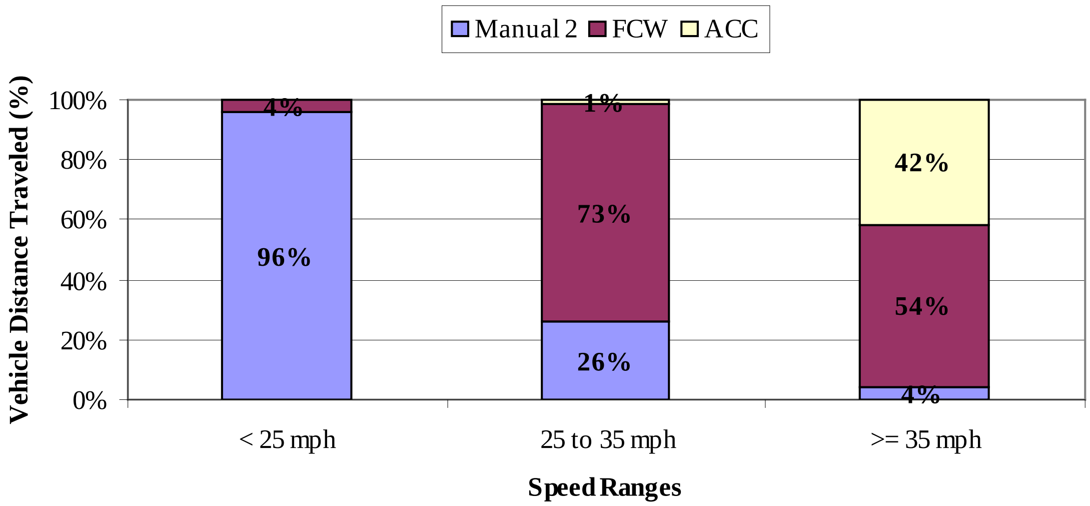


Figure 2-4. Distribution of VDT by ACAS-Enabled Driving Mode and Speed Range

2.3 EXPOSURE BY ACAS STATUS, DRIVING MODE, AND ROAD TYPE

FOT subjects drove about 85,000 km on freeways and about 72,000 km on non-freeways, accounting respectively for 54 percent and 46 percent of overall VDT during the FOT. Freeways encompass interstate highways and all other divided roadways with posted speed limits of 55 mph (89 km/h) or greater. Non-freeways include all other roadways. The total amount of distance traveled on each of these two Road Types is similar with slightly more on freeways

During the ACAS-Disabled test period, FOT subjects drove about 18,000 km on freeways and 17,000 km on non-freeways. On the other hand, FOT subjects drove 66,000 km on freeways and 54,000 km on non-freeways during the 3-week ACAS-Enabled test period. As noted above, considering the duration of the two test periods, the level of driving (VDT/week) is similar for the two periods. Figure 2-5 further shows the similarity between the two ACAS Status test periods in terms of percent distance traveled by road type. Thus, at this aggregate level of analysis, differences in road type exposure should not influence safety or user acceptance results.

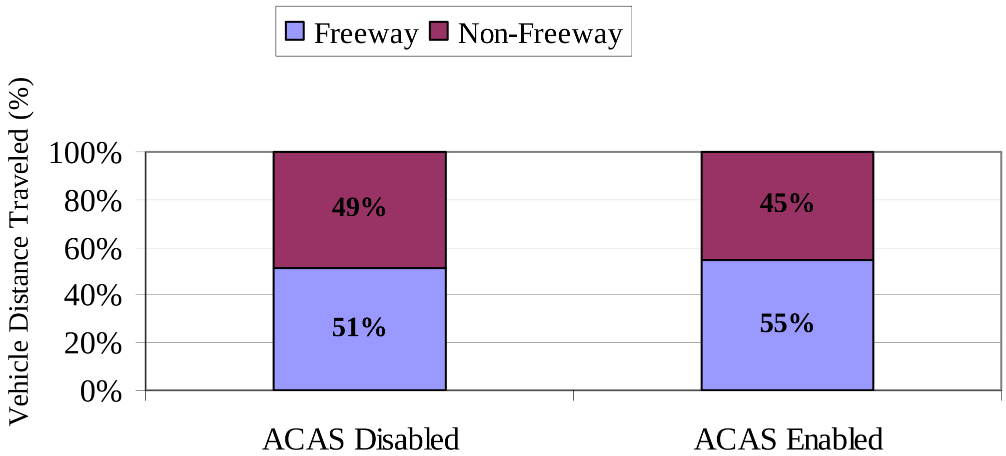


Figure 2-5. **Percent Vehicle Distance Traveled by ACAS Status and Road Type**

Figure 2-6 and Figure 2-7 further describe the distribution of VDT respectively for the ACAS-Disabled and the ACAS-Enabled driving modes by road type. The breakdown of the distance traveled in CCC between freeways and non-freeways is equal to that of ACC. CCC and ACC use is predominately on freeways – 85 percent of all VDT in each control mode. This appears to be a reflection of the fact that freeways offer greater opportunities for use of CCC or ACC in an environment of higher speeds and fewer traffic restrictions. Figure 2-7 shows that the Manual 2 driving mode is used predominately on non-freeways. This is reasonable since Manual 2 driving primarily occurs at speeds less than 25 mph. FCW driving represents most of the non-ACC driving at speeds greater than 25 mph and is slightly more prevalent on non-freeways than freeways. In comparison with Figure 2-5 for overall ACAS-Enabled test period (freeway driving slightly more than non-freeway driving), this FCW result is reasonable since ACC use will tend to diminish the use of FCW use on freeways.

Figure 2-8 and Figure 2-9 break down the VDT on freeways and non-freeways by ACAS-Disabled and ACAS-Enabled driving modes, respectively. Only one third of VDT on freeways is driven with CCC during the ACAS-Disabled test period. In contrast, a major portion of freeway driving (56%) is performed using ACC during the ACAS-Enabled test period. As for non-freeway driving, the relative VDT with ACC is twice that of CCC. As seen in Figure 2-9, FCW is active in 66 percent of the non-freeway VDT as opposed to only 42 percent of the freeway VDT.

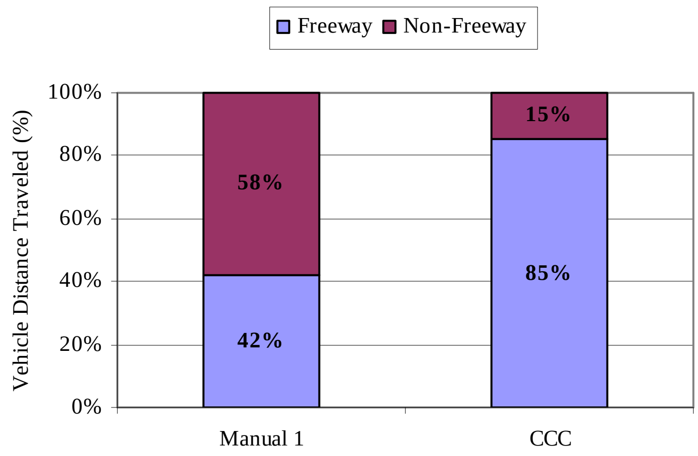


Figure 2-6. Percent VDT by ACAS-Disabled Driving Modes and Road Type

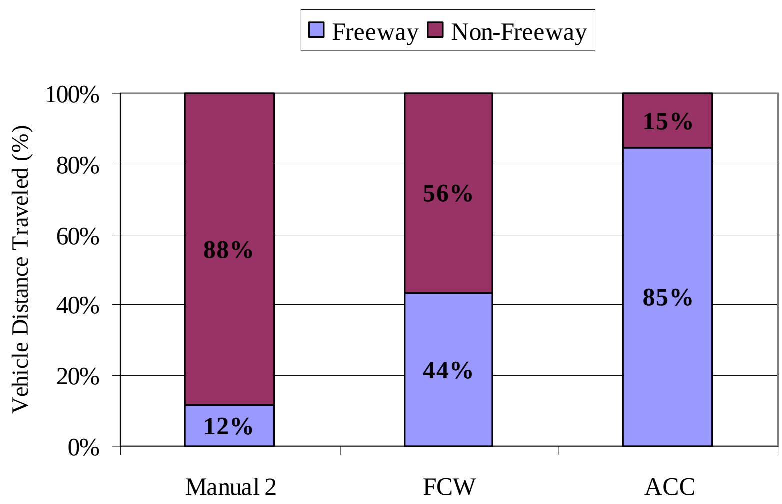


Figure 2-7. Percent VDT by ACAS-Enabled Driving Modes and Road Type

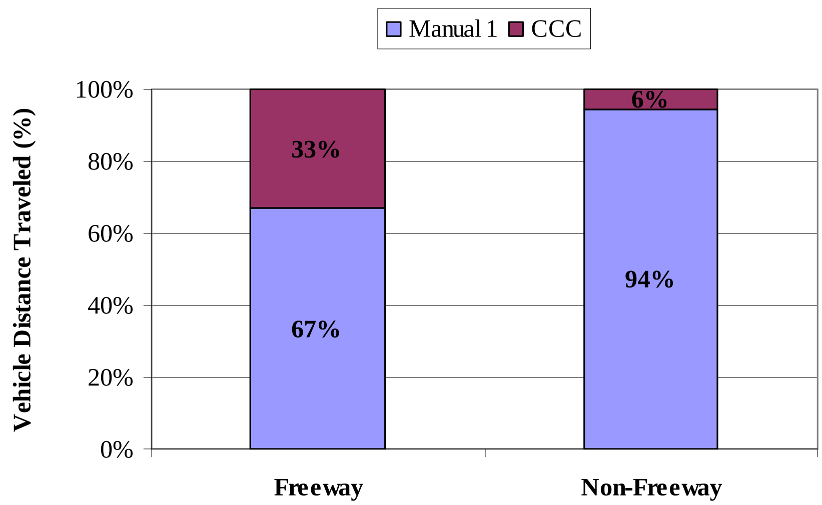


Figure 2-8. Percent VDT (ACAS-Disabled) by Road Type and Mode

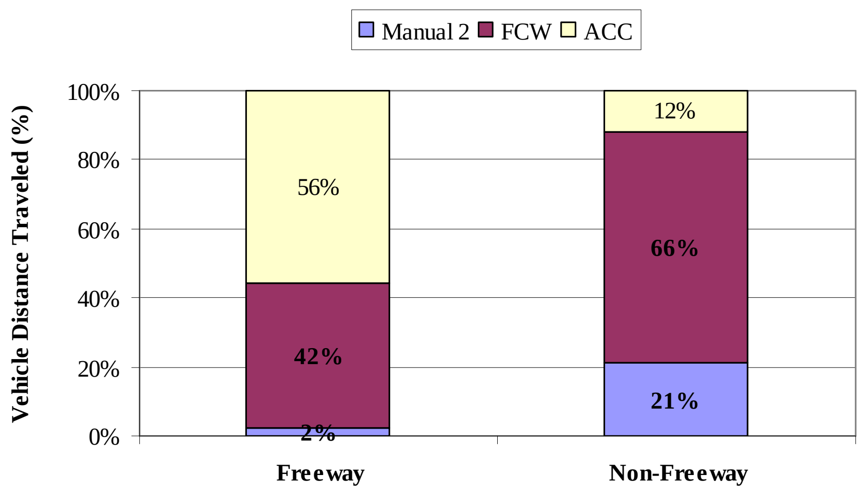


Figure 2-9. Percent VDT (ACAS-Enabled) by Road Type and Mode

2.4 EXPOSURE BY ACAS STATUS, AGE, AND GENDER

This section presents a detailed examination of exposure by the following FOT subject group categories of age and gender:

- Younger Male, Younger Female
- Middle-Age Male, Middle-Age Female
- Older Male, Older Female
- All Male, All Female
- All Younger, All Middle-Age, All Older
- All

Driver Age categories are defined as follows:

- Younger - Drivers between the ages of 20 and 30 years.
- Middle-age – Drivers between the ages of 40 and 50 years.
- Older – Drivers between the ages of 60 and 70 years

Figure 2-10 displays the distribution of valid VDT for the entire FOT by age and gender categories. The older male and older female groups drove slightly longer distances than the younger and middle-age groups; however, all groups drove comparable distances (the maximum distance group drove only 24 percent further than the minimum distance group).

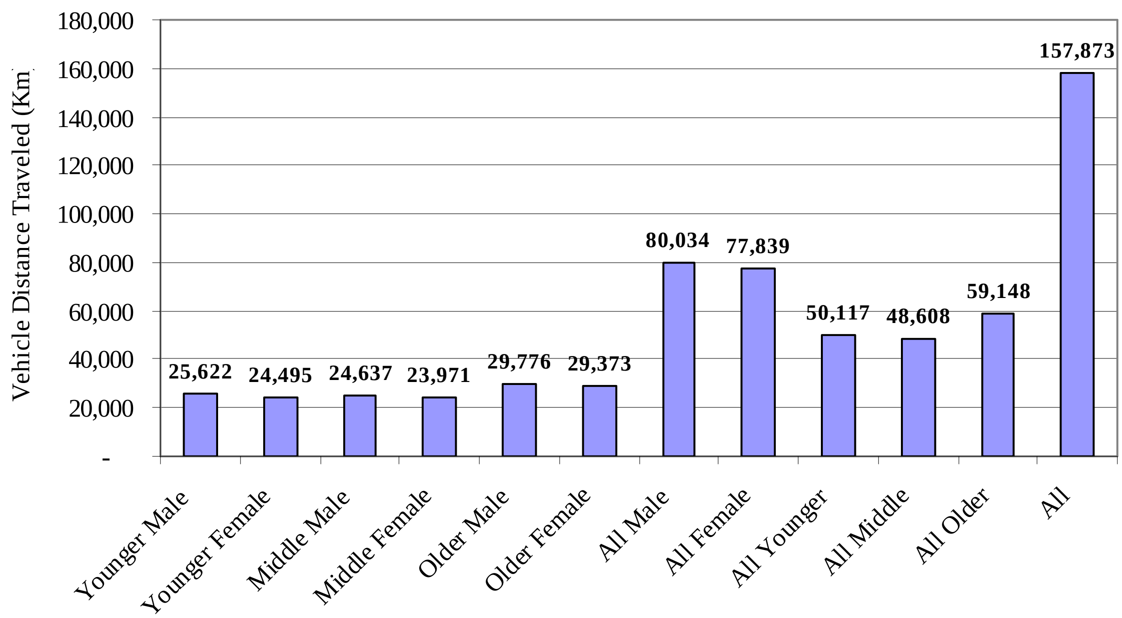


Figure 2-10. Total VDT by Age and Gender Categories

Figure 2-11 presents the distribution of valid VDT by ACAS Status (ACAS-Disabled or Enabled) for the various subject group combinations. The older female group drove the least distance with ACAS disabled whereas the older male group drove the most distance with ACAS disabled. All groups drove roughly similar distances; thus, at this aggregate level of analysis, differences in overall driving exposure between subject groups should not influence safety or user acceptance results.

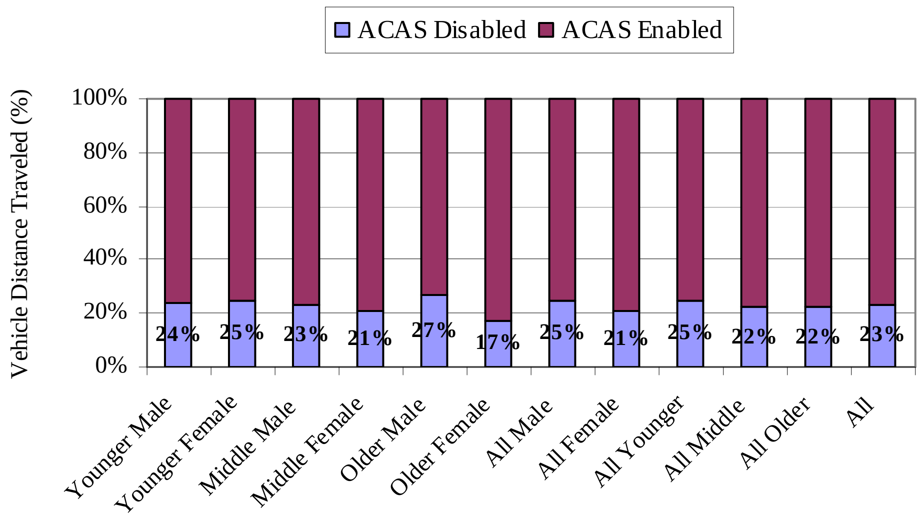


Figure 2-11. Percent VDT by ACAS Status and Age and Gender Categories

Figure 2-12 and Figure 2-13 illustrate the distribution of valid VDT by age and gender in the ACAS-Disabled and ACAS-Enabled test periods, respectively. The older male group drove the most with 22 percent of the ACAS-Disabled VDT whereas the older and middle-age female groups drove the least with 14 percent each. The total VDT with ACAS-Disabled was also distributed as follows:

- 55 percent by all male group and 45 percent by all female group, and
- 34 percent by all younger group, 30 percent by all middle-age group, and 36 percent by all older group.

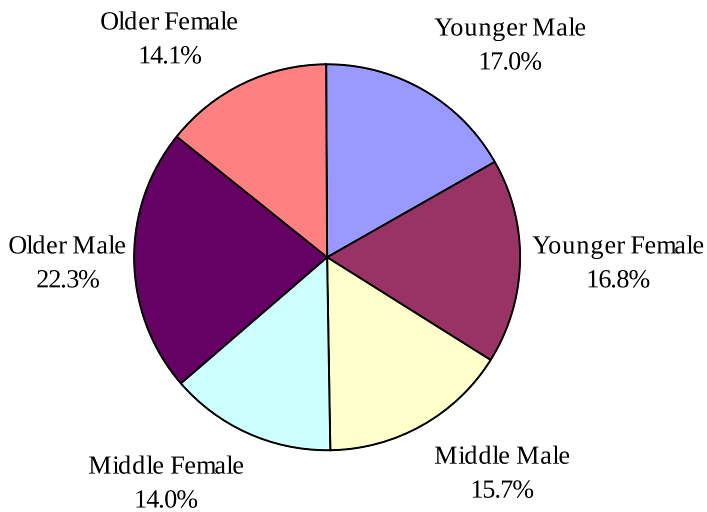


Figure 2-12. Percent VDT with ACAS-Disabled by Age and Gender

In the ACAS-Enabled test period, the older female group drove the most with 20 percent of the VDT whereas the younger female group drove the least with 15 percent. This VDT was also distributed as follows:

- 49 percent by all male group and 51 percent by all female group, and
- 31 percent by all younger group, 31 percent by all middle-age group, and 38 percent by all older group.

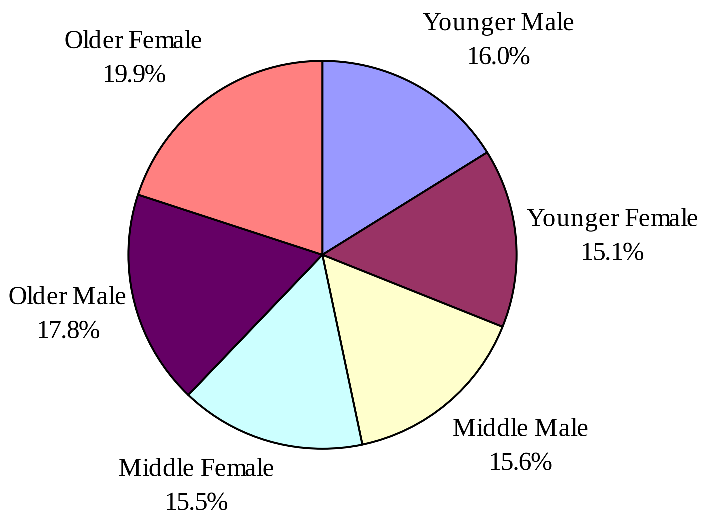


Figure 2-13. Percent VDT with ACAS-Enabled by Age and Gender

2.5 EXPOSURE BY DRIVING MODE, AGE, AND GENDER

This section presents a detailed examination of exposure by the 12 age and gender categories to the different driving modes. Figure 2-14 shows exposure, during the ACAS-Disabled test period, to the driving modes of Manual 1 and CCC. Overall, the subjects drove 21 percent of the ACAS-Disabled VDT with CCC. As the figure shows, there are some large differences in the use of CCC among the groups. The older male group drove 43 percent of their VDT using CCC, the highest rate among the groups. The lowest usage rate was among the middle-age female group.

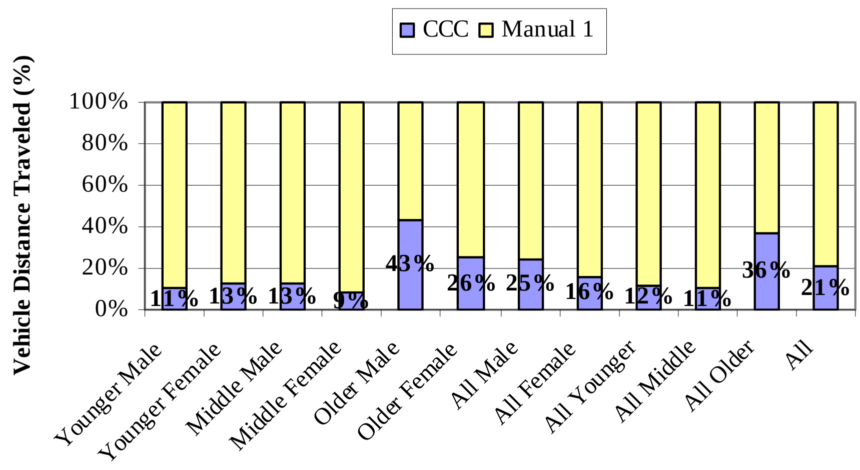


Figure 2-14. Percent VDT for ACAS-Disabled Driving Modes by Age and Gender

Figure 2-15 and Figure 2-16 provide more detailed distributions of valid VDT by age and gender for Manual 1 and CCC use, respectively. For manual control driving, Figure 2-15 shows that the highest usage rate was among younger males, at about 19 percent. All the groups showed relatively minor variations in manual control usage. The VDT in manual control was also distributed as follows:

- 52 percent by the all male group and 48 percent by the all female group
- 38 percent by the all younger group, 33 percent by the all middle-age group, and 29 percent by the all older group.

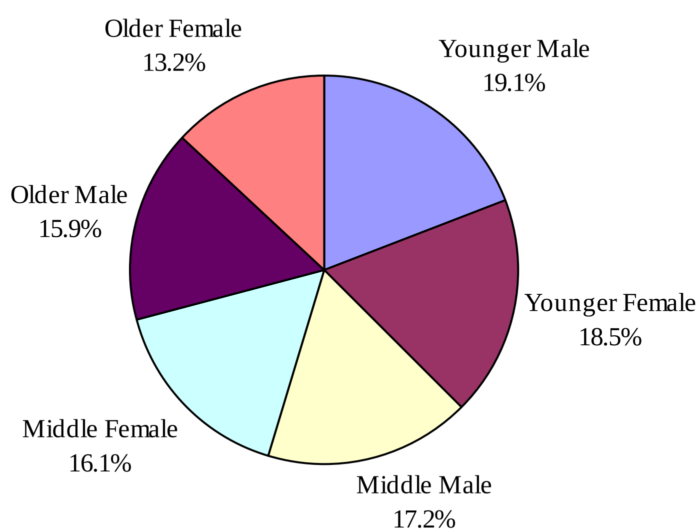


Figure 2-15. Percent VDT for Manual Control (ACAS-Disabled) by Age and Gender

For CCC driving as shown in Figure 2-16, a notable observation is that the older male group drove considerably more in CCC (47% of the VDT) than any of the other groups, which is consistent with the observation above (see Figure 2-14) that older males had the highest proportion of CCC versus manual control driving. The VDT in CCC with ACAS-Disabled was also distributed as follows:

- 66 percent by the all male group and 34 percent by the all female group
- 19 percent by the all younger group, 16 percent by the all middle-age group, and 65 percent by the all older group.

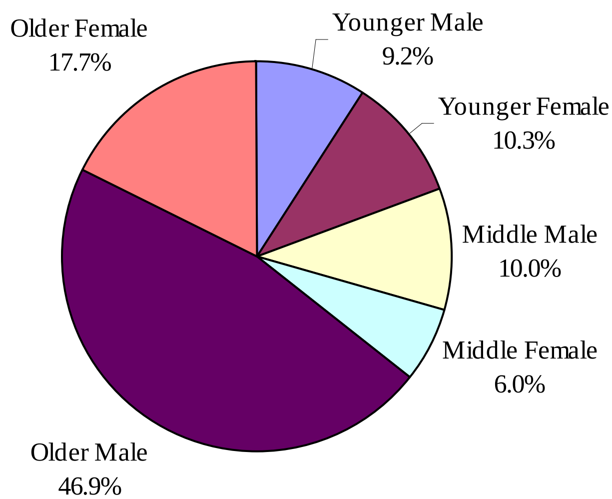


Figure 2-16. Percent VDT for CCC (ACAS-Disabled) by Age and Gender

Figure 2-17 shows exposure, during the ACAS-Enabled test period, to the Manual 2, FCW, and ACC driving modes. Overall, during the ACAS-Enabled test period, all subjects drove 36 percent of the VDT with ACC. As noted above, this contrasts with only a 21 percent usage rate for CCC. As the figure shows, there are some large differences in the use of ACC among the groups. The older female group drove 54 percent of their VDT using ACC, which is the highest rate among the groups. Although all groups showed an increase in ACC use compared to CCC use, the younger male group had the largest increase (11% to 38%). The older drivers, in general, used ACC the most (51%); middle-aged drivers used ACC the least (22%). The lowest usage rate was among middle-aged females (15%). The manual control (Manual 2) use rate was very similar among all groups.

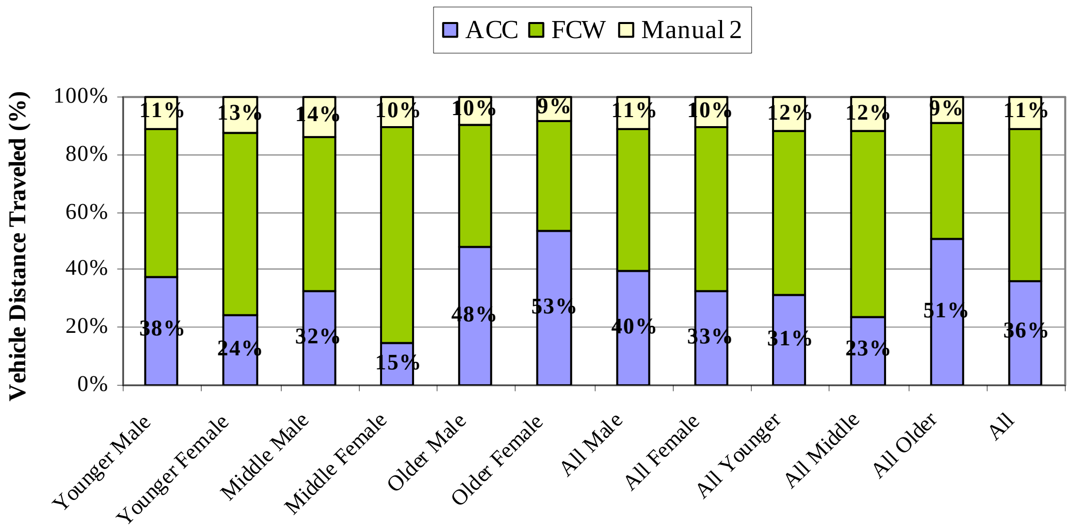


Figure 2-17. Percent VDT for ACAS-Enabled Driving Modes by Age and Gender

Figure 2-18, Figure 2-19, and Figure 2-20 provide more detailed distributions of valid VDT (ACAS-Enabled) by age and gender for ACC, FCW, and Manual 2 use, respectively. For ACC driving, the highest usage rate was among older females at about 29 percent. The VDT in ACC was also distributed as follows:

- 54 percent by the all male group and 46 percent by the all female group, and
- 27 percent by the all younger group, 20 percent by the all middle-age group, and 53 percent by the all older group.

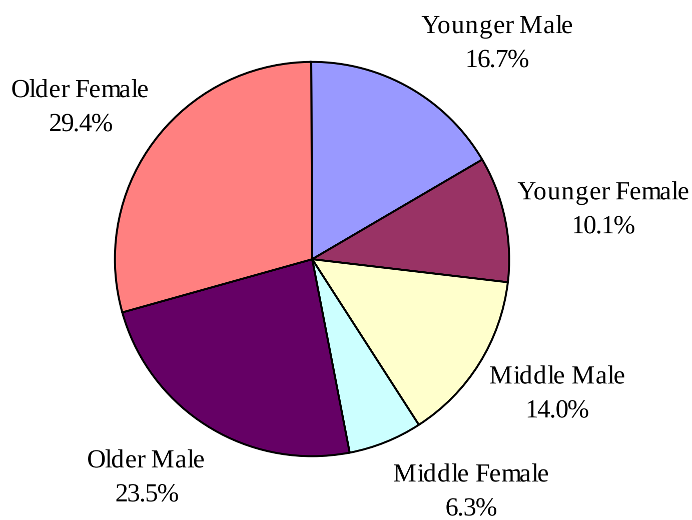


Figure 2-18. Percent VDT for ACC (ACAS-Enabled) by Age and Gender

Figure 2-19 shows the distribution of FCW VDT by age and gender. This total FCW VDT was also distributed as follows:

- 46 percent by the all male group and 54 percent by the all female group, and
- 33 percent by the all younger group, 38 percent by the all middle-age group, and 29 percent by the all older group.

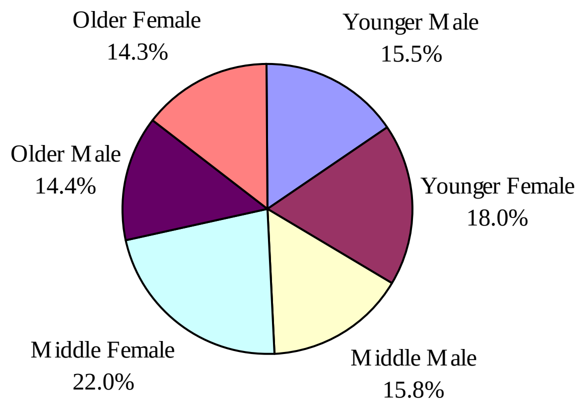


Figure 2-19. Percent VDT for FCW (ACAS-Enabled) by Age and Gender

Figure 2-20 presents the distribution of VDT in manual control (Manual 2) by age and gender. This VDT was also distributed as:

- 52 percent by the all male group and 48 percent by the all female group, and
- 33 percent by the all younger group, 35 percent by the all middle-age group, and 32 percent by the all older group.

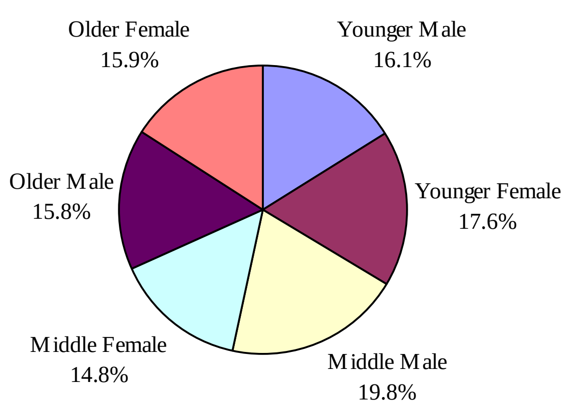


Figure 2-20. Percent VDT for Manual Control (ACAS-Enabled) by Age and Gender

2.6 EXPOSURE BY RELATIVE USE OF ACC VERSUS CCC

Figure 2-21 shows the relative exposure of subjects to ACC and CCC use expressed as a ratio of ACC to CCC VDT. Overall, the use of ACC by the FOT subjects is 1.8 times higher than CCC, that is; the percent of ACAS-Enabled VDT with ACC use is 1.8 times greater than the percent of ACAS-Disabled VDT with CCC use. As seen in Figure 2-21, the greatest increase in ACC use over CCC use was seen in the younger male group.

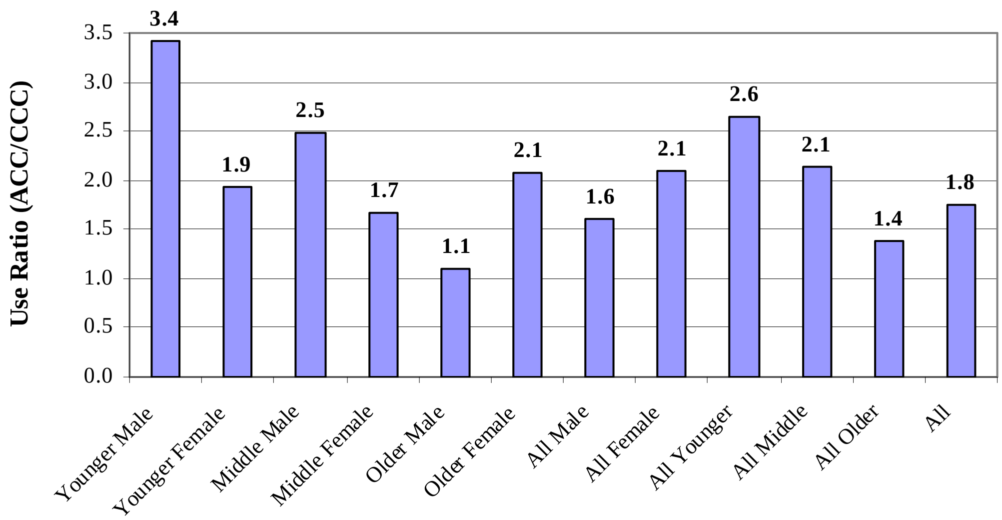


Figure 2-21. Relative Use of ACC Compared to CCC by VDT

2.7 EXPOSURE BY ACAS STATUS, DRIVING MODE, ROAD TYPE, AGE, AND GENDER

As noted above, the proportion of VDT between the two ACAS Status test periods by road type was very similar. Figure 2-22 and Figure 2-23 extend this analysis to include age and gender. As indicated in Figure 2-22, the proportion of driving on non-freeways by males and females is the same between the two ACAS Status test periods. Males and females also have about the same proportion of distance traveled, 52 percent for males and 48 percent for females. Driving on freeways shows a minor variation in this pattern. Females drove proportionately more than males for the ACAS-Enabled test period (53% versus 47%) whereas females drove slightly less than males for the ACAS-Disabled test period (43% versus 57%).

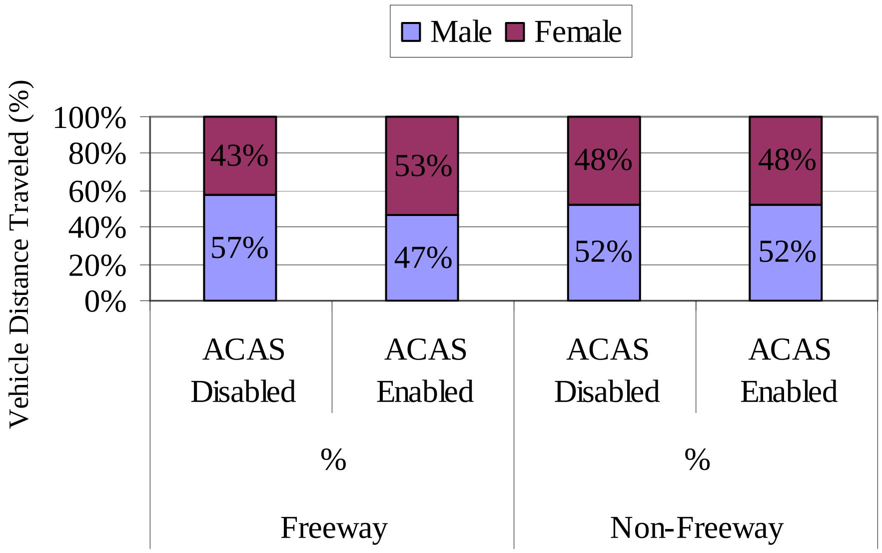


Figure 2-22. Percent VDT by ACAS Status, Road Type, and Gender

As indicated in Figure 2-23, the proportions of driving by road type and by age are relatively uniform between the two ACAS Status test periods. In general, older drivers tended to drive slightly more on freeways than non-freeways, whereas the opposite is apparent for middle-age and younger drivers.

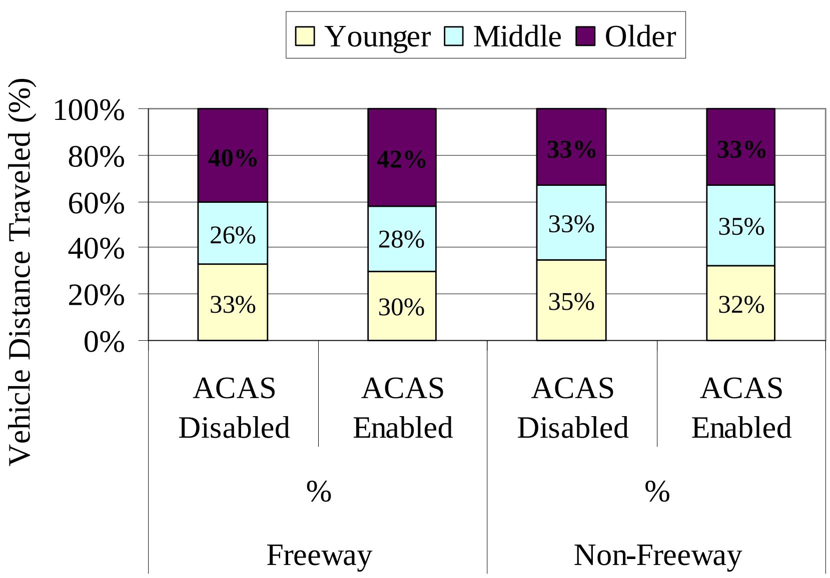


Figure 2-23. Percent VDT by ACAS Status, Road Type, and Age

Figure 2-24 shows the distribution of VDT for ACAS-Enabled driving modes by road type and gender. The proportion of ACC driving is nearly equal between males and females (males slightly more) for both freeways and non-freeways. The proportion of FCW driving is similar between males and females on non-freeways but females have a higher FCW usage rate on freeways. Manual control (Manual 2) driving is also nearly equal between males and females for both road types.

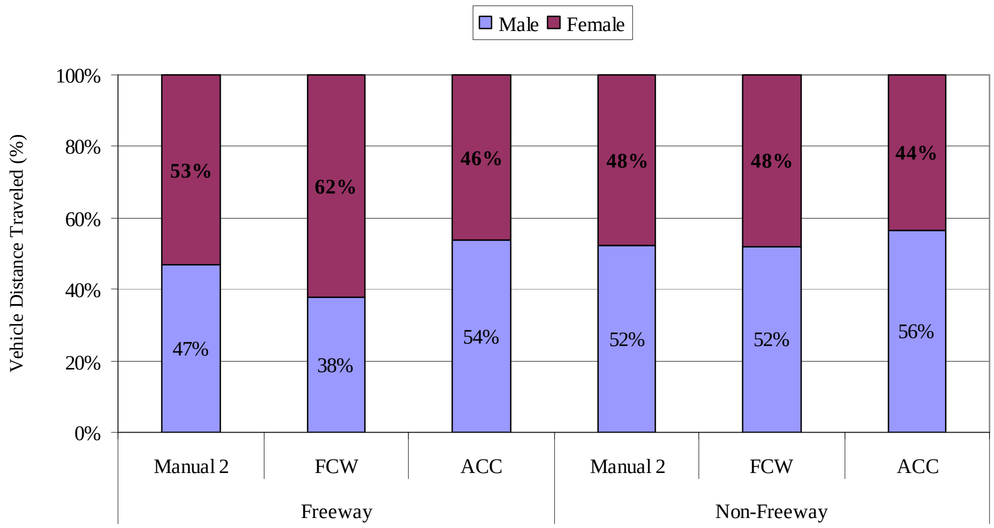


Figure 2-24. Percent VDT by ACAS-Enabled Driving Modes, Road Type, and Gender

Figure 2-25 shows the distribution of ACAS-Enabled VDT by road type and age. In addition to the patterns discussed above for gender, Figure 2-25 shows that, regardless of road type, older drivers generally use ACC the most, followed by younger drivers and middle-age drivers. The proportion of FCW driving is similar between age groups for both road types. Manual control is also about equally divided between the age groups for both Road Types.

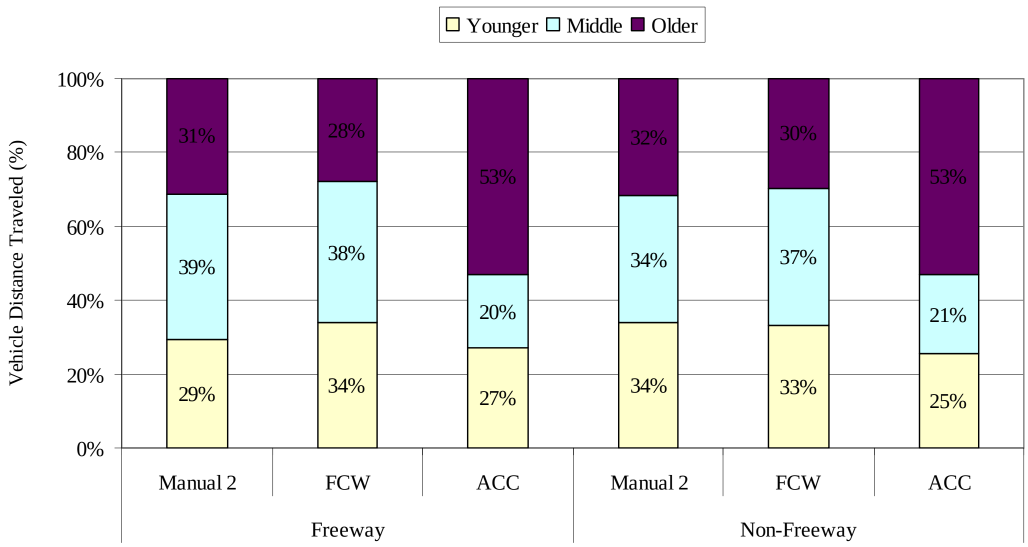


Figure 2-25. Percent VDT by ACAS-Enabled Driving Modes, Road Type, and Age

2.8 EXPOSURE BY ACAS STATUS, DRIVING MODE, AGE, GENDER, AND WEATHER

Figure 2-26 presents the distribution of VDT by ACAS Status, age, gender, and weather. Weather was classified as either clear or adverse as determined by activation of the windshield wipers. The proportion of driving for clear and adverse weather by the various ACAS Status, age, and gender categories is very similar. In general, all categories are close to the average of 92 percent of all driving in clear weather.

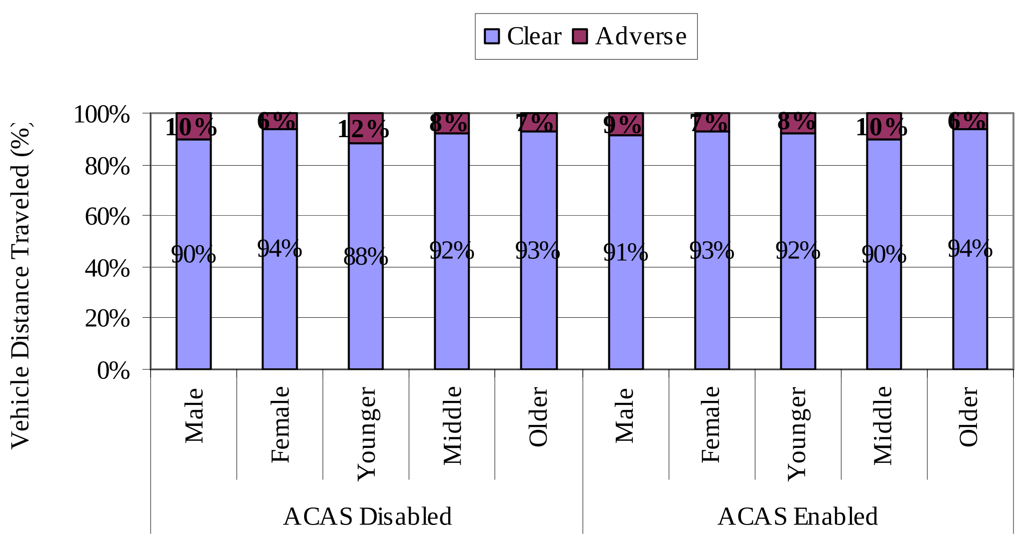


Figure 2-26. Percent VDT by ACAS Status, Age, Gender, and Weather

Exposure data for driving by weather were examined further for various driving modes. In general, the same patterns as shown in Figure 2-26 prevailed. The results are summarized below:

- Manual control (Manual 1), ACAS-Disabled:
  - 91 percent of this driving is performed in clear weather:
    - 51 percent by all males and 49 percent by all females, and
    - 36 percent by all younger, 34 percent by all middle-age, and 30 percent by all older
  - 9 percent of this driving is performed in adverse weather:
    - 62 percent by all males and 38 percent by all females, and
    - 48 percent by all younger, 29 percent by all middle-age, and 23 percent by all older

- CCC, ACAS-Disabled:
  - 94 percent of this driving is performed in clear weather:
    - 64 percent by all males and 36 percent by all females, and
    - 19 percent by all younger, 16 percent by all middle-age, and 65 percent by all older
  - 6 percent of this driving is performed in adverse weather:
    - 96 percent by all males and 4 percent by all females, and
    - 34 percent by all younger, 10 percent by all middle-age, and 56 percent by all older

- Manual control (Manual 2), ACAS-Enabled:
  - 91 percent of this driving is performed in clear weather:
    - 51 percent by all males and 49 percent by all females, and
    - 34 percent by all younger, 34 percent by all middle-age, and 32 percent by all older
  - 9 percent of this driving is performed in adverse weather:
    - 54 percent by all males and 46 percent by all females, and
    - 33 percent by all younger, 42 percent by all middle-age, and 25 percent by all older
- FCW, ACAS-Enabled:
  - 90 percent of this driving is performed in clear weather:
    - 45 percent by all males and 55 percent by all females, and
    - 34 percent by all younger, 37 percent by all middle-age, and 29 percent by all older
  - 10 percent of this driving is performed in adverse weather:
    - 51 percent by all males and 49 percent by all females, and
    - 33 percent by all younger, 41 percent by all middle-age, and 27 percent by all older

- ACC, ACAS-Enabled:
  - 96 percent of this driving is performed in clear weather:
    - 54 percent by all males and 46 percent by all females, and

        - 27 percent by all younger, 20 percent by all middle-age, and 53 percent by all older
    - 4 percent of this driving is performed in adverse weather:
        - 67 percent by all males and 33 percent by all females, and
        - 19 percent by all younger, 36 percent by all middle-age, and 44 percent by all older

Figure 2-27 and Figure 2-28 break down the VDT in clear and adverse weather by the driving modes of ACAS-Disabled and ACAS-Enabled test periods, respectively. About 21 percent of the VDT in clear weather was accumulated by the CCC driving mode during the ACAS-Disabled test period, as opposed to 38 percent of clear weather VDT by ACC during the ACAS-Enabled test period. ACC usage rate was also higher than CCC in adverse weather VDT. During the ACAS-Enabled test period, the relative VDT with FCW in adverse weather was higher than in clear weather due to the lower usage rate of ACC in adverse weather.

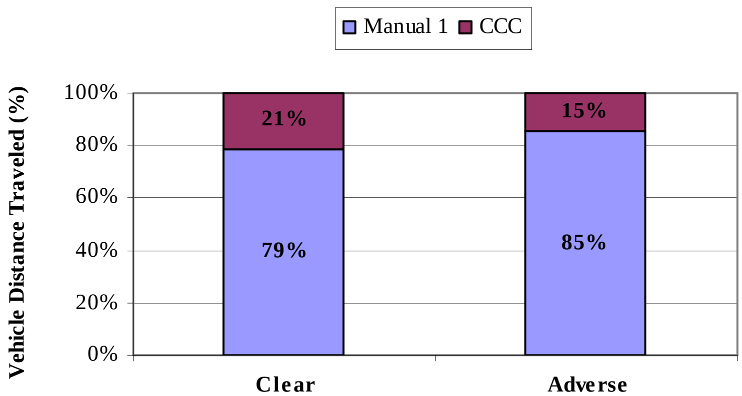


Figure 2-27. Breakdown of VDT by Weather and Driving Mode with ACAS Disabled

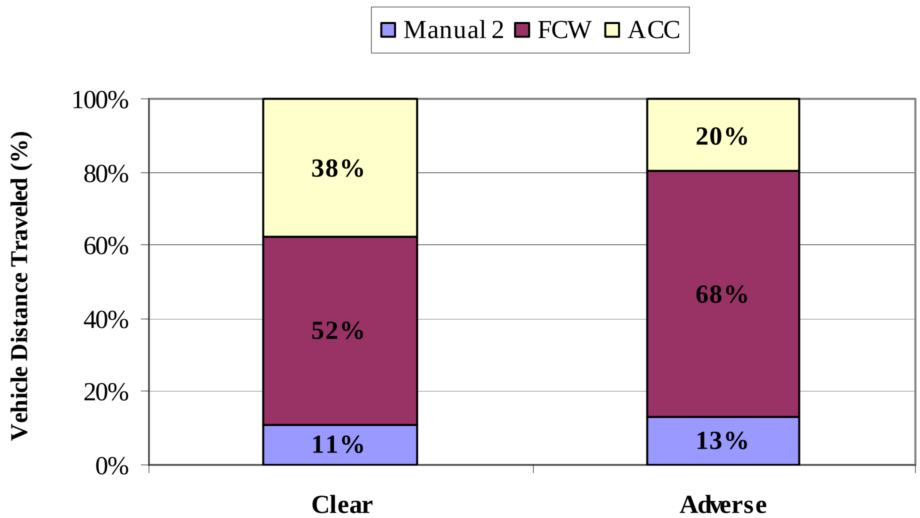


Figure 2-28. Breakdown of VDT by Weather and Driving Mode with ACAS-Enabled

2.9 EXPOSURE BY ACAS STATUS, DRIVING MODE, AGE, GENDER, AND AMBIENT LIGHT

In the ACAS-Disabled test period, FOT subjects drove 26,000 km in lighted conditions and 10,000 km in the dark, accounting respectively for 73 percent and 27 percent of all VDT in this period. By comparison, in the ACAS-Enabled test period, subjects drove 90,000 km in lighted conditions and 32,000 km in the dark, comprising respectively 74 percent and 26 percent of all VDT in this period. Ambient light was classified as either light or dark as determined by the photo sensor in the host vehicle that automatically activates the headlights when it gets dark outside. The proportion of driving for light and dark by the two ACAS Status test periods is very similar. About 74 percent of all driving is performed during lighted conditions.

Figure 2-29 shows the distribution of VDT for ACAS-Disabled driving modes by ambient light. The proportion of driving by light and dark is nearly identical between Manual 1 and CCC driving.

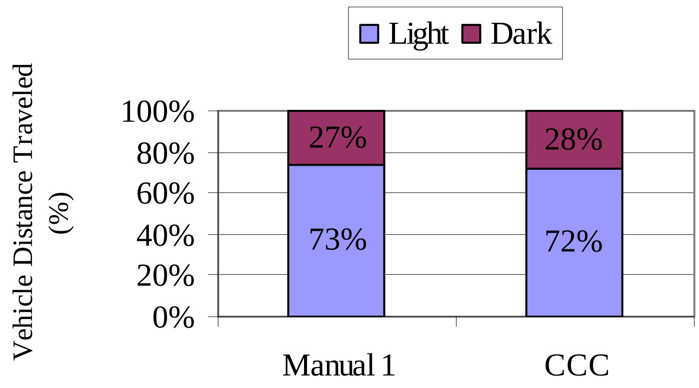


Figure 2-29. Percent VDT by ACAS-Disabled Driving Modes and Ambient Light

Figure 2-30 shows the distribution of VDT for ACAS-Enabled driving modes by ambient light. The proportion of driving by light and dark is nearly identical between Manual 2, FCW, and ACC driving. These distributions are also very similar to the ACAS-Disabled driving modes.

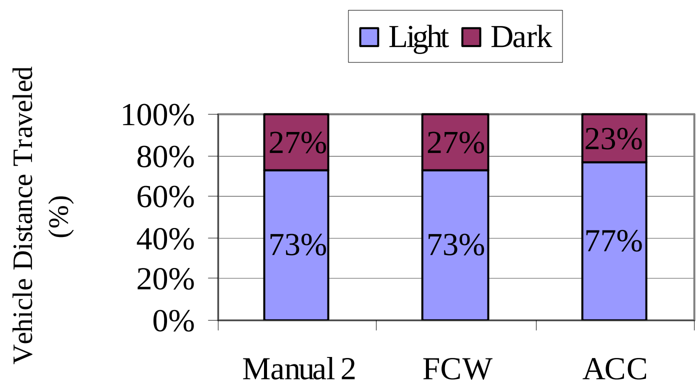


Figure 2-30. Percent VDT by ACAS-Enabled Driving Modes and Ambient Light

Figure 2-31 shows the distribution of VDT for ACAS Status, age, and gender by ambient light. The proportion of driving by light and dark is very similar for gender and age, with two minor exceptions: comparing driving with ACAS-Enabled versus ACAS Disabled, younger drivers tended to drive slightly less during light conditions (69% versus 65%) and older drivers tended to drive slightly more during light conditions (84% versus 79%).

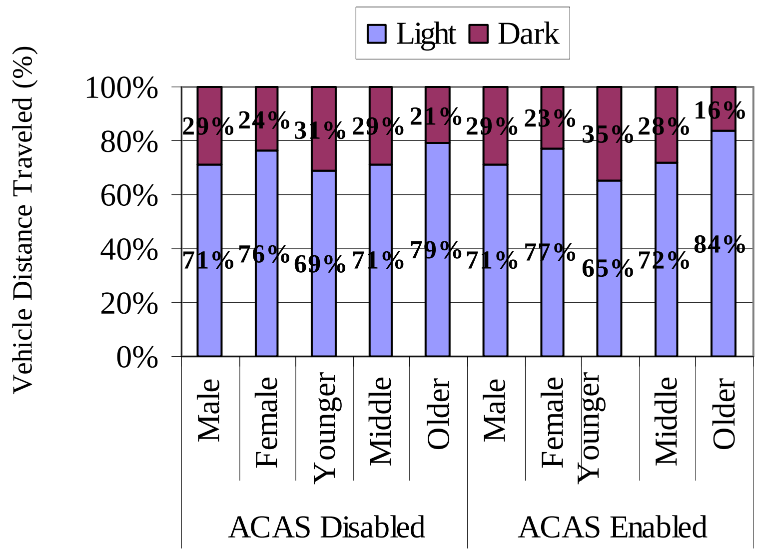


Figure 2-31. Percent VDT by ACAS Status, Age, Gender, and Ambient Light

Figure 2-32 shows the distribution of VDT for ACAS-Enabled driving modes, age, and gender by ambient light. The proportion of driving within the gender and age groups is quite similar between the driving modes. The largest difference is within females, who drove ACC slightly more during lighted conditions (81%) than FCW (75%) and Manual 2 (76%). Between groups, the use patterns are very similar, but show a progression of an increased proportion of ACAS use during lighted conditions from younger (about 65%) to middle (about 72%) to older (about 84%) (see also Figure 2-31).

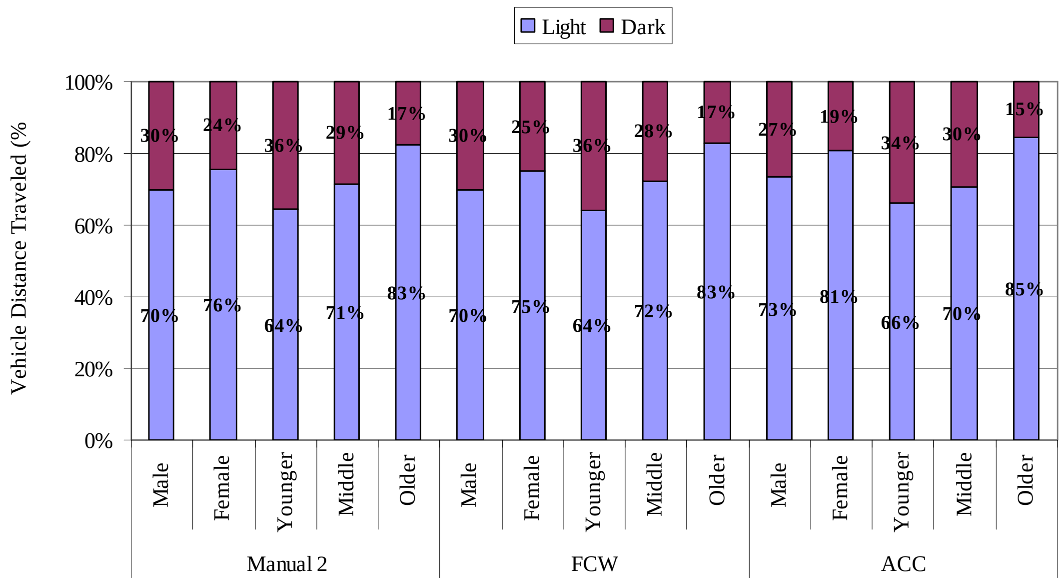


Figure 2-32. Percent VDT by ACAS-Enabled Driving Modes, Age, Gender, and Ambient Light

Figure 2-33 and Figure 2-34 break down the VDT in lighted and dark conditions by the driving modes of ACAS-Disabled and ACAS-Enabled test periods, respectively. About 20 percent of the VDT in lighted conditions was accumulated by the CCC driving mode during the ACAS-Disabled test period, as opposed to 37 percent of light VDT by ACC during the ACAS-Enabled test period. ACC usage rate was also higher than CCC in dark VDT. During the ACAS-Enabled test period, the relative VDT with FCW in dark conditions was higher than in lighted conditions due to the lower usage rate of ACC in the dark.

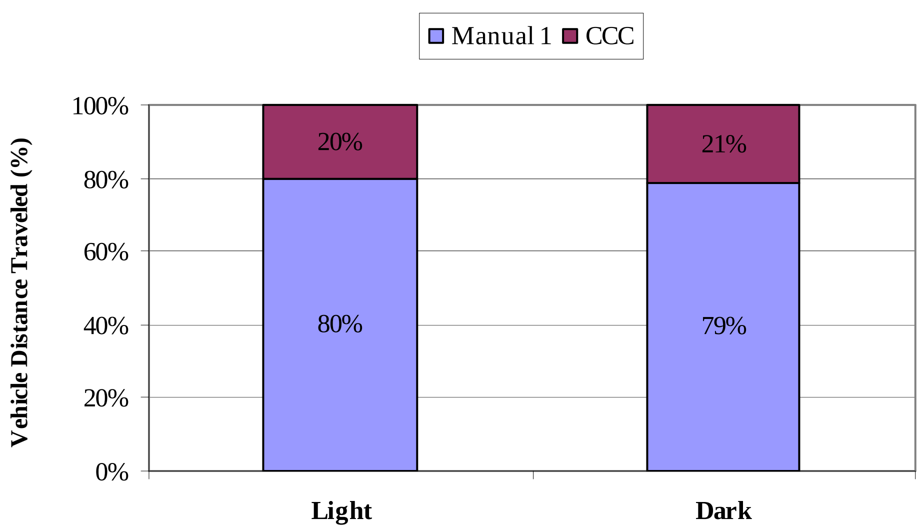


Figure 2-33. Breakdown of VDT by Ambient Light and Driving Mode with ACAS Disabled

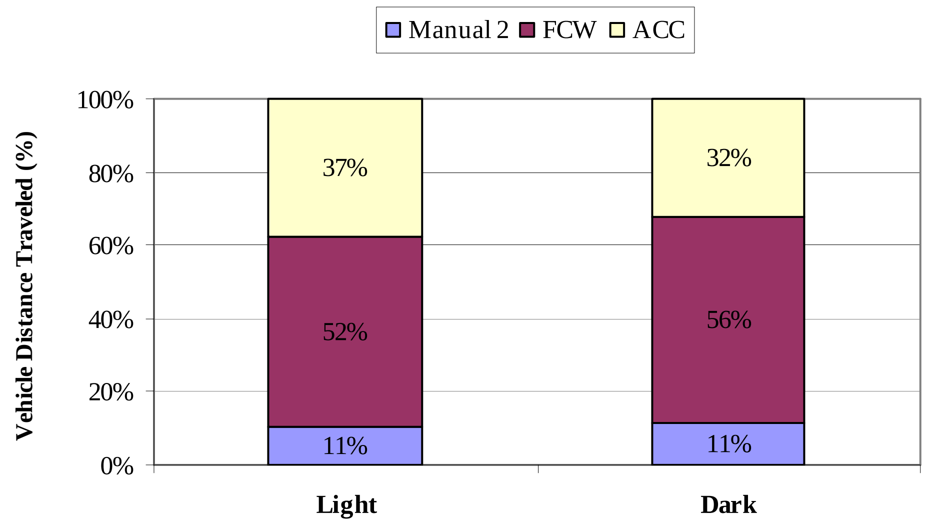


Figure 2-34. Breakdown of VDT by Ambient Light and Driving Mode with ACAS-Enabled

2.10 EXPOSURE BY ACAS STATUS, DRIVING MODE, AGE, GENDER, AND TRAFFIC

This section presents the distribution of VDT by ACAS Status, driving mode, age, gender, and traffic Level. Traffic level is classified as low, moderate, or heavy. The Traffic level classifications are determined from FOT data based on road characteristics, vehicle speed, and vehicle target counts using the Traffic State Identification algorithm. This algorithm, developed specifically for the ACAS evaluation, approximates the Level of Service as defined by the Highway Capacity Manual. Low traffic corresponds to service levels A and B, Moderate traffic to C and D, and Heavy traffic to E and F. A more detailed description of the Traffic State Identification algorithm can be found in this reference (Koopmann and Najm, 2003).

During the ACAS-Disabled test period, FOT subjects drove:

- 24,000 km or 67 percent of VDT in low traffic
- 10,000 km or 27 percent of VDT in moderate traffic
- 1,000 km or 3 percent of VDT in heavy traffic
- 1,000 km in unknown level of traffic

During the ACAS-Enabled test period, the subjects drove:

- 84,000 km or 69 percent of VDT in low traffic
- 33,000 km or 27 percent of VDT in moderate traffic
- 4,000 km or 3 percent of VDT in heavy traffic
- 1,000 km in unknown level of traffic

The proportion of driving by traffic level between the two ACAS Status test periods is very similar. About 69 percent of all driving distance is traveled in low traffic, 27 percent in moderate traffic, and only about 3 percent in heavy traffic. The relative small amount of travel in heavy traffic will likely diminish the statistical reliability of ACAS safety impacts analyses for heavy traffic.

Figure 2-35 shows the distribution of VDT for ACAS-Enabled driving modes by traffic level. The proportion of driving in low traffic increases and correspondingly decreases in moderate and heavy traffic as the driving mode transitions from Manual 2 to FCW to ACC. This indicates that meaningful analyses of ACC driving in heavy traffic are unlikely.

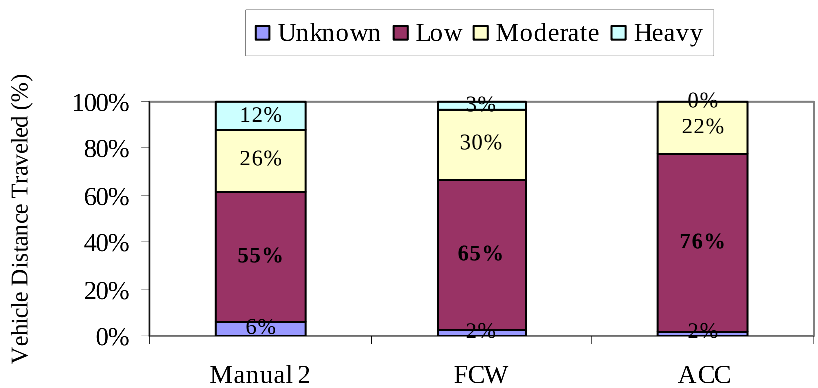


Figure 2-35. Percent VDT by ACAS-Enabled Driving Modes and Traffic Level

Figure 2-36 shows the distribution of VDT for ACAS Status, age, and gender by traffic level. The proportion of driving by traffic level is very similar for gender and age between ACAS-Enabled and ACAS-Disabled test periods. Traffic level should therefore not introduce any bias in comparisons between the two ACAS Status periods.

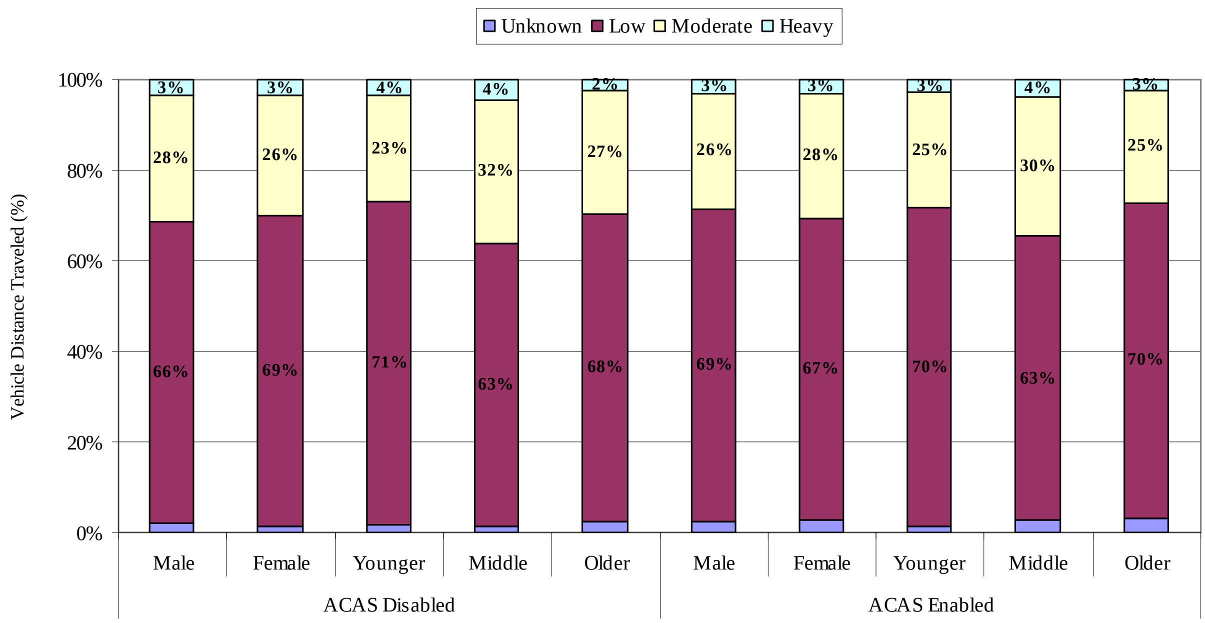


Figure 2-36. Percent VDT by ACAS Status, Age, Gender, and Traffic Level

Figure 2-37 shows the distribution of VDT for ACAS-Enabled driving modes, age, and gender by traffic level. The proportion of driving within the gender and age groups is quite similar for each driving modes. As noted above, however, for all driver groups, the proportion of driving in low traffic increases with use of ACC. Conversely, most driving in heavy traffic is performed in Manual 2. Figure 2-37 also shows that ACC use in low traffic is highest among younger drivers (81%) and lowest among middle-age drivers (72%).

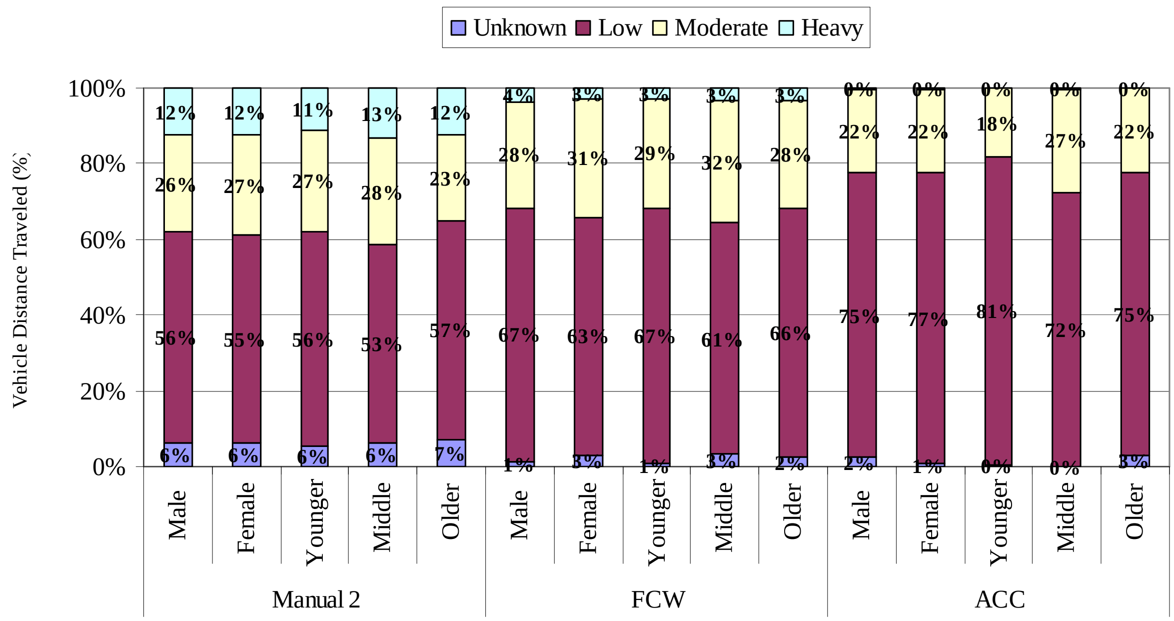


Figure 2-37. Percent VDT by ACAS-Enabled Driving Modes, Age, Gender, and Traffic Level

Figure 2-38 and Figure 2-39 break down the VDT in traffic levels by the driving modes of ACAS-Disabled and ACAS-Enabled test periods, respectively. CCC use accounted for 23 percent and 13 percent of the VDT in low and moderate traffic, respectively. In contrast, ACC accounted for 40 percent and 30 percent of the VDT respectively in low and moderate traffic. Thus, ACC use was relatively higher than CCC in moderate traffic. During the ACAS-Enabled test period, the relative VDT with FCW in moderate traffic was the highest among the three traffic levels.

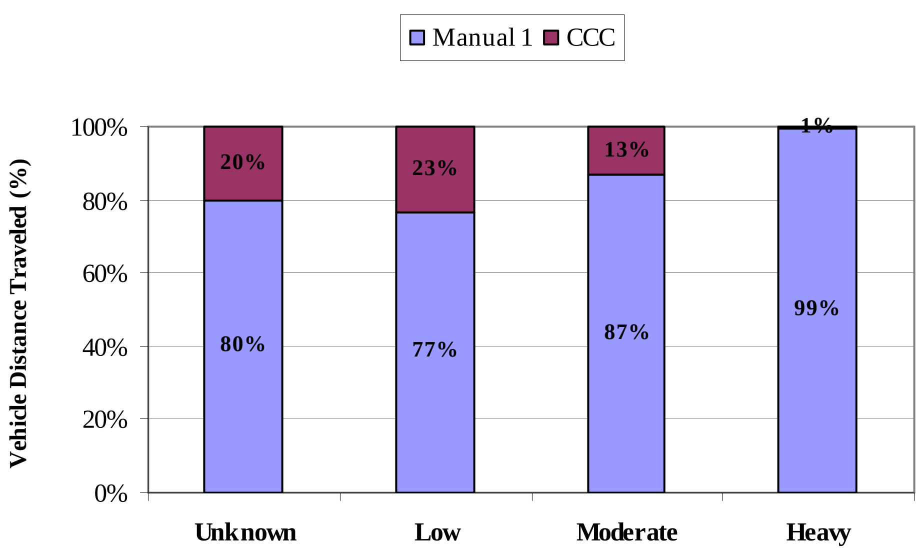


Figure 2-38. Breakdown of VDT by Traffic Level and Driving Mode with ACAS Disabled

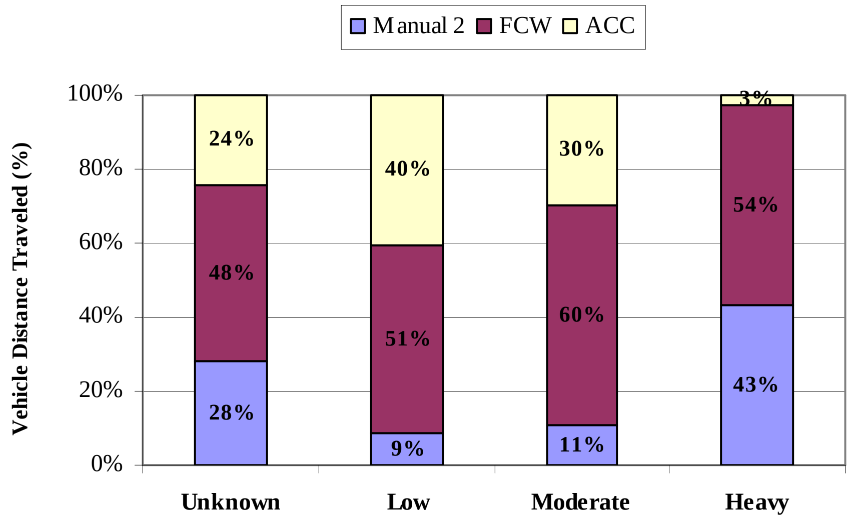


Figure 2-39. Breakdown of VDT by Traffic Level and Driving Mode with ACAS-Enabled

2.11 EXPOSURE BY ACAS USAGE PATTERNS

2.11.1 Distribution of FCW Sensitivity Settings

2.11.1.1 Distribution of FCW Sensitivity Settings, Period 3 versus Period 4

Figure 2-40 illustrates the breakdown of VDT with FCW during the ACAS-Enabled test period by FCW sensitivity settings. The most sensitive setting, S6, accounted for the highest FCW VDT among the six FCW sensitivity settings. At this setting, FOT subjects would have experienced the highest rate of visual cautionary alerts because FCW responds to the host vehicle closing in on obstacles ahead from farther ranges with lower range rates. It should be noted that FCW sensitivity setting does not affect the crash-imminent alert rate (simultaneous flashing visual and auditory tone). The other two dominant settings were S3 and S1 (S1 - least sensitive setting). At the least sensitive setting of FCW, FOT subjects would have experienced the least rate of visual cautionary alerts because FCW responds to the host vehicle closing in on obstacles ahead from closer ranges with higher range rates.

To investigate the effects of ACAS learning and experimentation when FOT subjects start to drive with the assistance of FCW and ACC functions, the ACAS-Enabled test period was divided into two periods, Period 3 and Period 4, based on almost half the distance traveled by each subject in this test period. If the halfway distance for a particular subject occurred in the middle of a trip during the ACAS-Enabled test period, that trip and subsequent trips would then be placed in Period 4. As a result, Period 3 and Period 4 amounted respectively to about 58,000 and 64,000 Km. It should be noted that the ACAS-Disabled test period was similarly divided into two periods, Period 1 and Period 2, to examine driver familiarity with a new vehicle as discussed in Section 4. FCW and ACC usage rates were attributed respectively to 54 percent and

34 percent of the VDT in Period 3. By comparison, FCW and ACC usage rates accounted respectively for 52 percent and 38 percent of the VDT in Period 4. ACC usage rate in Period 4 was slightly higher than in Period 3 due to more driving on freeways in Period 4. Figure 2-41 shows the distribution of VDT with FCW by FCW sensitivity settings for ACAS-Enabled Periods 3 and 4. The usage patterns for both periods are similar with the minor exception that Period 4 shows slightly less use of S6 and slightly more use of S2. The relative similarity of patterns indicates little modification in setting preference as subjects became more familiar with the system. Usage of settings S1, S3, and S6 tends to dominate and suggests that fewer settings might be acceptable for most users.

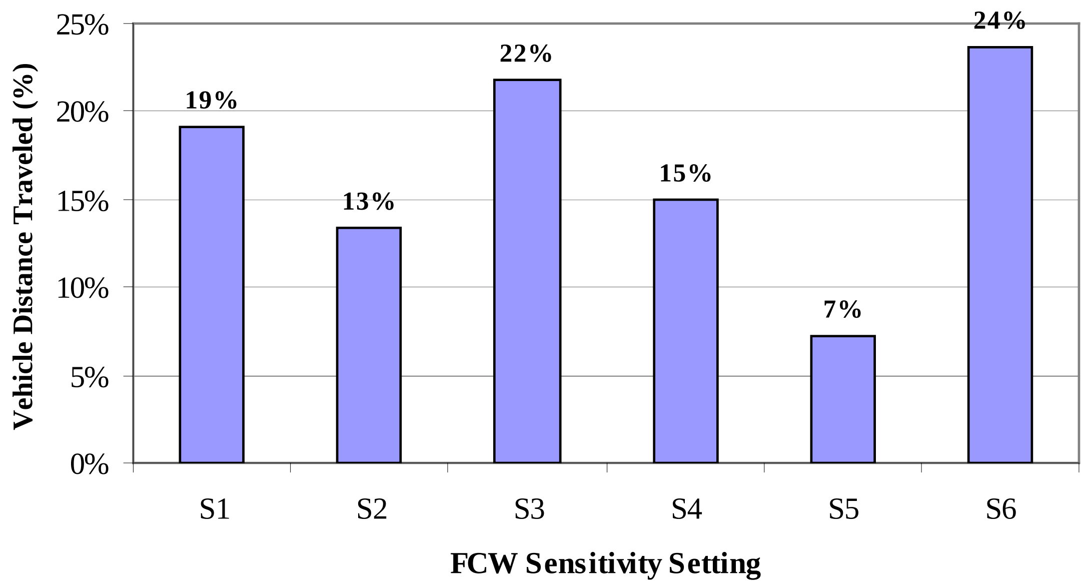


Figure 2-40. Breakdown of VDT with FCW during ACAS-Enabled by FCW Sensitivity Settings

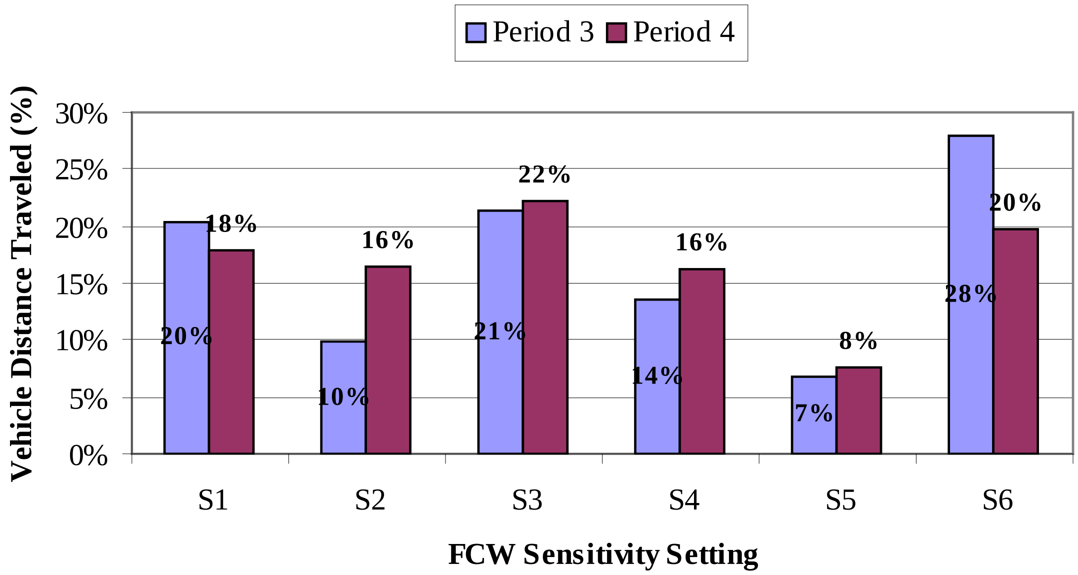


Figure 2-41. Distribution of FCW Sensitivity Settings, Period 3 versus Period 4

2.11.1.2 Distribution of FCW Sensitivity Settings by Subject Group, Period 4 Only

Figure 2-42 shows the distribution of VDT with FCW by FCW sensitivity settings and subject group for the ACAS-Enabled Period 4 only. The results indicate considerable differences in setting preference between subject groups:

- Younger subjects tend to use lower settings (77% of use is with S1 to S3)
- Middle-age subjects tend to use lower settings (72% of use is with S1 to S3)
- Older subjects tend to use higher settings (71% of use is with S4 to S6)
- Males tend to use higher settings (61% of use is with S4 to S6)
- Females tend to use lower settings (71% of use is with S1 to S3)

It is not clear why the different subject groups tended toward these patterns. Lower settings result in more critical visual cautionary alerts; however, the alerts are less frequent. Younger drivers might prefer the lower settings, as this would allow for a more aggressive style of driving without frequent occurrence of visual alert icons. Older drivers might prefer the higher settings where cautionary tailgating alerts occur at longer headways, as this would allow for more response time to these cautionary alerts. Moreover, the visual alerts might not be too frequent if the driving style is generally conservative.

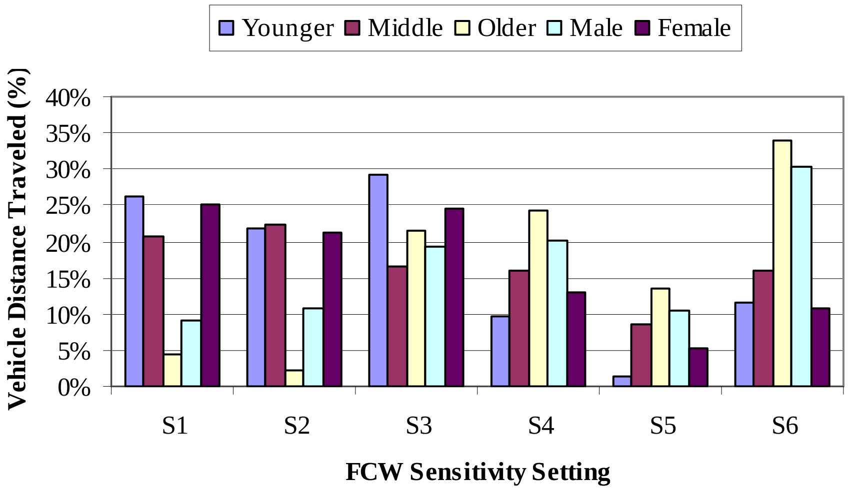


Figure 2-42. Distribution of FCW Sensitivity Settings by Subject Group, Period 4

2.11.1.3 Distribution of FCW Sensitivity Settings by Road Type and Subject Group, Period 4 Only

Figure 2-43 and Figure 2-44 display the distribution of VDT with FCW by FCW sensitivity settings by subject group for the ACAS-Enabled Period 4 only on freeways and non-freeways, respectively. Middle-age drivers are nearly evenly split between lower and higher settings on non-freeways, and the female tendency to use lower settings is slightly lessened (65% of use is with S1 to S3).

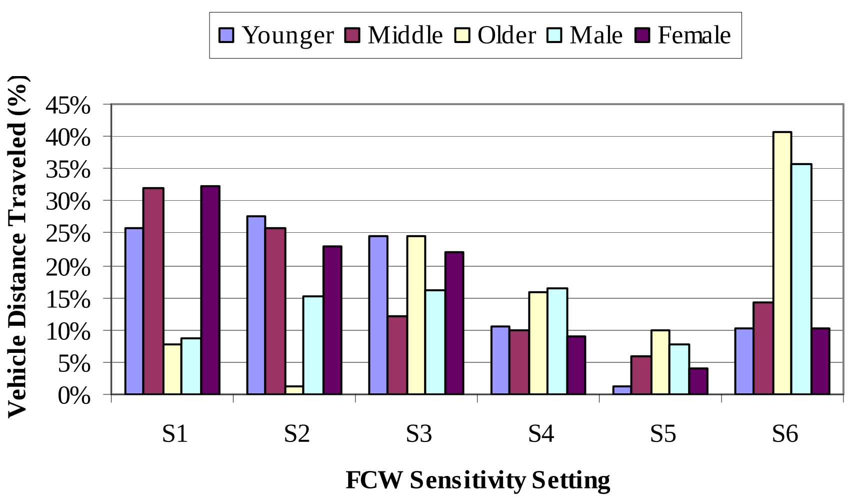


Figure 2-43. Distribution of FCW Sensitivity Settings for Freeways by Subject Group, Period 4

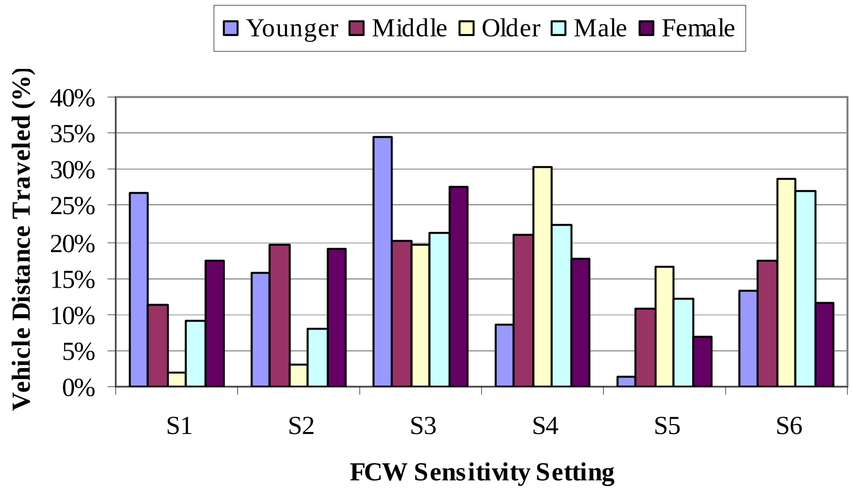


Figure 2-44. Distribution of FCW Sensitivity Settings for Non-Freeways by Subject Group, Period 4

2.11.2 Distribution of ACC Sensitivity Settings

2.11.2.1 Distribution of ACC Sensitivity Settings, Period 3 versus Period 4

Figure 2-45 illustrates the breakdown of VDT with ACC during the ACAS-Enabled test period by ACC gap settings. The most dominant setting was 2-second time gap, accounting for 31 percent of all VDT driven with ACC during the ACAS-Enabled test period. Figure 2-46 shows the distribution of ACC gap settings for ACAS-Enabled Periods 3 and 4. The usage patterns for both periods are similar with the minor exception that Period 4 shows slightly less use of 2-second gap setting and slightly more use of 1.2-second setting. The relative similarity of patterns indicates little modification in setting preference as subjects became more familiar with the system. This usage pattern is also similar to that for FCW; however, the ACC settings tend to be slightly higher (55% of ACC use is with settings 1.6 and 2 seconds versus 43% for S4 to S6 with FCW). As with FCW use, the dominant use of settings S1, S3, and S6 suggests that fewer settings might be acceptable for most users.

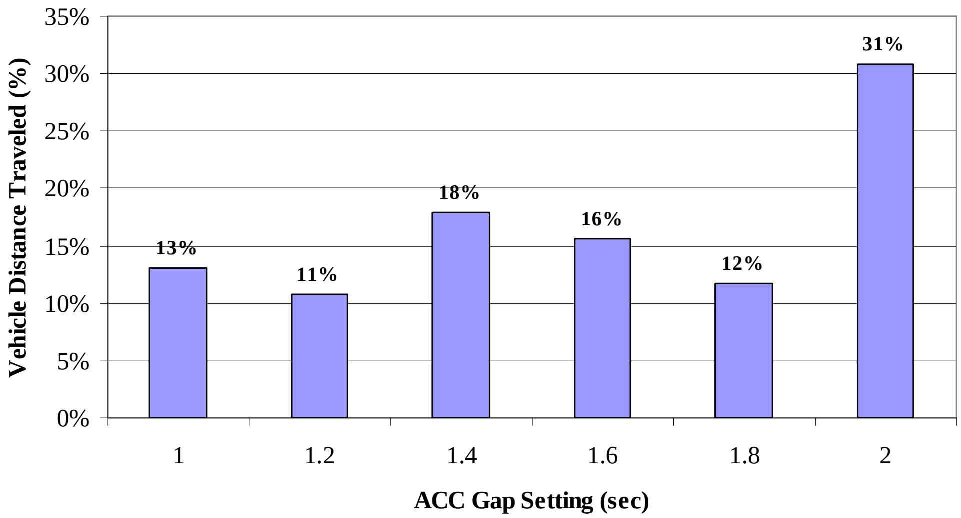


Figure 2-45. Breakdown of VDT with ACC during ACAS-Enabled by ACC Gap Settings

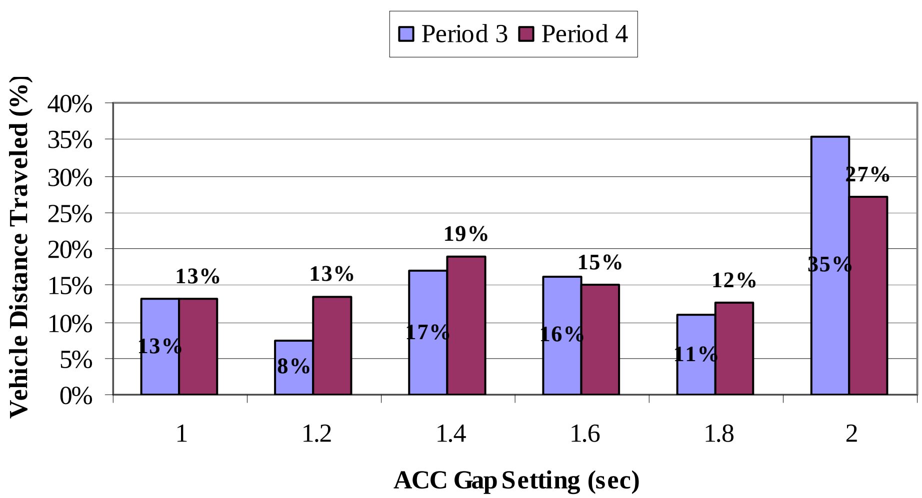


Figure 2-46. Distribution of ACC Gap Settings, Period 3 versus Period 4

2.11.2.2 Distribution of ACC Sensitivity Settings by Subject Group, Period 4 Only

Figure 2-47 shows the distribution of VDT with ACC by ACC gap settings and subject groups for the ACAS-Enabled Period 4 only. The results indicate considerable differences in setting preference between subject groups. These differences are summarized below and are also compared with the corresponding FCW settings:

- Younger subjects tend to use lower ACC settings (79% of use is with 1 and 1.4 seconds versus 77% for S1 to S3 with FCW)

- Middle-age subjects tend to use higher ACC settings (60% of use is with 1.6 and 2 seconds versus 28% for S4 to S6 with FCW)
- Older subjects tend to use higher ACC settings (74% of use is with 1.6 and 2 seconds versus 71% for S4 to S6 with FCW)
- Males tend to use higher ACC settings (51% of use is with 1.6 and 2 seconds versus 61% for S4 to S6 with FCW)
- Females tend to use higher ACC settings (59% of use is with 1.6 and 2 seconds versus 29% for S4 to S6 with FCW)

The pattern of ACC gap settings for the different subject groups tends to agree with expectations. As driver age increases, the gap settings increase. This is also consistent with results from the ICC evaluation, where it was found that older drivers tended to select longer time headways (Koziol et al., 1999). Overall, the male group has a slightly lower gap setting pattern relative to females, which might be a reflection of a slightly more aggressive driving style.

An examination of the differences between the ACC and FCW setting patterns by middle-aged and female subject groups provides some possible insight as to their motivations for the FCW settings selected. Both middle-aged and female groups had higher gap/sensitivity settings when using ACC than when using FCW. This suggests that the motivation for lower FCW settings might be to avoid FCW visual alerts since the ACC gap settings indicate a contrary driving style that tends toward conservative; i.e., longer headways.

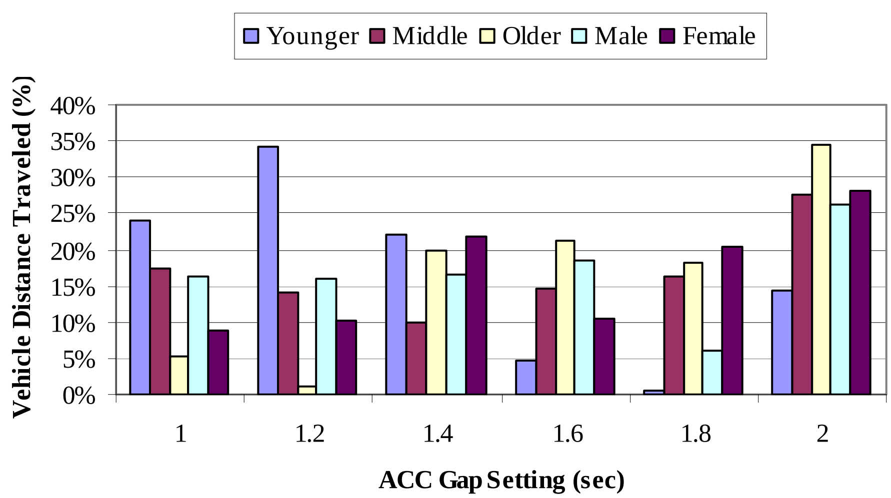


Figure 2-47. Distribution of ACC Gap Settings by Subject Group, Period 4

2.11.3 Distribution of ACC Sensitivity Settings by Road Type and Subject Group, Period 4

Figure 2-48 provides a breakdown of VDT with ACC by gap setting and road type for the ACAS-Enabled Period 4 only. Higher gap settings (≥ 1.4 seconds) were selected on non-freeways than on freeways. Figure 2-49 and Figure 2-50 show the distribution of VDT with

ACC by ACC gap settings and subject group for the ACAS-Enabled Period 4 only on freeways and non-freeways, respectively. The results indicate considerable differences in setting preference between subject groups, but the patterns are quite similar for the overall results for Period 4.

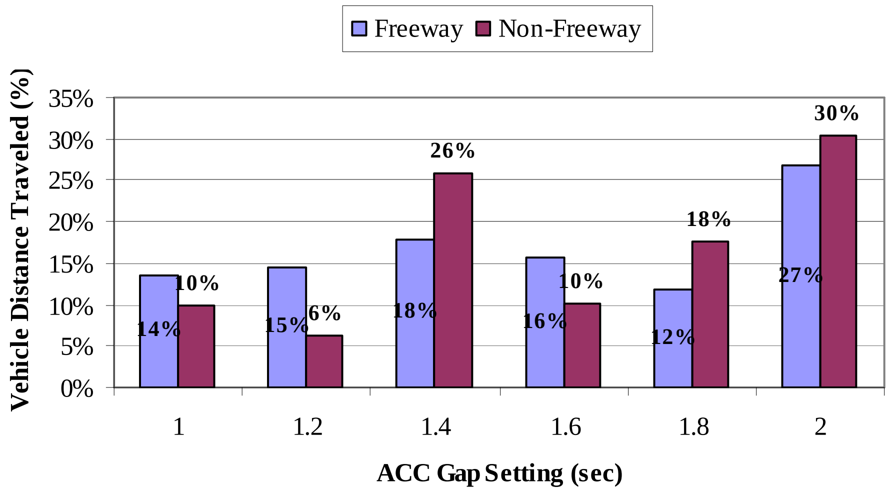


Figure 2-48. Distribution of ACC Gap Settings by Road Type, Period 4

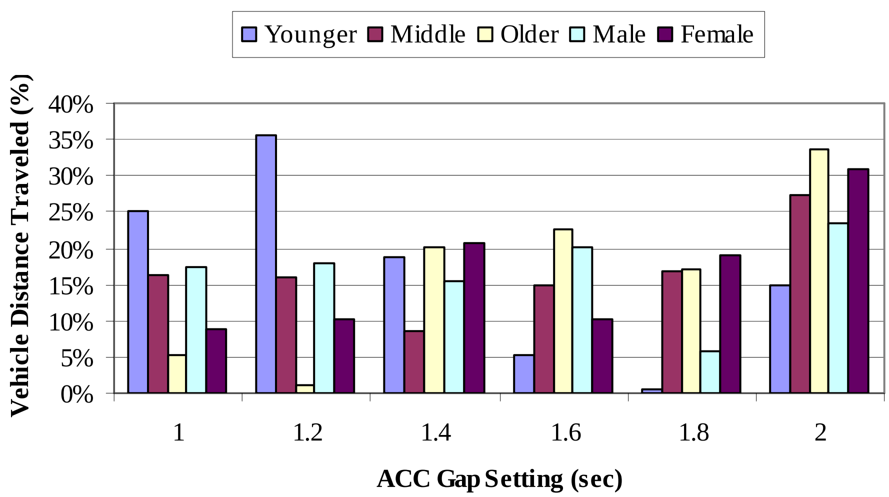


Figure 2-49. Distribution of ACC Gap Settings for Freeways by Subject Group, Period 4

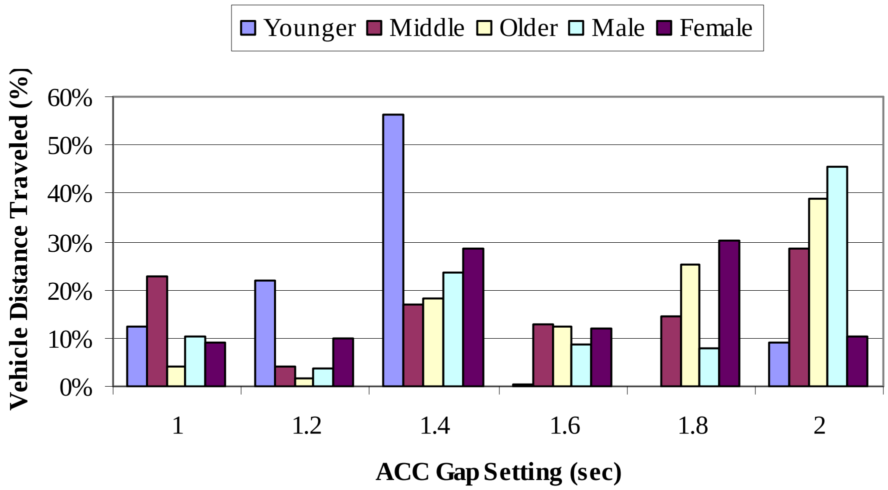


Figure 2-50. Distribution of ACC Gap Settings for Non-Freeways by Subject Group, Period 4

2.12 SUMMARY OF EXPOSURE RESULTS

A total of 66 subjects drove about 163,000 km during the FOT. Each subject had an instrumented vehicle for a period of four weeks: ACAS was disabled during the first week and later enabled for the following three weeks. About 97 percent of the total VDT or 158,000 km reflected valid trip data used in evaluation analyses:

- The ACAS-Disabled and ACAS-Enabled test periods comprised respectively 23 percent (36,000 km) and 77 percent (122,000 km) of the total valid VDT.
- CCC was engaged in 21 percent (7,000 km) of VDT in the ACAS-Disabled test period. On the other hand, ACC was engaged in 36 percent (44,000 km) of VDT in the ACAS-Enabled test period. Thus, ACC use was about 1.8 times more than CCC in terms of percent of distance traveled. FCW was active in 53 percent (64,000 km) of VDT in the ACAS-Enabled test period. FCW and ACC collectively accounted for 89 percent of the VDT in the ACAS-Enabled test period. The remaining 11 percent were driven in manual mode at speeds below 20 mph and when FCW and ACC were inactive over 20 mph due to braking by the host vehicle and other disabling factors that affect system operation such as dirty radar.
- Older subjects drove the most distance in both test periods: 36 percent of VDT in ACAS-Disabled test period and 38 percent of VDT in ACAS-Enabled test period. Moreover, older subjects were the highest users of cruise control: 36 percent of their ACAS-Disabled VDT and 51 percent of their ACAS-Enabled VDT was in ACC. However, the largest ACC to CCC use ratio was observed at 2.6 for younger subjects.
- About 84 percent and 87 percent of VDT, respectively, in the ACAS-Disabled and ACAS-Enabled test periods were accumulated at vehicle speeds greater than or equal to 35 mph. CCC use comprised 24 percent of the ACAS-Disabled VDT at that speed range,

while ACC use accounted for 42 percent of the ACAS-Enabled VDT in the same speed range. CCC or ACC use was only 1 percent of the VDT at vehicle speeds below 35 mph.

- About 51 percent and 55 percent of VDT respectively in the ACAS-Disabled and ACAS-Enabled test periods were driven on freeways. CCC use comprised 33 percent of the ACAS-Disabled VDT on freeways, while ACC use accounted for 56 percent of the ACAS-Enabled VDT on freeways. On non-freeways, CCC and ACC comprised respectively 6 percent and 12 percent of VDT
- Over 90 percent of the VDT was driven in clear weather during the FOT. CCC was used in 15 percent of the adverse weather VDT in the ACAS-Disabled test period, as opposed to 20 percent of this VDT by ACC in the ACAS-Enabled test period. FCW was active in 52 percent of the VDT in clear weather and arose to 68 percent of the VDT in adverse weather due to lower engagement rate of ACC.
- Over 73 percent of the VDT was driven in lighted conditions during the FOT. There was no noticeable change in CCC use rate between lighted and dark conditions (≈ 20%). There was a slight reduction in ACC use rate from 37 percent of VDT in lighted conditions to 32 percent of VDT in dark conditions. As a result, FCW active rate was slightly higher in dark conditions than in lighted conditions.
- About 67 percent of the VDT in the ACAS-Disabled test period was driven in low level of traffic, which was similar to the ACAS-Enabled test period (68%). CCC use rate dropped from 23 percent of the VDT in low traffic to 13 percent of the VDT in moderate traffic. On the other hand, ACC use rate fell from 40 percent to 30 percent of the VDT respectively in low and moderate traffic levels. Consequently, FCW active rate jumped from 51 percent to 60 percent of the VDT respectively in low and moderate traffic levels.
- The most sensitive FCW sensitivity setting, S6, was selected in 24 percent of the overall VDT in the ACAS-Enabled test period. Setting S3 followed at 22 percent of the VDT. The least sensitive setting, S1, was ranked third at 19 percent of the VDT. During the second half of the VDT in the ACAS-Enabled test period, S3 became the most widely selected setting and S6 dropped to second.
- The 2-second time gap was the most chosen ACC gap setting, accounting for 31 percent of the overall VDT driven with ACC, followed in descending order by 1.4- and 1-second gap settings. During the second half of the VDT in the ACAS-Enabled test period, the same order of gap settings remained except for a lower use rate of 2-second time gap. Finally, FOT subjects tended to use higher ACC gap settings on non-freeways than on freeways.

3. SYSTEM CAPABILITY

The system capability analysis of the independent evaluation examined the operational performance of ACAS by addressing its major components individually, as illustrated in Figure 3-1. Accordingly, this analysis consisted of four objectives that characterize the capability of the system to either alert the driver in a timely manner and/or apply automatic controls when required. The following highlights the four objectives:

1. Sensor suite: To characterize the performance of the forward-looking sensor in rejecting out-of-path targets, and detecting and tracking closest in-path targets.
2. Alert logic: To examine the performance of the warning logic (decision-making) in alerting the driver to driving conflicts that might lead to rear-end crashes.
3. Automatic controls: To assess the ability of ACC to maintain a pre-set longitudinal distance to a lead vehicle ahead, particularly the acceleration and deceleration authority under dynamic driving conditions.
4. Driver-Vehicle Interface (DVI): To evaluate the capability of the DVI to properly convey visual and audible information to the driver.

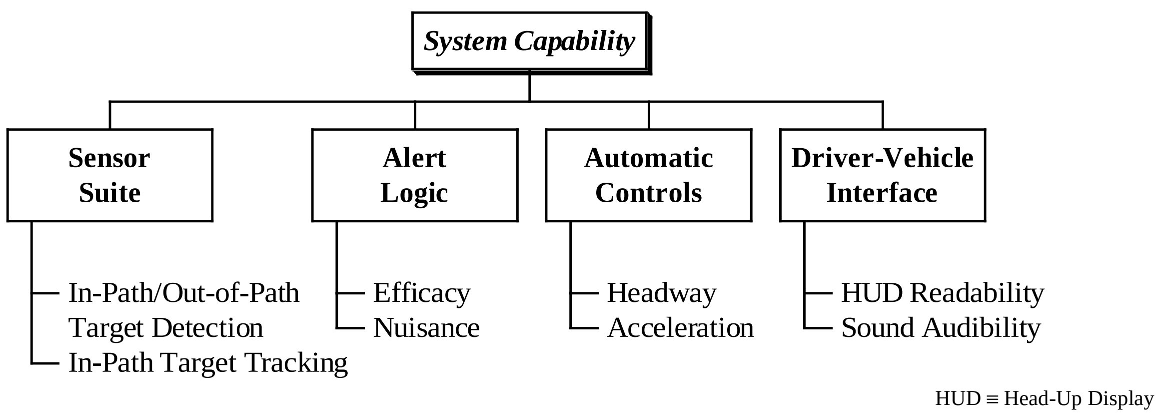


Figure 3-1. Analysis Framework of System Capability

This analysis employed objective and subjective data from the FOT, and objective data from a system characterization test conducted by the independent evaluator. Appendix A describes this independent test that provided supplementary data to measure some system performance parameters on different roadway configurations. Table 3-1 lists the objectives and sub-objectives of the system capability goal, data sources, and concomitant analyses.

The characterization of the forward-looking sensor suite examined how well the system rejected out-of-path targets, and detected and tracked closest in-path targets. This analysis was based in part on observations from 8-second FOT episodes of video and numerical data, which were triggered by crash-imminent alerts during the ACAS-Disabled and ACAS-Enabled test periods. Appendix B describes the data logger and coding instructions used to record observations of video episodes. In particular, this analysis focused on most-occurring alert episodes that were caused by moving in-path and stationary out-of-path targets. Data from the system characterization test were used to determine the rejection ratio of out-of-path targets and the rates of missed, lost, or intermittent detection of in-path targets. In addition, FOT surveys provided a subjective evaluation of the missed and false target rates by the forward-looking sensor suite.

Table 3-1. Data Sources and Concomitant Analyses of System Capability

Objectives	Sub-Objectives	FOT Objective Data	FOT Subjective Data	System Characterization Test
Sensor suite	In-path/out-of-path target detection	- General characteristics of crash-imminent alerts - Analysis of moving in-path target alerts - Analysis of stationary out-of-path target alerts	- Missed and false targets	- Late detections - Out-of-path target rejection
	In-path target tracking			- Intermittent detections - Lost tracking
Alert logic	Efficacy	- Crash imminent alert rates under different driving conditions - Driver response (type and reaction time) to crash-imminent alerts - Driver inattention during crash-imminent alerts - Mapping of crash-imminent alert events to near-crashes	- Timing of FCW auditory alert - Design changes to FCW alert timing setting	
	Nuisance		- Appropriateness of alerts - Unnecessary alerts and unidentified source of alert	
Automatic controls	Headway maintenance		- Design changes to ACC gap setting	
	Auto acceleration/deceleration		- ACC autobrake response timing - ACC acceleration/deceleration authority	- ACC response time - Autobraking due to out-of-path targets
Driver-vehicle interface	HUD readability		- Drive & see HUD - See information on HUD - Visual crash alert detections - Alert recognition	
	Sound audibility		- Audible alert detection	

The ability of the alert logic component of the system to issue a correct signal (efficacy) was examined using data from FOT episodes triggered by crash-imminent alerts and FOT surveys. The ACAS issues a "true" signal (warning/autobraking) when the host vehicle is on a rear-end crash course with an in-path obstacle (i.e., situations requiring a signal). On the other hand, a "false" signal is issued in situations not requiring a signal such as out-of-path targets or the host vehicle not on a collision path with a lead vehicle in its lane. The degree of nuisance generated by ACAS alerts was qualitatively measured using FOT surveys. Drivers would most likely perceive out-of-path target alerts as nuisance. Moreover, "true positive" signals issued by the ACAS might also be considered as "nuisance" if drivers subjectively judged them as too early or not necessary.

Subjective data from FOT surveys were used to assess the ability of ACC to control a pre-set headway and apply comfortable braking or acceleration to deal with transient driving conditions (lead vehicle braking, cutting in from adjacent lanes, accelerating, or moving out to adjacent lanes). System characterization test data were employed to objectively portray ACC response times to transient driving conditions, and examine autobraking events in response to out-of-path moving vehicles.

The ability of the DVI to properly convey system information to the driver was qualitatively evaluated using FOT surveys. In particular, this evaluation reported the opinions of FOT subjects on how well they were able to see the HUD while driving, read the displayed information, and hear auditory alerts from the speaker embedded in the vehicle dashboard.

3.1 SENSOR SUITE

This section discusses the capability of the forward-looking sensor suite to discriminate between in-path and out-of-path targets, and to detect and track closest in-path targets. First, a general description of FOT crash-imminent alerts is provided since this discussion is primarily based on data from FOT episodes triggered by these alerts. A discussion of in-path target detection and tracking follows. After that, this section deals with the detection and rejection of out-of-path targets.

3.1.1 General Characteristics of Crash-Imminent Alerts

The 66 FOT subjects who drove the ACAS-equipped vehicles with Algorithm C received a total of 980 crash-imminent alerts in both ACAS-Disabled and ACAS-Enabled test periods. A total of 253 "unheard" crash-imminent alerts or 25.8 percent of all Algorithm C alerts were issued during the first week when ACAS was disabled. The remaining 727 crash-imminent alerts were conveyed to FOT subjects during the subsequent three weeks of driving when ACAS was enabled. The majority or 90 percent of these "heard" alerts occurred with FCW driving mode. It should be noted that 27 subjects drove ACAS-equipped vehicles with Algorithm C embedded with software containing a bug that unintentionally resulted in the suppression of ACC alerts associated with moving targets (University of Michigan Transportation Research Institute and General Motors, 2005). Five more drivers had this flawed software initially but their vehicles were converted to new, fixed software during their FOT experience. The remaining 34 subjects drove ACAS-equipped vehicles exclusively with the new software. Figure 3-2 shows the breakdown of crash-imminent alerts by driving mode. Overall, the FOT subjects experienced about 0.62 crash-imminent alerts per 100 km traveled. This alert rate was 0.7 during the ACAS-Disabled test period, as opposed to 0.6 during the ACAS-Enabled test period. Figure 3-3 provides the alert rate for each driving mode.

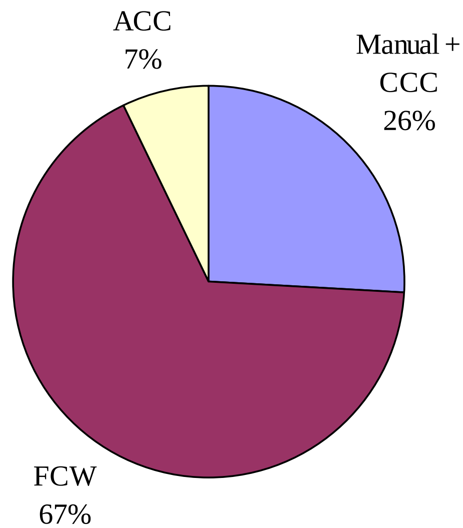


Figure 3-2. Breakdown of Crash-Imminent Alerts by Driving Mode

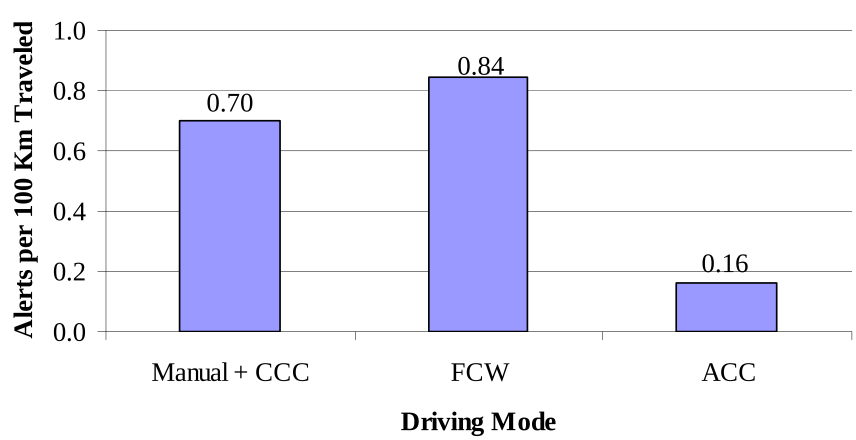


Figure 3-3. Crash-Imminent Alert Rates per Distance Traveled by Driving Mode

In-path targets (e.g., vehicles or objects in the path and same lane of the host vehicle) triggered only 57 percent of all alerts. The remaining 43 percent of all crash-imminent alerts were due to out-of-path targets (e.g., vehicles or objects in adjacent travel lanes, objects on the side of the road, or overhead bridges/signs), and thus considered false warnings. Moving in-path or out-of-path targets caused 62 percent of all alerts. Figure 3-4 illustrates the breakdown of all alerts by target motion state and location relative to the host vehicle. About 92 percent of these alerts fall under two categories: moving in-path targets and stationary out-of-path targets. Some alerts due to moving in-path targets could be sources of nuisance to drivers who judge that these situations do not pose any immediate rear-end crash threat.

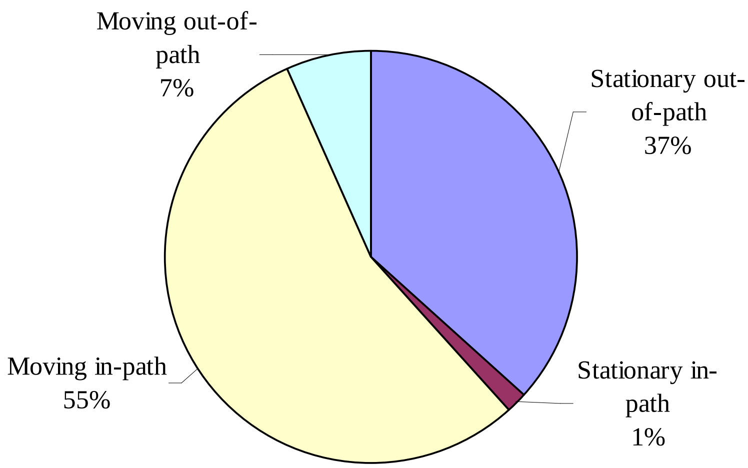


Figure 3-4. Breakdown of Crash-Imminent Alerts by Target Motion and Location

3.1.2 In-Path Target Detection and Tracking

In-path targets triggered 0.35 crash-imminent alerts per 100 km traveled. The majority of these alerts (535), or 0.34 alerts per 100 km, was attributed to moving targets. As seen in Figure 3-5, the majority of moving in-path target alerts was triggered when both the host and lead vehicles were traveling on a straight road. Only 7 percent of these alerts were issued when both vehicles were on a curve.

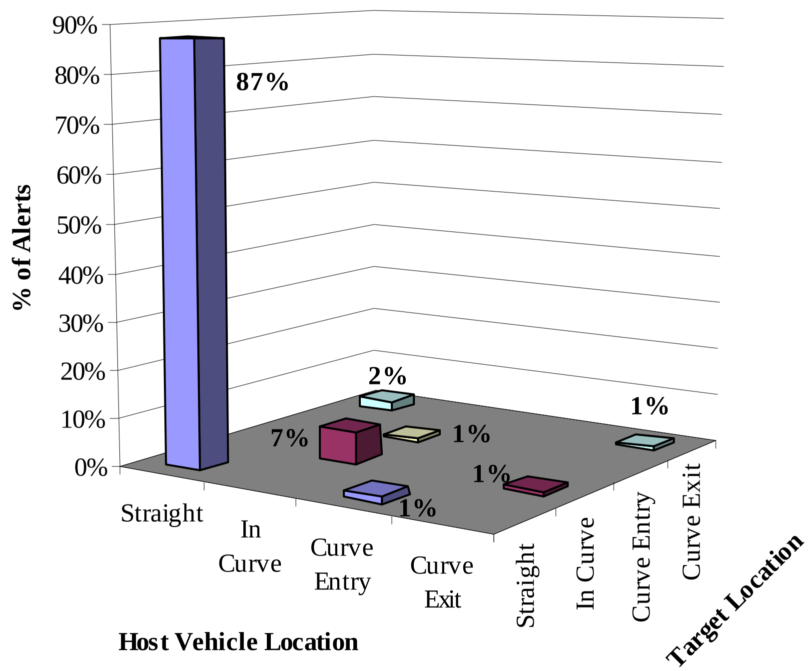


Figure 3-5. **Breakdown of Crash-Imminent Alerts by Host Vehicle Location versus Moving Target Location**

A lead vehicle turning ahead of the host vehicle triggered 34 percent of the moving in-path target alerts, while 10 percent of these alerts involved a lead vehicle changing lanes. On the other hand, the host vehicle conducting a passing maneuver and a lane change maneuver caused, respectively, 7 percent and 4 percent of these alerts. In total, 62 crash-imminent alerts were due to host vehicle changing lanes, turning, or passing behind an in-path moving vehicle. This total is about 12 percent of all moving in-path target alerts, equivalent to about 0.04 alerts per 100 km traveled. Figure 3-6 shows the distribution of moving in-path target alerts by the host vehicle maneuver in correlation with the lead vehicle maneuver. Crash imminent alerts caused by the lead vehicle changing lanes, turning, or making a left turn across the path (LTAP) of the host vehicle accounted for 47 percent of the moving in-path target alerts, which is equivalent to about 0.15 alerts per 100 km traveled. Of these, 83 percent and 11 percent involved a lead vehicle respectively cutting out and crossing over the path of the host vehicle. In most of these cases, the lead vehicle posed no danger to the host vehicle. A lead vehicle cutting in the path of the host vehicle triggered the remaining 6 percent of these cases.

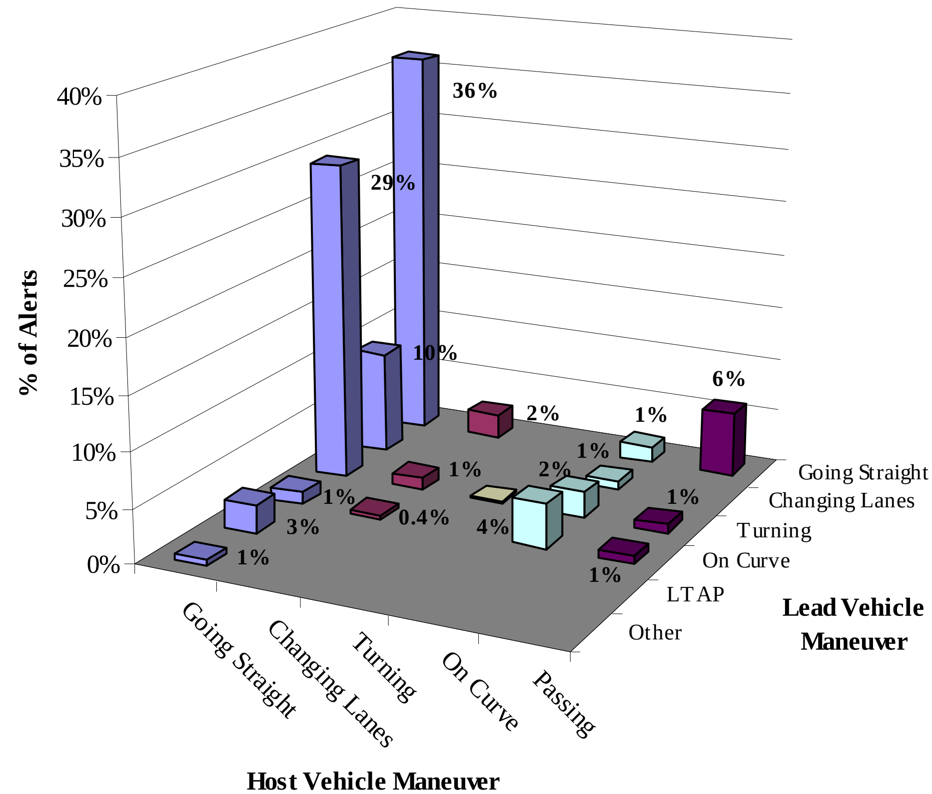


Figure 3-6. Breakdown of Crash-Imminent Alerts by Host Vehicle Maneuver versus Moving Target Maneuver

About 81 percent of all moving in-path target alerts were issued based on a lead vehicle decelerating ahead of the host vehicle. Figure 3-7 shows that only 11 percent of moving in-path target alerts were associated with a lead vehicle moving at a slower constant speed. Moreover, an accelerating lead vehicle triggered only 3 percent of moving in-path target alerts.

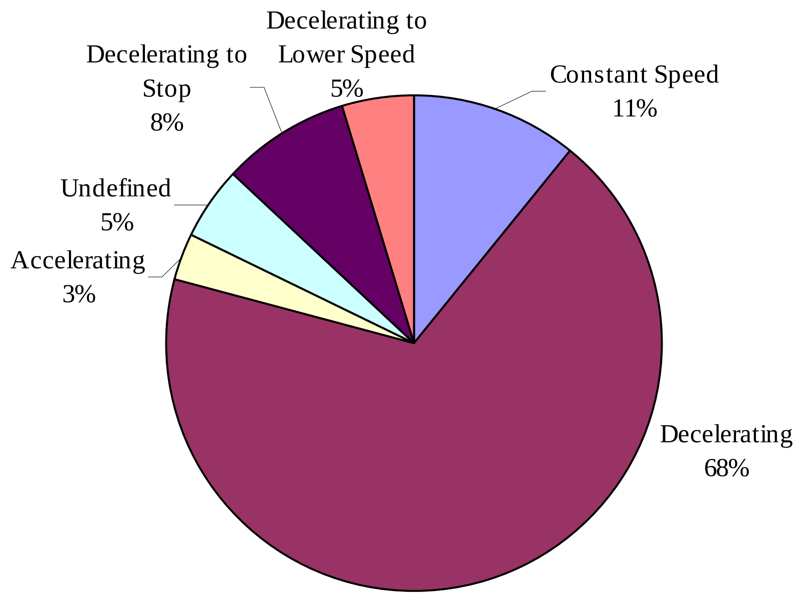


Figure 3-7. Breakdown of Moving In-Path Target Alerts by Lead Vehicle Dynamic State

The breakdown of crash-imminent alerts due to moving in-path targets by the various driving conditions is as follows:

- Road type: 82 percent or 0.61 alerts per 100 km traveled on non-freeways, and 18 percent or 0.11 alerts per 100 km traveled on freeways.
- Weather: 89 percent or 0.33 alerts per 100 km traveled in clear conditions, and 11 percent or 0.45 alerts per 100 km traveled in adverse weather.
- Ambient light: 82 percent or 0.38 alerts per 100 km traveled in lighted conditions, and 18 percent or 0.23 alerts per 100 km traveled in dark conditions.
- Traffic: 14 percent or 0.07 alerts per 100 km traveled in low traffic, 72 percent, or 0.9 alerts per 100 km traveled in moderate traffic, and 14 percent or 1.42 alerts per 100 km traveled in heavy traffic.
- Road junction: 62 percent of alerts occurred in the vicinity of intersections and driveways as illustrated in Figure 3-8.
- Host vehicle speed: About 40 percent of all moving in-path target alerts were triggered at host vehicle speed below 35 mph as shown in Figure 3-9.

Alert rates were observed to be higher on non-freeways, adverse weather, lighted conditions, and heavy traffic. This is perhaps due to higher volume of traffic and heavier level of service under these conditions. Also, as might be expected, most alerts happened at junctions where more driving conflicts with other cars normally occur. The majority of moving in-path target alerts was triggered at vehicle travel speeds over 35 mph. At these higher speeds, the host vehicle requires a longer distance to stop and thus warnings tend to be issued earlier and on more distant objects.

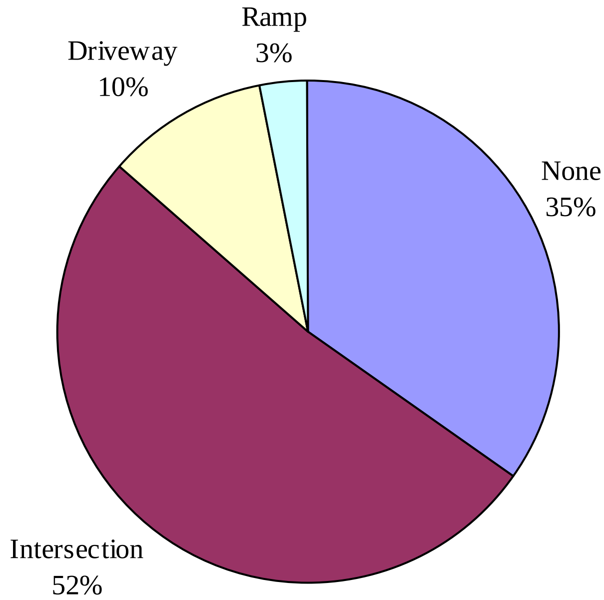


Figure 3-8. Breakdown of Moving In-Path Target Alerts by Relation to Junction

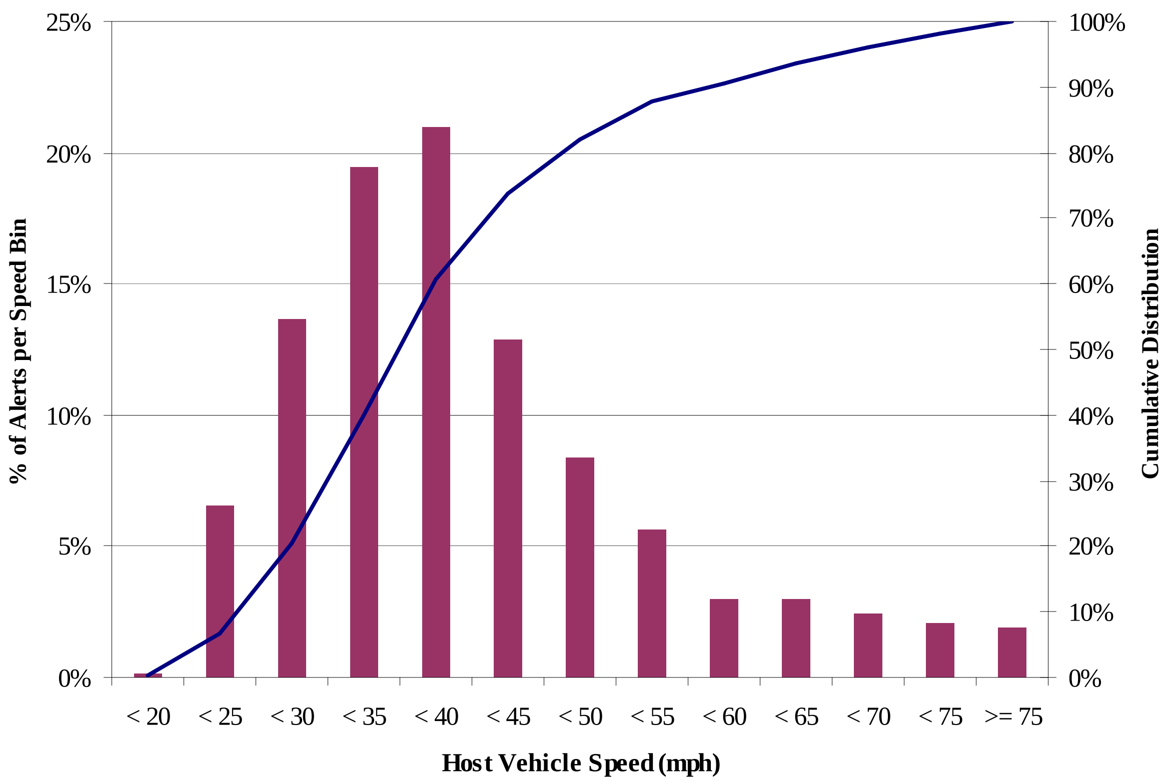


Figure 3-9. Distribution of Moving In-Path Target Alerts by Host Vehicle Speed

Table 3-2 presents data from the system characterization test about the detection and tracking of in-path vehicles by the forward-looking sensor suite under different roadway curvatures and environmental conditions. This analysis only included targets that were entirely within the same lane as the host vehicle, and were moving within 100 m or stopped within 70 m from the host vehicle. Detection here refers to lead vehicles being declared as closest in-path targets by the system, and not crash-imminent alerts. Late detection was marked if the sensor suite did not detect the lead vehicle under these conditions when it appeared in the lane of the host vehicle (e.g., lead vehicle changing lanes, host vehicle changing lanes, or host vehicle approaching lead vehicle from afar). Intermittent detection was noted if the sensor suite first detected the target under these conditions and then lost it for up to 3 seconds before target reacquisition. Any detection lost for 3 seconds or more was recorded as lost detection. Accurate determination of upcoming roadway geometry is a critical element for the forward-looking sensor suite to discern whether or not a target ahead lies in the host vehicle path. Roadway curvature or radius was therefore broken into 3 categories for non-freeways and 4 categories for freeways. The definition of "freeway" encompasses all divided roadways with posted speed limits greater than or equal to 55 mph. Sharp curves with less than 500 m radius fall below the design specifications of ACAS. Curves of 500 to 1,000 m radius are considered of medium radius. The third category, 1,000 to 2,000 m radius, was added to freeways only because the system could have difficulty determining whether or not targets are in-path at long ranges (50-100 m) when driving at high speeds on curves. The last curvature category indicates essentially straight roads for either freeway ($R \geq 2,000$ m) or non-freeway ($R \geq 1,000$ m).

Table 3-2 lists the rates of late, intermittent, and lost detections by roadway curvature and environmental condition (the numerator in parentheses refers to the number of detection anomalies while the denominator indicates the number of all vehicles classified under the conditions above during the system characterization test). The forward-looking sensor suite was late in detecting about 17 percent of the vehicles encountered on curves below 500 m radius, as opposed to 14 percent on curves with higher radius. Moreover, late detections were observed in 18 percent and 15 percent of the targets respectively in rain and clear weather. Intermittent detection was noted in 28 percent of the targets on curves below 500 m radius, as opposed to 24 percent on curves with higher radius. The results of late and intermittent detections do not show a significant impact by sharp curves (radius < 500 m). In contrast, sharp curves accounted for lost detection in 22 percent of the targets as opposed to only 8 percent on curves with higher radius. A higher rate of lost detections was observed in rain than in clear weather during the day, and much higher rate at night than the day in clear weather. It should be noted that the denominator values in each of the columns of Table 3-2 are different due to the conditions under which the host vehicle acquires the lead vehicle (late detection case), and due to the conditions that both host and lead vehicles, or either vehicle, must be on the specified curve (intermittent and lost detection cases).

Table 3-2. Late, Intermittent, and Lost Detection Rates for In-Path Targets

	Roadway Curvature (m)				Environmental Conditions		
	R < 500	500≤R<1000	1000≤R<2000[1]	R≥1000 or 2000[2]	Day Clear	Day Rain	Night Clear
Late Detection	17% (39/228)	10% (4/40)	17% (10/60)	15% (52/357)	17% (75/445)	18% (22/119)	7% (8/121)
Intermittent Detection	28% (88/316)	29% (16/56)	17% (12/72)	24% (118/485)	23% (134/589)	22% (34/153)	35% (66/187)
Lost Detection	22% (63/291)	7% (3/43)	2% (1/61)	9% (37/394)	9% (46/491)	14% (19/138)	24% (39/160)

[1] 1000 ≤ R < 2000 only on freeways with speed ≥ 55 mph
[2] R ≥ 1000 on non-freeways or R ≥ 2000 on freeways

Subjectively, FOT subjects were asked the following question in a post-drive survey about ACC, which relates to the detection capability of the ACAS forward-looking sensor suite:

- While using ACC, how often, if ever, did the system not indicate the presence of a vehicle when one did exist (*missing an in-path target*)?

The question was scaled from 1 (never), 2 (once or twice total), to 6 (several times a day – over 30 total). About 80 percent of the subjects indicated that ACC never missed a vehicle, while about 17 percent reported a missed vehicle once or twice in total. The average response was 1.27 with a standard deviation of 0.73.

3.1.3 Out-of-Path Target Detection and Rejection

Out-of-path targets caused 0.27 crash-imminent alerts per 100 km traveled. There were a total of 357 crash-imminent alerts due to stationary out-of-path targets during the FOT at a rate of 0.23 alerts per 100 km traveled. A total of 42 percent, 10 percent, and 8 percent of these objects were located respectively on curve, curve entry, and curve exit. On the other hand, the host vehicle received 36 percent, 16 percent, and 4 percent of these alerts while located respectively on curve entry, curve, and curve exit. Thus, the majority of stationary out-of-path target alerts were associated with curved roadways. As seen in Figure 3-10, 37 percent of these alerts occurred when both the host vehicle and the target were on a straight road. It should be mentioned that the host vehicle could be performing a maneuver at the time of the alert on a straight road, such as changing lanes, turning, or passing. Figure 3-11 shows that objects on straight roads triggered 32 percent of stationary out-of-path target alerts when the host vehicle was simply traveling straight. This could be caused by radar misalignment in case of roadside objects, or a weakness in the bridge rejection algorithm in case of a bridge or overhead sign.

The breakdown of crash-imminent alerts due to stationary out-of-path targets by the various driving conditions is as follows:

- Road type: 77 percent or 0.38 alerts per 100 km traveled on non-freeways, and 23 percent or 0.10 alerts per 100 km traveled on freeways.
- Weather: 96 percent or 0.24 alerts per 100 km traveled in clear conditions, and 4 percent or 0.10 alerts per 100 km traveled in adverse weather.
- Ambient light: 82 percent or 0.25 alerts per 100 km traveled in lighted conditions, and 18 percent or 0.16 alerts per 100 km traveled in dark conditions.
- Road junction: Only 9 percent of stationary out-of-path alerts occurred in the vicinity of intersections and driveways as opposed to 62 percent of moving in-path target alerts. As

observed in Figure 3-12, 87 percent of stationary out-of-path target alerts were triggered at non-junctions.

- Host vehicle speed: Only 25 percent of all stationary out-of-path target alerts were triggered at host vehicle speed below 35 mph as shown in Figure 3-13.

The rate of stationary out-of-path target alerts on non-freeways is higher than on freeways due to sharper curves and more abundant roadside furniture on non-freeways. It is important to note that the adverse weather does not appear to affect the radar sensor in creating false targets as apparent in the lower alert rate in adverse weather. The higher alert percentage at non-junctions can be explained by the presence of more curves than at road junctions. Finally, most or 75 percent of all stationary out-of-path target alerts were triggered at host vehicle speeds over 35 mph. Thus, suppressing this type of alert at lower speeds would affect a quarter of these false alerts.

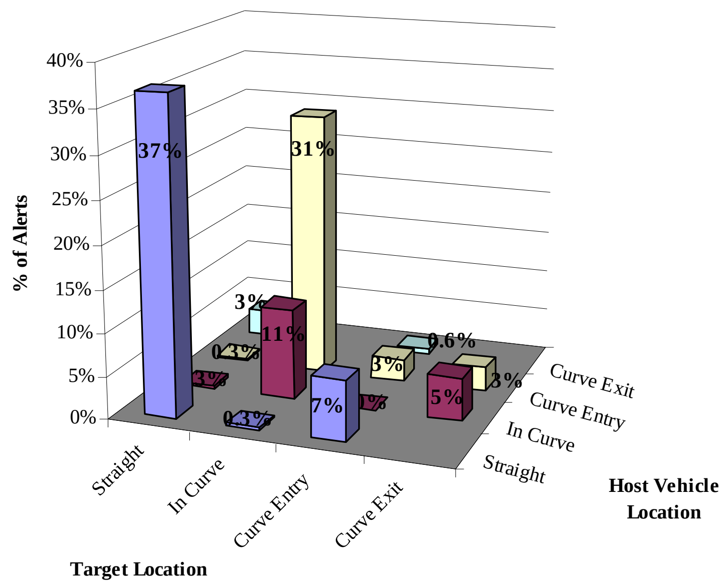


Figure 3-10. Breakdown of Stationary Out-Of-Path Target Alerts by Target and Host Vehicle Locations

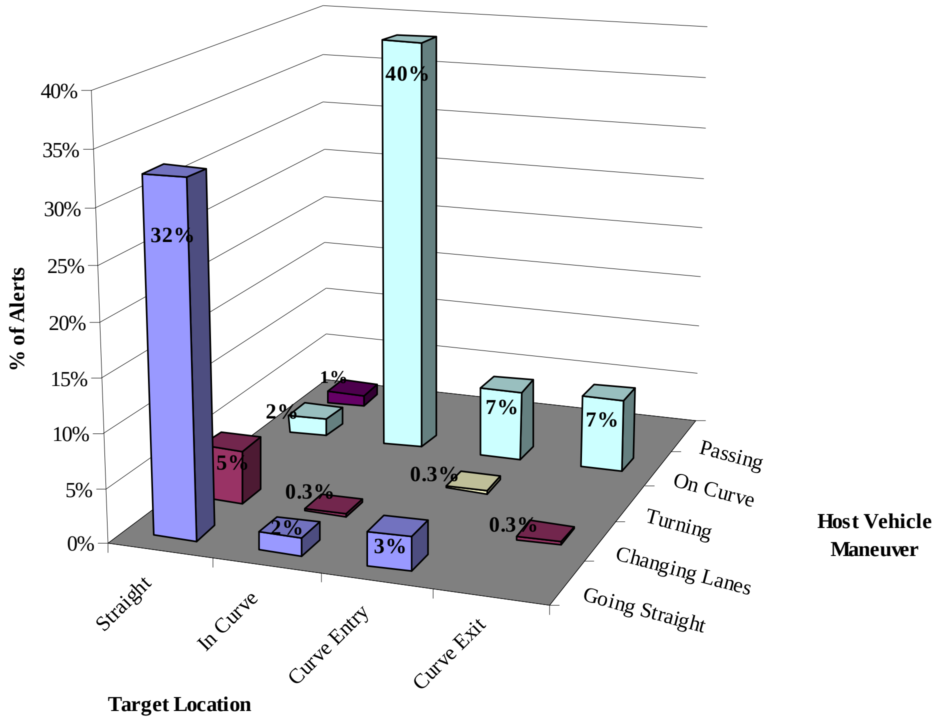


Figure 3-11. Breakdown of Stationary Out-Of-Path Target Alerts by Vehicle Maneuver versus Target Location

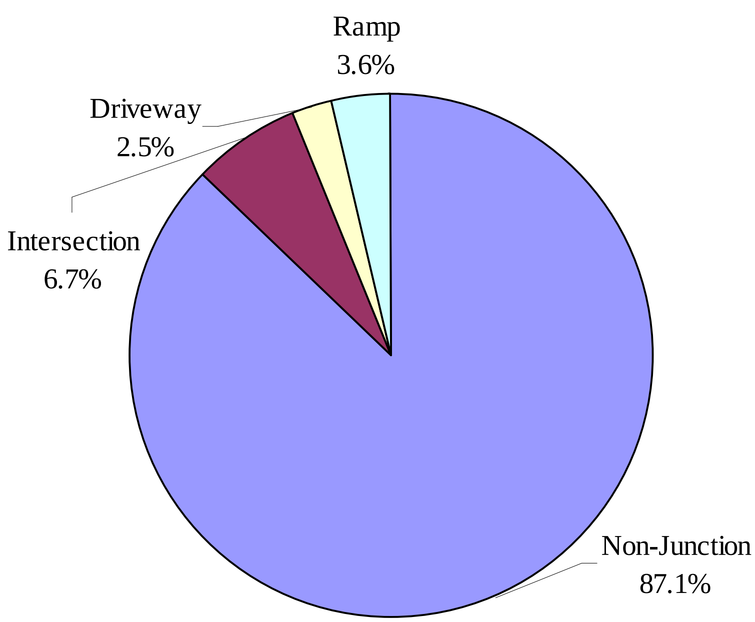


Figure 3-12. Breakdown of Stationary Out-Of-Path Target Alerts by Relation to Junction

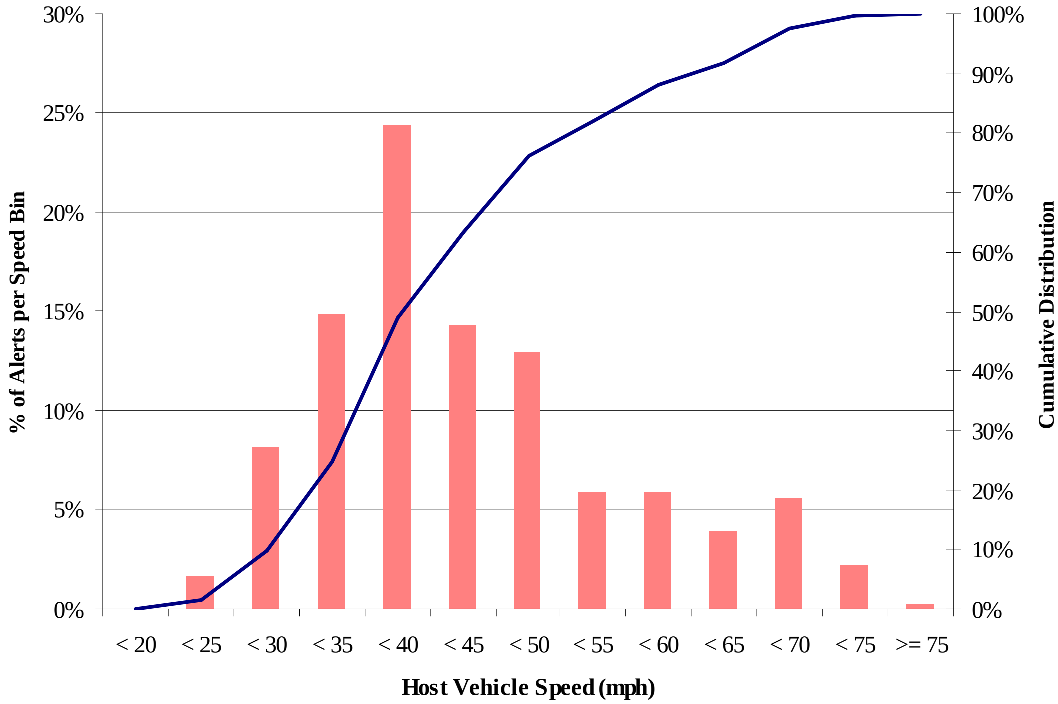


Figure 3-13. Distribution of Stationary Out-Of-Path Target Alerts by Host Vehicle Speed

The capability of the forward-looking sensor suite to reject out-of-path targets was assessed using data from the system characterization test. Table 3-3 presents results of rejection ratios for crash-imminent alerts by roadway curvature and environmental conditions. The category of "overhead object" included bridges, overhead signs, and walkways. The category of "out-of-path stationary target" comprised mailboxes, signs, guardrails, light poles, and other stationary roadside objects, excluding overhead objects. The "lead vehicle in adjacent lane" documented the presence of a lead vehicle in the four roadway curvature categories shown in Table 3-3, while the host vehicle was in the first three roadway curvature categories (not on straight roadways, R≥1,000 or 2,000). The last category of "vehicle maneuver" included host vehicle passing, host vehicle lane changing, and lead vehicle turning. A total of 10 crash-imminent alerts were received during system characterization test – 5 on straight roadways and 5 on sharp curves (R < 500 m). Stationary objects caused three straight roadway alerts – concrete median barrier, metal fence, and plastic construction barrel. The remaining two straight roadway alerts were due to lead vehicle turning and lead vehicle in the adjacent lane. A lead vehicle in the adjacent lane and lead vehicles turning ahead triggered respectively one and four crash-imminent alerts on sharp curves.

The rejection ratio of overhead objects was 100 percent for crash-imminent alerts, given that 308 such objects were encountered during the system characterization test. Moreover, the threat assessment algorithm rejected 97.9 percent of out-of-path stationary objects, and 99.6 percent of lead vehicles in the adjacent lane when the host vehicle was negotiating a curve. The lead vehicle turning caused 5 crash-imminent alerts as seen in the last row of Table 3-3. In 3 of these cases, the lead vehicle was more than half way out of the host vehicle lane. Overall, the threat assessment algorithm suppressed 97.7 percent of crash-imminent alerts that might have been triggered by either host or lead vehicle maneuver to change lanes. Environmental conditions did not appear to have any impact on crash-imminent alert rejection due to out-of-path targets.

Table 3-3. Rejection Ratios of Crash-Imminent Alerts Due to Out-Of-Path Targets

	Roadway Curvature (m)				Environmental Conditions		
	R < 500	500≤R<1000	1000≤R<2000[1]	R≥1000 or 2000[2]	Day Clear	Day Rain	Night Clear
Overhead Object	100% (0/35)	100 % (0/27)	100% (0/50)	100% (0/196)	100% (0/234)	100% (0/71)	100% (0/3)
Out-of-Path Stationary Target	100% (0/72)	100% (0/11)	100% (0/4)	95% (3/58)	98% (2/93)	100% (0/33)	95% (1/19)
Lead Vehicle in Adjacent Lane	99% (1/154)	100% (0/79)	100% (0/93)	99% (1/133)	99% (2/216)	100% (0/97)	100% (0/13)
Vehicle Maneuver[3]	90% (4/40)	100% (0/16)	100% (0/23)	99% (1/138)	98% (3/153)	100% (0/32)	94% (2/32)

[1] 1000 ≤ R < 2000 only on freeways with speed ≥ 55

[2] R ≥ 1000 on non-freeways or R ≥ 2000 on freeways

[3] Vehicle Maneuver = Host veh. passing, host veh. lane change, lead veh. turning

Table 3-4 shows results of rejection ratios for visual alerts by roadway curvature and environmental conditions using system characterization test data. Visual alerts only displayed warning icons to the driver on the HUD. The icons range from small green vehicle indicating target detection, to large yellow vehicle indicating a crash-imminent alert would be issued if no action were taken. All icons were accounted for regardless of their level or length of time displayed. The system characterization test was conducted with FCW sensitivity setting at 3, an intermediate setting. The rejection ratios in Table 3-4 are noticeably lower than in Table 3-3 due to the filtering ability of the ACAS threat assessment algorithm. In the “Lead Vehicle in Adjacent Lane” row, the total values of the numerator and denominator in the “Roadway Curvature” part of Table 3-4 are lower than the values of the “Environmental Conditions” part due to the exclusion of values in the “R ≥ 1000 or 2000” cell highlighted in the table below.

Table 3-4. Rejection Ratios of Visual Alerts Due to Out-Of-Path Targets

	Roadway Curvature (m)				Environmental Conditions		
	R < 500	500≤R<1000	1000≤R<2000[1]	R≥1000 or 2000[2]	Day Clear	Day Rain	Night Clear
Overhead Object	100% (0/31)	100% (0/21)	96% (2/45)	96% (8/181)	98% (5/204)	93% (5/71)	100% (0/3)
Out-of-Path Stationary Target	79% (9/43)	100% (0/7)	100% (0/3)	82% (6/33)	94% (2/36)	81% (6/32)	61% (7/18)
Lead Vehicle in Adjacent Lane	71% (36/123)	65% (19/54)	85% (11/73)		72% (51/185)	55% (44/97)	50% (4/8)
Vehicle Maneuver[3]	96% (1/25)	100% (0/13)	100% (0/22)	90% (11/110)	96% (5/122)	87% (4/30)	83% (3/18)

[1] 1000 ≤ R < 2000 only on freeways with speed ≥ 55

[2] R ≥ 1000 on non-freeways or R ≥ 2000 on freeways

[3] Vehicle Maneuver = Host veh. passing, host veh. lane change, lead veh. turning

The ACAS suppressed the display of visual warning icons in 96.4 percent of overhead objects encountered during the system characterization test. Moreover, the ACAS did not issue visual alerts to 82.8 percent of out-of-path stationary objects, and 73.6 percent of lead vehicles in the adjacent lane when the host vehicle was negotiating a curve. Visual alerts were also suppressed during 92.9 percent of host or lead vehicle lane changing maneuvers. In contrast to crash-imminent alerts, environmental conditions appear to have some impact on the rejection ratios of visual alerts due to out-of-path targets. The lowest rejection ratios were observed during nighttime driving. Moreover, rejection ratios were lower in rain than in clear weather during daytime driving.

The following two questions in the post-drive survey provided a subjective assessment of the ACAS forward-looking sensor suite to deal with out-of-path targets:

1. While using ACC, how often, if ever, did the system indicate the presence of a vehicle when none existed (*false target*)?
2. How often, if ever, did FCW give you a warning that was false (*false target*)?

The first question was scaled from 1 (never), 2 (once or twice total), to 6 (several times a day – over 30 total). On the other hand, the second question was scaled from 1 (very frequently) to 7 (very infrequently) with 0 for never. About 75 percent of the subjects responded that ACC never falsely detected a vehicle ahead as opposed to about 25 percent who indicated one or two false target detections in total. The average response to this question was 1.25 with a standard deviation of 0.43. As for FCW performance in response to the second question, only 3 percent replied that FCW never had a warning when there were no other vehicles to warn about. About 56 percent of the subjects indicated infrequent (scales 5-7) false warnings as opposed to 21 percent who reported frequent (scales 1-3) false warnings.

3.2 ALERT LOGIC

This section assesses the efficacy of crash-imminent alerts based on FOT triggered episodes, and evaluates their nuisance on drivers using FOT survey data. It first provides a general examination of all alerts received in ACAS-Disabled and ACAS-Enabled test periods. The alert efficacy is then judged by driver response in both driving modes, driver reaction time to in-path target alerts during ACAS-Enabled test period, driver inattention, and mapping of alert-triggered episodes to near-crashes. The nuisance of alerts is evaluated by asking FOT subjects whether or not the alerts they received were inappropriate or unnecessary.

3.2.1 Examination of All Crash-Imminent Alerts

FOT subjects received 0.62 crash-imminent alerts per 100 km traveled during the test in ACAS-Disabled test period (unheard alert) and ACAS-Enabled test period (heard alert). The breakdown of all crash-imminent alerts by the various driving conditions is as follows:

- Road type: 80 percent or 1.08 alerts per 100 km traveled on non-freeways, and 20 percent or 0.23 alerts per 100 km traveled on freeways.
- Weather: 92 percent or 0.62 alerts per 100 km traveled in clear conditions, and 8 percent or 0.62 alerts per 100 km traveled in adverse weather.
- Ambient light: 82 percent or 0.69 alerts per 100 km traveled in lighted conditions, and 18 percent or 0.42 alerts per 100 km traveled in dark conditions.
- Traffic: 39 percent or 0.35 alerts per 100 km traveled in low traffic, 53 percent, or 1.19 alerts per 100 km traveled in moderate traffic, and 8 percent or 1.58 alerts per 100 km traveled in heavy traffic.

– Road junction: About 55 percent of all alerts were received at non-junctions as seen in Figure 3-14.
– Host vehicle speed: Figure 3-15 shows that about two thirds (67%) of all alerts were triggered at host vehicle speed over 35 mph. Moreover, Figure 3-16 illustrates a relatively high rate of 2.18 alerts per 100 km traveled at travel speeds between 25 and 35 mph. This speed bin had about 28 percent of all alerts.

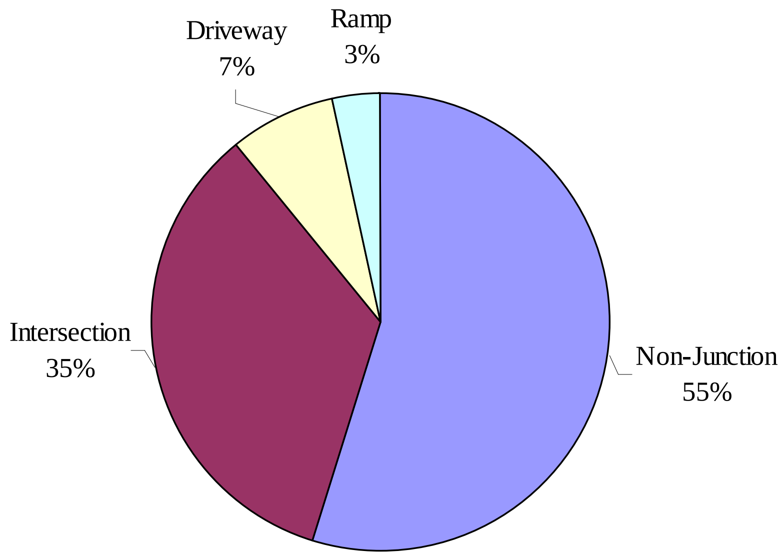


Figure 3-14. Breakdown of All Alerts by Relation to Junction

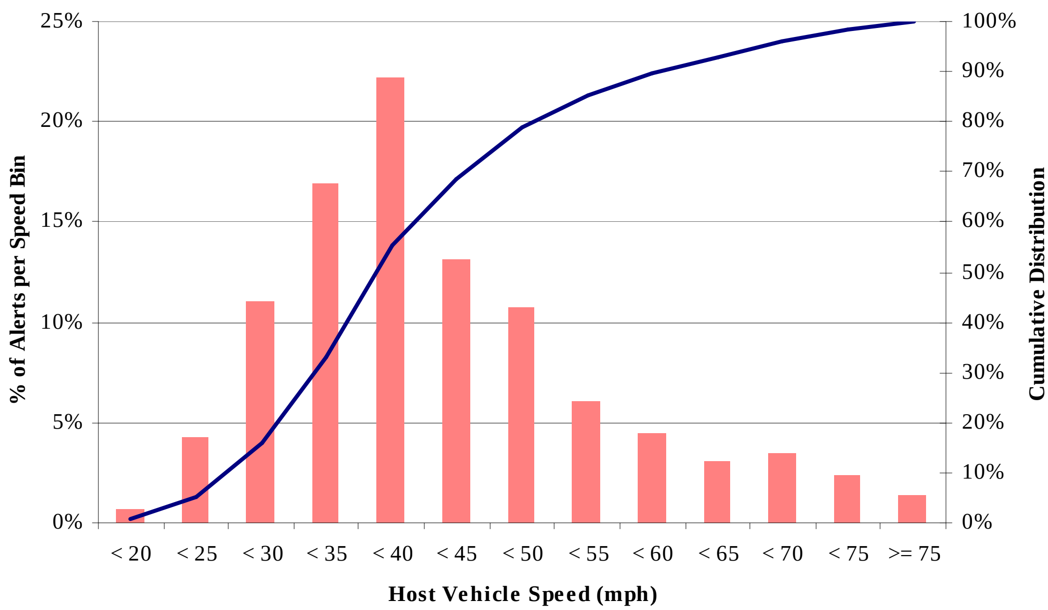


Figure 3-15. Distribution of All Alerts by Host Vehicle Speed

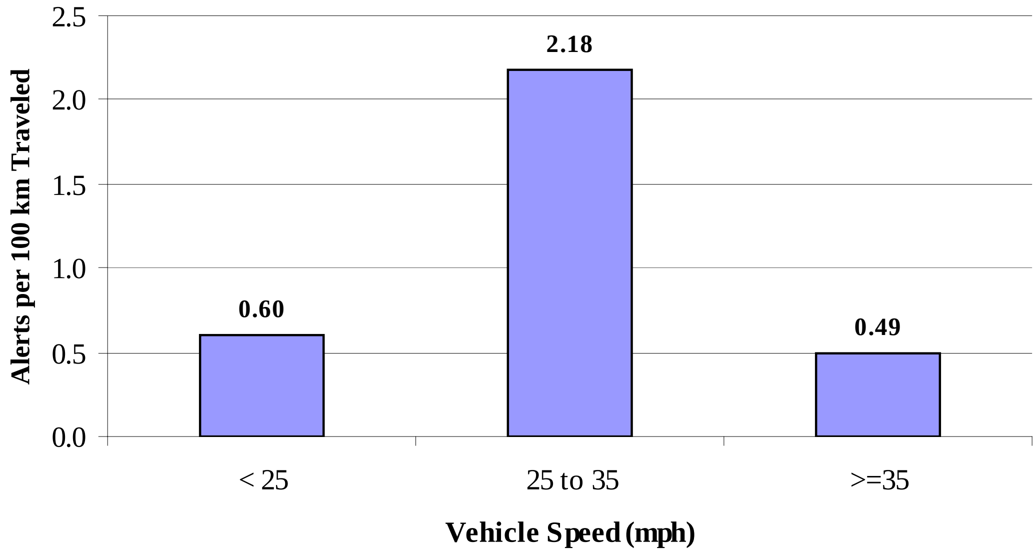


Figure 3-16. Crash-Imminent Alert Rates per Distance Traveled by Host Vehicle Speed

Out-of-path target alerts accounted for 43.5 percent of all alerts, which warned of objects that are not in the path of the vehicle and thus posing no safety risk. On the other hand, alerts triggered by in-path targets amounted to 549 alerts or 56.5 percent of all alerts that may or may not warn of an impending crash. Stationary objects triggered a total of 14 alerts or 2.6 percent of all in-path target alerts. The forward-looking sensor suite declared only 2 of the 14 stationary objects as movable (seen moving prior to stopping) objects. A total of 422 or 76.9 percent of all in-path target alerts were triggered in the ACAS-Enabled test period. A total of 28 crash-imminent alerts due to in-path targets were deemed "true" alerts to a potential impending rear-end collision by the independent evaluator (See Safety Impact section). This total is about 5 percent of all crash-imminent alerts due to in-path targets, equivalent to about 1.8 alerts per 10,000 km traveled.

To further examine the efficacy of in-path target crash-imminent alerts, driver response before (≈ 5 seconds) and after (≈ 3 seconds) the alert is identified below for the ACAS-Disabled and ACAS-Enabled test periods. In addition, reaction time to the alert is delineated in case of driver response while in the ACAS-Enabled test period or the "heard" alert period. Moreover, driver inattention is examined in terms of distraction and eyes-off-the-road.

3.2.2 Driver Response to In-Path Target Alerts

Figure 3-17 compares driver response before and after in-path target crash-imminent alerts during the ACAS-Disabled test period in which FOT subjects did not hear the alert. The percentage of off-throttle response exhibited before the alert was significantly reduced from 44 percent to 5 percent of the in-path target alert episodes, giving rise to a higher percentage of brake response after the alerts from 11 percent to 46 percent. This increase in brake response might be attributed to driving conflicts that the ACAS is warning about. FOT subjects did not initiate any type of response in 39 percent and 43 percent of all in-path target alert episodes, respectively, before and after the alert during the ACAS-Disabled test period. Figure 3-18 compares driver response before and after in-path target alerts during the ACAS-Enabled test period in which FOT subjects did hear the alert. Similar to the ACAS-Disabled test period, the percentage of off-throttle response was significantly reduced, from 45 percent before the in-path alert to 9 percent after the alert during the ACAS-Enabled test period. On the other hand, the brake response jumped from 8 percent before the alert to 56 percent after the alert. In contrast to the ACAS-Disabled test period, the percentage of no response declined from 43 percent before the alert to 29 percent after the alert during the ACAS-Enabled test period.

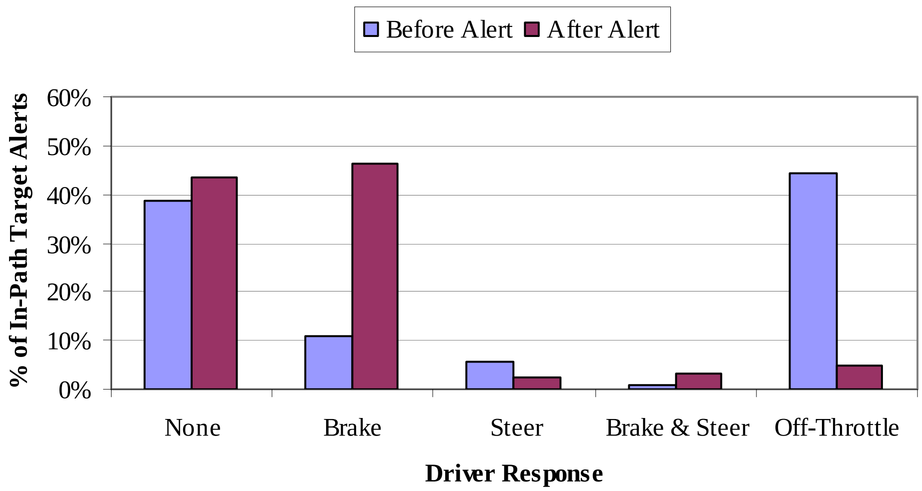


Figure 3-17. Breakdown of Driver Response Type Before and After In-Path Target Alerts during ACAS-Disabled Test Period

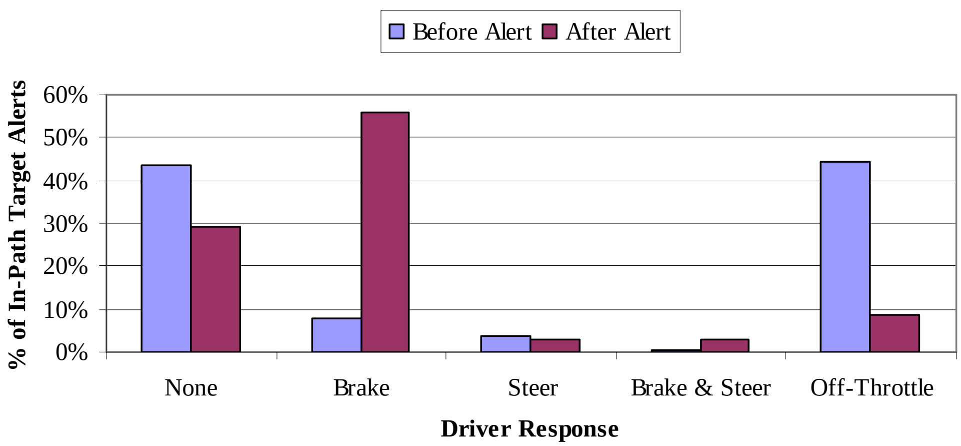


Figure 3-18. Breakdown of Driver Response Type Before and After In-Path Target Alerts during ACAS-Enabled Test Period

Figure 3-19 compares driver response after the in-path target alert between the ACAS-Disabled and ACAS-Enabled test periods. FOT subjects had higher response rates and braked more when they heard the alerts during the ACAS-Enabled test period. This would suggest that heard in-path target alerts elicited drivers to respond, but this is greatly dependent on the driving situations.

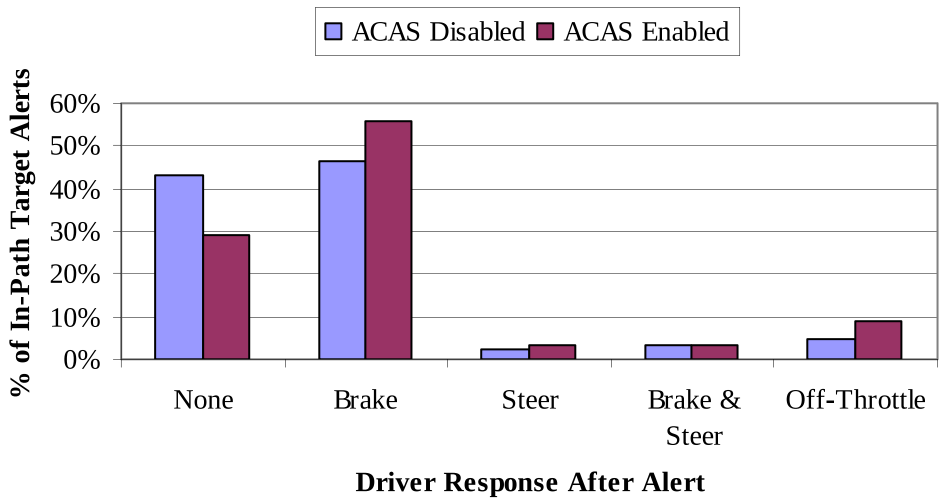


Figure 3-19. Comparison of Driver Response Type After In-Path Target Alerts between ACAS-Disabled and ACAS-Enabled Test Periods

3.2.3 Driver Reaction Time to In-Path Target Alerts

Driver reaction time is defined as the time period between the time of in-path target alert onset and the time of response initiation. Reaction time averaged about 0.55 seconds per driver to in-path target alerts during the ACAS-Enabled test period, with a standard deviation of 0.38 seconds (standard error = 0.05 seconds and number of subjects in this analysis = 60). It should be noted that six FOT subjects did not experience in-path target alerts during the ACAS-Enabled test period. Taking reaction time to all alerts from all subjects altogether, reaction time averaged about 0.53 seconds with a standard deviation of 0.49 seconds (standard error = 0.03 second). Figure 3-20 shows the empirical probability density function and cumulative distribution of the average reaction time per driver to in-path target alerts during the ACAS-Enabled test period. About 53 percent of the 60 subjects reacted on average within 0.5 seconds of the alert, and 95 percent of the subjects reacted within 1 second of the alert.

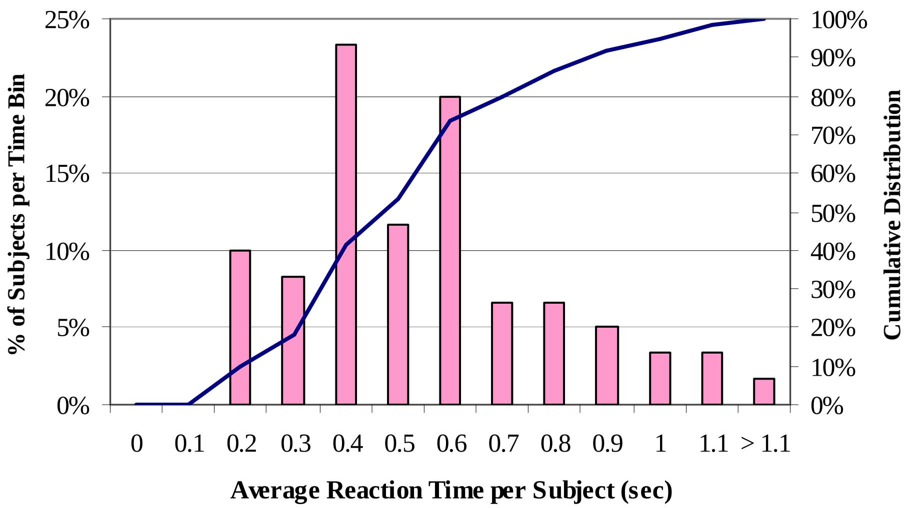


Figure 3-20. Distribution of Average Reaction Time per Subject to In-Path Target Alerts during ACAS-Enabled Test Period

Brake reaction time averaged about 0.57 seconds per driver to in-path target alerts during the ACAS-Enabled test period, with a standard deviation of 0.44 seconds (standard error = 0.06 seconds and number of subjects in this analysis = 60). This brake reaction time ranged from a minimum of 0.1 seconds to a maximum of 2.8 seconds. Taking reaction time to all alerts from all subjects altogether, brake reaction time averaged about 0.54 seconds with a standard deviation of 0.53 seconds (standard error = 0.03 second). These average values of brake reaction time are much less than experimental data on brake reaction times of drivers under surprise conditions that are typically greater than 1 second (Henderson, 1987; Taoka, 1989; Olson et al., 1984). This suggests that drivers in the FOT were about to initiate braking when they received the crash-imminent alert in the majority of alert cases. Steer reaction time averaged about 0.4 seconds per driver to in-path target alerts during ACAS-Enabled test period, with a standard deviation of 0.31 seconds (standard error = 0.09 seconds and number of subjects in this analysis = 11). On the other hand, brake and steer reaction time averaged about 0.39 seconds per driver with a standard deviation of 0.32 seconds (standard error = 0.09 seconds and number of subjects in this analysis = 12). Similar to brake reaction times observed in the FOT, steer and brake and steer reaction times indicate that subjects in most alert cases were about to initiate their response to the in-path obstacle as soon as they got the crash-imminent alerts.

3.2.4 Driver Inattention in Alert-Triggered Episodes

Figure 3-21 shows the involvement of driver distraction in all in-path target and out-of-path target alert-triggered episodes. Driver distraction includes dialing phone, talking/ listening to the phone, singing/whistling, grooming, adjusting controls, scratching face, yawning, drinking/eating/smoking, talking to passenger, reading, searching interior, scanning back adjacent lanes, scanning rear-view mirror, looking to the side/outside car, reaching for items, and other distractions. The subject was observed being distracted in about 39 percent of the in-path target alert episodes. However, drivers were not distracted in slightly over 50 percent of the episodes.

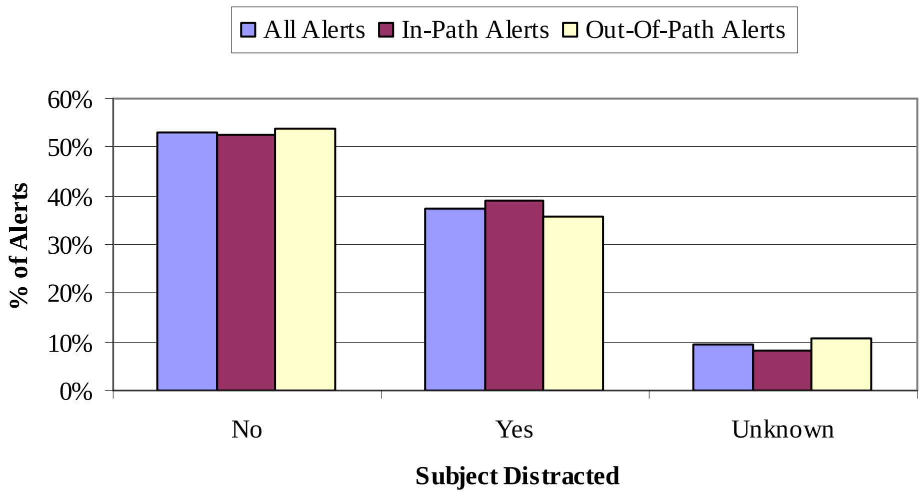


Figure 3-21. Breakdown of Various Alerts by Subject Distraction

Reaction time of a distracted driver averaged about 0.45 seconds per driver to in-path target alerts during the ACAS-Enabled test period, with a standard deviation of 0.25 seconds (standard error = 0.04 seconds and number of subjects in this analysis = 47). Taking reaction time to all alerts from all distracted subjects altogether, reaction time averaged about 0.49 seconds with a standard deviation of 0.46 seconds (standard error = 0.04 seconds). Figure 3-22 shows the empirical probability density function and cumulative distribution of the average reaction time per distracted driver to in-path target alerts during the ACAS-Enabled test period. About 66 percent of the 47 distracted subjects reacted on average within 0.5 seconds of the alert, and 98 percent of the subjects reacted within 1 second of the alert.

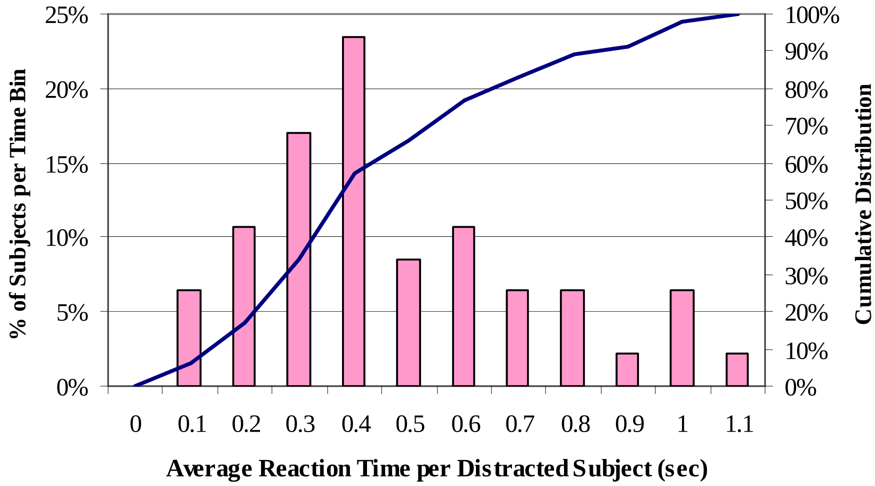


Figure 3-22. Distribution of Average Reaction Time per Distracted Subject to In-Path Target Alerts during ACAS-Enabled Test Period

Brake response to crash-imminent alerts for in-path targets was observed in 77 percent of distracted driver cases, off-throttle in 11 percent, steer in 7 percent, and brake and steer in 5 percent of the cases. Brake reaction time of a distracted driver averaged about 0.49 seconds per driver to in-path target alerts during the ACAS-Enabled test period, with a standard deviation of 0.39 seconds (standard error = 0.06 seconds and number of subjects in this analysis = 42). This brake reaction time of a distracted driver ranged from a minimum of 0.1 seconds to a maximum of 1.9 seconds. It should be noted that driver distractions included smoking, talking, eating, or other things where the driver was actually looking straight at the lead vehicle ahead. Moreover, the dynamic situations between the host and lead vehicles greatly affected brake reaction time to in-path target alerts in most cases. This may explain why the average brake reaction time to in-path target alerts by distracted drivers is lower in this sample than the overall average brake reaction time.

Figure 3-23 shows the percentage of driver eyes-off-the-road in all in-path and out-of-path target alert-triggered episodes. An FOT subject was noted to have his/her eyes off the road if the driver glanced away from the road ahead for a time period greater than or equal to 1.5 seconds before and during the alert. FOT subjects had their eyes off the road in fewer than 5 percent of the alert-triggered episodes. Even though they are considered a source of nuisance, out-of-path target alerts issued during the time period when the subject had his/her eyes away from the road could be very helpful in diverting his/her attention back to the road again. There was an instance in Algorithm A FOT where a subject veered off the road during the ACAS-Disabled test period due to eyes-off-the-road and a stationary object alert was issued. Even though the subject corrected back to the road on her own without hearing an alert, this case would have been helpful to a subject who did not correct his/her path back on the traveled road.

Reaction time of a driver whose eyes were off the road averaged about 0.6 seconds per driver to in-path target alerts during the ACAS-Enabled test period, with a standard deviation of 0.46 seconds (standard error = 0.19 seconds and number of subjects in this analysis = 6). Taking reaction time to all alerts from all subjects with eyes-of-road altogether, reaction time averaged about 0.66 seconds with a standard deviation of 0.57 seconds (standard error = 0.21 second). Only brake response to the crash-imminent alert was observed in cases where driver eyes were off the road.

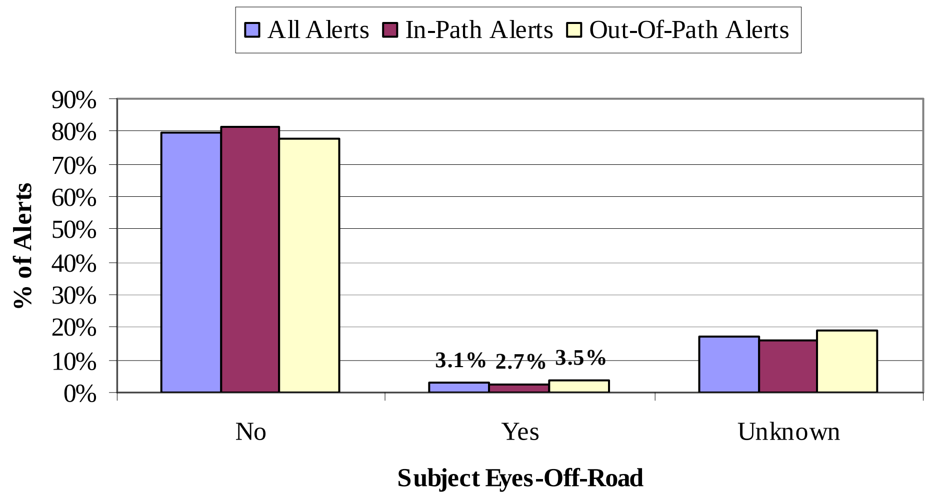


Figure 3-23. Breakdown of Various Alerts by Subject Eyes-Off-Road

3.2.5 Mapping of Alert Episodes to Near-Crashes

By examining the severity of driving episodes in which an in-path target alert was issued in both ACAS-Disabled and ACAS-Enabled test periods, about 57 percent of these episodes were classified as low-intensity near-crashes. On the other hand, only 15 percent of these episodes resulted in high-intensity near-crashes. The definition of low-intensity and high-intensity near-crashes is provided in the Safety Impact chapter of this report

3.2.6 Subjective Rating of Alert Efficacy

Subjects were asked to rate the timing of the FCW auditory alert and ACC autobraking response to a vehicle ahead with the following questions respectively:

1. Overall, evaluate the timing of the auditory alert when FCW was responding to a vehicle ahead.
2. What did you think of the timing of ACC braking in response to a vehicle ahead?

Figure 3-24 shows the mean and standard deviation values of responses to the two questions cited above. About 36 percent of the subjects thought that FCW alert timing was just right. In contrast, about 54 percent thought that ACC autobraking response was just right (scale value 4). About 52 percent of the subjects judged FCW timing as late at various degrees (scale values 5-7) as opposed to only 12 percent who judged it as early at various degrees (scale values 1-3). In comparison, about 20 percent of the subjects felt that ACC braking response was early, as opposed to 26 percent who thought of it as late at various degrees.

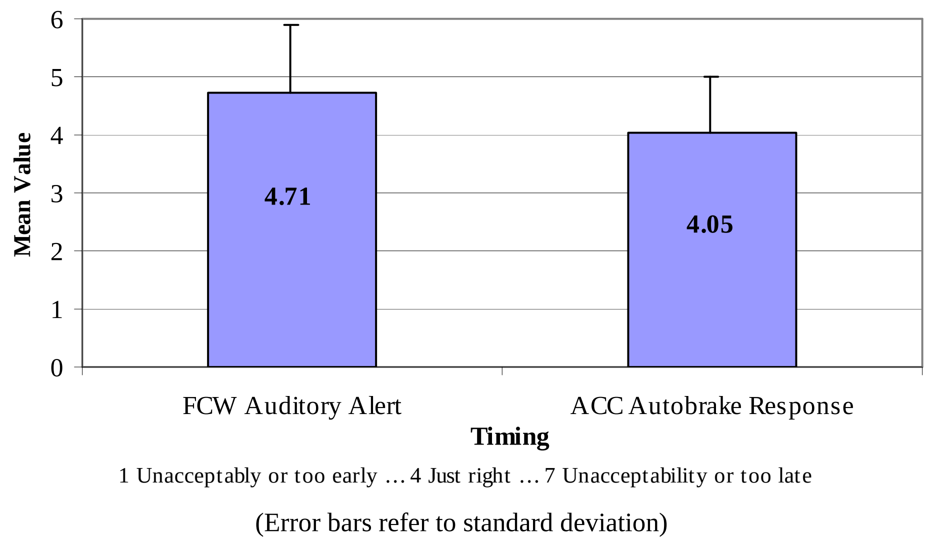


Figure 3-24. Subjective Evaluation of FCW Alert and ACC Auto-Brake Timing

An inquiry was made into the subjects' opinion about changing the design of FCW alert timing by two survey items translated below into one statement:

– If I were designing an FCW system, I would add an alert timing setting that allowed me to receive alerts *sooner*/*later* than the *most*/*least* sensitive alert timing setting that I experienced with this FCW system.

Figure 3-25 presents the mean and standard deviation values of the responses for sooner or later alert settings. About 67 percent of the subjects disagree (scales 1-3) to having *later* alert setting as apposed to 45 percent who disagree to *sooner* setting. On the other hand, 21 percent of the subjects agree (scales 5-7) to *later* setting as opposed to 47 percent for *sooner* setting.

The *usefulness* of FCW alerts was investigated by asking the subjects to "rate the extent to which FCW alerts were useful in providing a warning about a driving situation that might result in a collision," at a scale between 1 (not at all useful) and 7 (very useful). The mean response was 4.83 with a standard deviation of 2.05. About 59 percent of the subjects rated it to be useful (scales 5-7) as opposed to only 27 percent who judged it not to be useful (scales 1-3).

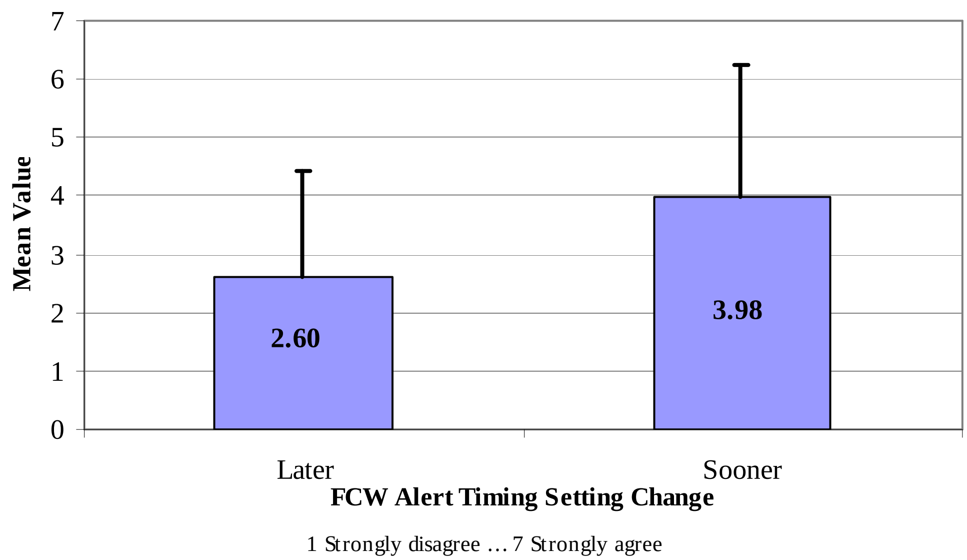


Figure 3-25. Subjective Response to Design Change of FCW Alert Timing Setting

Two more questions were asked of subjects, which address the efficacy of FCW alerts:

1. How often, if ever, did FCW not give you an alert when you felt that one was necessary (*missed alert*)?
2. How often, if ever, did FCW give you an alert in a situation that you felt was appropriate (*appropriate alert*)?

Figure 3-26 displays the mean and standard deviation values of driver responses to above questions. About 61 percent of the subjects felt that they never had a missed alert, and 17 percent experienced 1 or 2 missed alerts in total. On the other hand, only 12 percent indicated that they never had an appropriate alert. About 64 percent of the subjects felt that they experienced 1 to 6 appropriate alerts in total.

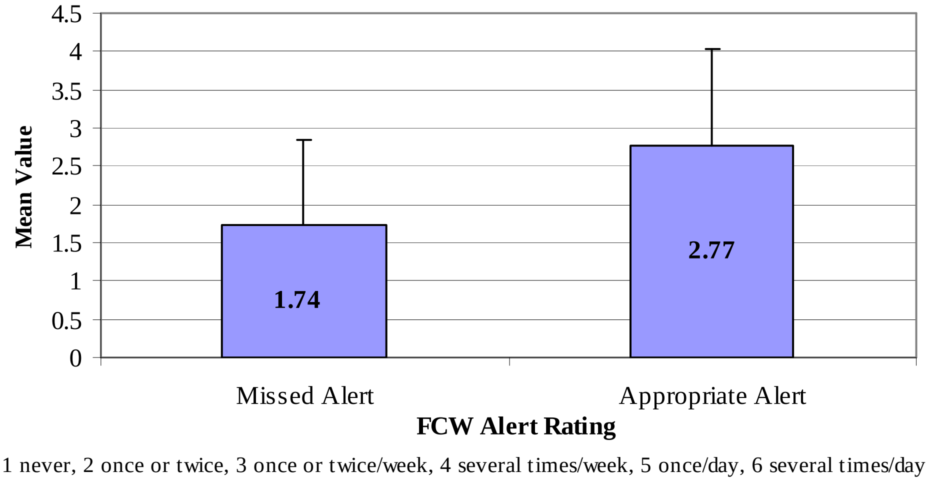


Figure 3-26. Subjective Evaluation of FCW Alert Efficacy

3.2.7 Subjective Rating of Alert Nuisance

Few questions were asked of subjects that indirectly refer to alerts that might be the source of nuisance:

1. How often, if ever, did FCW give you an alert where you could not identify the source of the alert (*unidentified source*)?
2. How often, if ever, did FCW give you an alert in a situation that you felt was not appropriate (*inappropriate alert*)?
3. How frequently did "*driving situations listed below*" result in FCW alerts that you felt were not necessary?
   a. When a vehicle ahead of me turned
   b. When I passed a moving vehicle
   c. When a vehicle ahead changed lanes
   d. When my vehicle changed lanes
   e. When a vehicle cut in front of me
   f. When I cut in behind another vehicle
   g. When I passed a sign, light post, or guard rail
   h. When I passed a parked vehicle

Figure 3-27 illustrates the mean and standard deviation values for the questions listed above. One third of the subjects indicated that they never got an alert that they could not identify its source. About 62 percent acknowledged that they received between 1 and 6 alerts in total with an unknown source. About 56 percent indicated that they received 1 to 6 inappropriate alerts in total, with 15 percent indicating never to receive an inappropriate alert. The reader is referred to Section 5, Driver Acceptance, for a more comprehensive analysis of FOT subjects' opinions and observations about the ACAS.

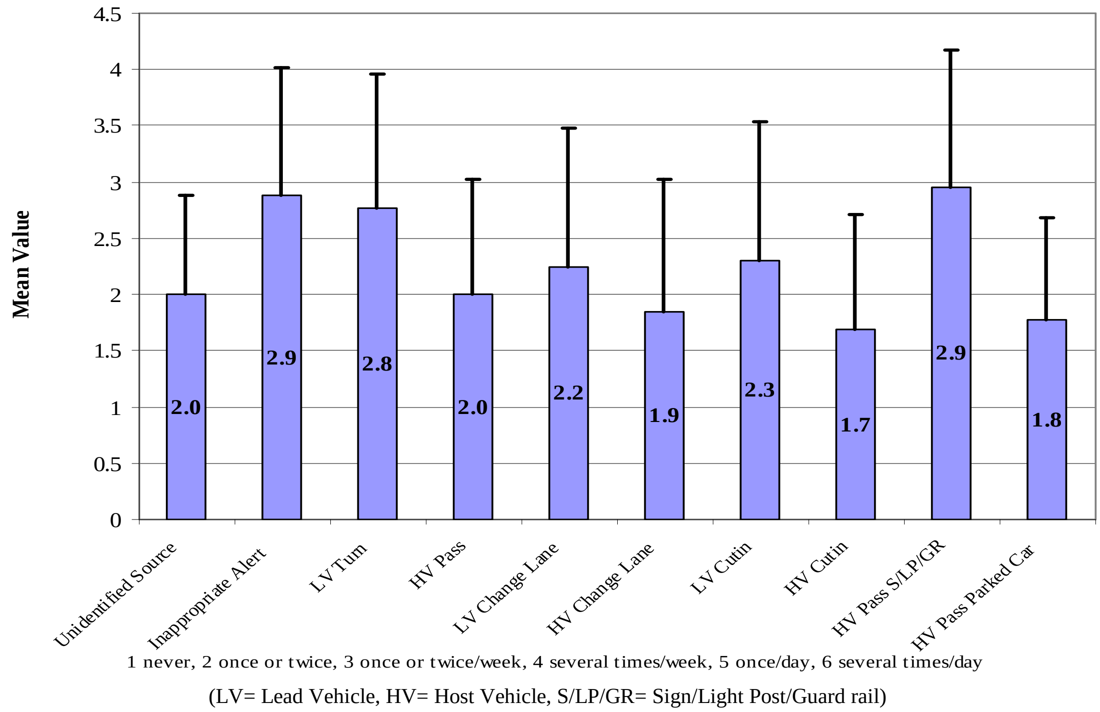


Figure 3-27. Subjective Evaluation of Inappropriate FCW Alerts

3.3 AUTOMATIC CONTROLS

This section addresses the automatic capability of ACC to control pre-set headways and respond to dynamic conditions of lead vehicles ahead. This analysis is based on data collected from the system characterization test and FOT surveys. The characterization test data were used to examine the response of ACC autobraking to decelerating or slower lead vehicles, and to check for false autobraking due to out-of-path moving vehicles. FOT surveys added subjective data to evaluate the gap settings and acceleration/deceleration authority of ACC.

3.3.1 Autobraking Response

The system characterization test employed ACC only on the freeway portion (divided roadways with speed limit ≥ 45 mph) of the test route under daylight clear conditions. Traffic conditions included low, moderate, and heavy but were generally at a moderate level of service. Headway settings were varied as equally as possible to include nearest (1.0 second), medium (1.4 seconds), and farthest (2.0 seconds) settings, which accounted respectively for 31.9 percent, 33.7 percent, and 34.4 percent of ACC drive time. ACC set speed was usually chosen to ensure that the host vehicle was moving with the flow of traffic or slightly faster, thus increasing the likelihood of encountering and detecting a lead vehicle.

ACC autobraking was examined in response to a lead vehicle decelerating ahead. Figure 3-28 provides a quantitative description of time delay between the start of lead vehicle braking and the initiation of ACC autobraking. Based on 44 events, autobraking was initiated at an average of 2.2 seconds after the lead vehicle began braking (brake lights on) at different levels of deceleration (standard deviation = 2.2 seconds and standard error = 0.3 seconds). The autobrake delay time was over 2 seconds in 45 percent of these events. Figure 3-29 illustrates the distribution of time delay between the end of lead vehicle braking and the release of ACC autobraking. This figure is based on 30 events in which the lead vehicle stopped braking (brake lights off) while remaining in the path of the host vehicle. In the other 14 lead vehicle braking events, the lead vehicle simply changed lanes, the host vehicle changed lanes, or the host vehicle speed fell below 20 mph. The ACC released the autobrakes at an average of 2.6 seconds after the end of lead vehicle braking, with a standard deviation of 2.1 seconds and standard error of 0.4 seconds. It took over 3 seconds to release the autobrakes in 40 percent of the events. Further examination of time delay in autobrake release was conducted by observing the time difference between the closing speed becoming zero (range rate = 0) and the end of ACC autobraking. Figure 3-30 shows the results of this time delay based on 63 events in which the host vehicle was closing in on a lead vehicle decelerating or moving at slower constant speed. ACC stopped braking on an average of 2 seconds after matching the speed of the lead vehicle, with a standard deviation of 1.5 seconds and standard error of 0.2 seconds. The delay was over 3 seconds in 25 percent of these events. These time delay characteristics affect the response and reaction of vehicles following the host vehicle, which could annoy drivers in following vehicles.

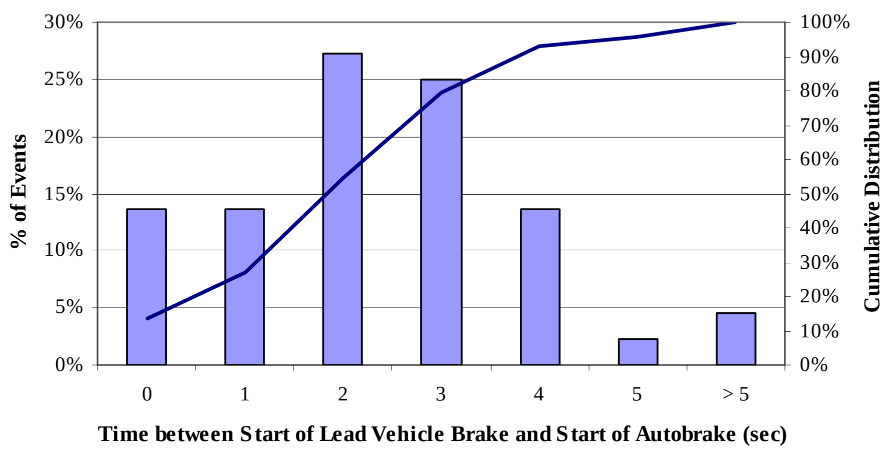


Figure 3-28. Distribution of Autobraking Response Time to Lead Vehicle Decelerating

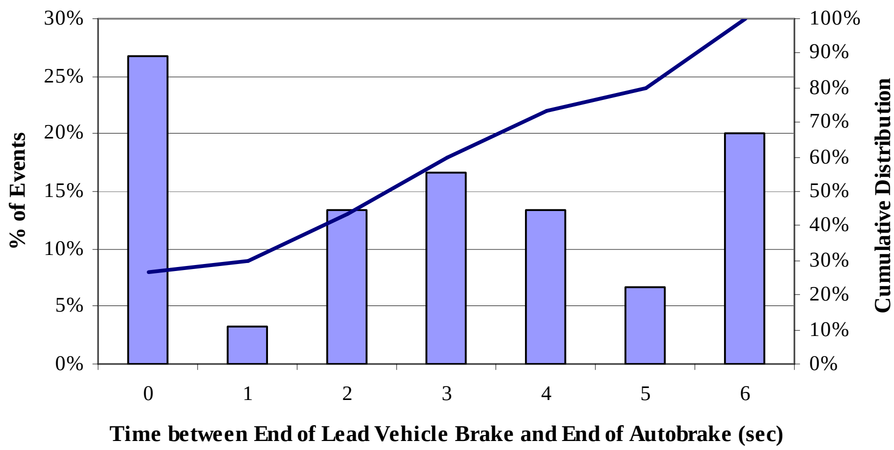


Figure 3-29. Distribution of Autobrake Release Time from End of Lead Vehicle Decelerating

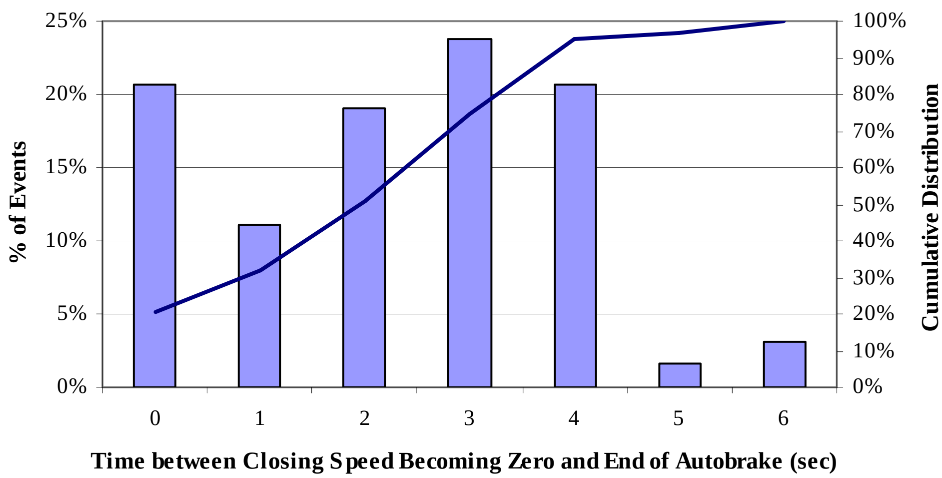


Figure 3-30. Distribution of Autobrake Release Time from Zero Closing Speed

A total of 5 false autobraking events were experienced while driving with ACC during the system characterization test. The host vehicle passing a large truck caused one false autobraking event, while the remaining 4 were in response to slower vehicles in adjacent lanes on curves. There were 17 passing maneuvers by the host vehicle. It should be mentioned that the dynamic conditions of the passing maneuver have a significant impact on triggering false autobraking events. The host vehicle also conducted a total of 44 lane changes, none of which triggered false autobraking. In addition, the host vehicle encountered 128 slower lead vehicles in adjacent lanes on curves. The lead vehicle was detected in 23 percent of these cases, as observed by the visual icon on the HUD. Of these detected lead vehicles, 4 or 13 percent triggered false autobraking. These occurred on a limited access, divided roadway with 40 mph speed limit and sharp curves.

This suggests that ACC should only be engaged on interstate or State highways with large curves and speed limits of 55 mph and higher; otherwise, the driver may experience unnecessary autobraking events.

3.3.2 ACC Gap Setting and Acceleration/Deceleration Authority

An inquiry was made into the subjects' opinion about changing the design of ACC gap setting by two survey items translated below into one statement:

- If I were designing an ACC system, I would add a following distance (gap) setting that allowed me to follow other vehicles *more closely*/*farther* than the *closest*/*farthest* headway setting that I experienced with this ACC system.

Figure 3-31 shows the mean and standard deviation values of the responses for closer or farther ACC gap settings. About 74 percent of the subjects disagreed (scales 1-3) to having more closely than the closest gap setting (1 second) as apposed to only 17 percent who agreed (scales 5-7). On the other hand, 60 percent of the subjects disagreed to having farther than the farthest gap setting (2 seconds) as opposed to 19 percent who agreed. Subjects who scored 4 (neutral) were about 9 percent and 21 percent for closer and farther gap setting changes, respectively. Thus, there is stronger disagreement to adding a closer gap setting than a farther gap setting by a small margin. These survey responses suggest that the majority of subjects appear to be in agreement with the current gap setting range between 1 and 2 seconds headway.

The following two questions were asked of subjects, which address the auto-acceleration and autobraking authority of ACC:

1. What did you think of the acceleration provided by ACC when pulling into an adjacent lane to pass other vehicles?
2. What did you think of the deceleration provided by ACC when following other vehicles?

Figure 3-32 shows the mean and standard deviation values for driver evaluation of ACC's capability to brake or accelerate the host vehicle. Slightly over 50 percent of the subjects picked the score 4 (neutral) in response to the 2 questions listed above – 53 percent to Question 1 and 52 percent to Question 2. Only 11 percent of the subjects indicated that ACC is fast (scales 1-3) to accelerate when pulling into an adjacent lane to pass other vehicles in contrast with 36 percent who thought that ACC was slow (scales 5-7). This suggests that ACC might be a little slow when accelerating in passing maneuvers. As for ACC deceleration when following other vehicles, 27 percent of the subjects indicated that it is fast as opposed to 21 percent who thought otherwise.

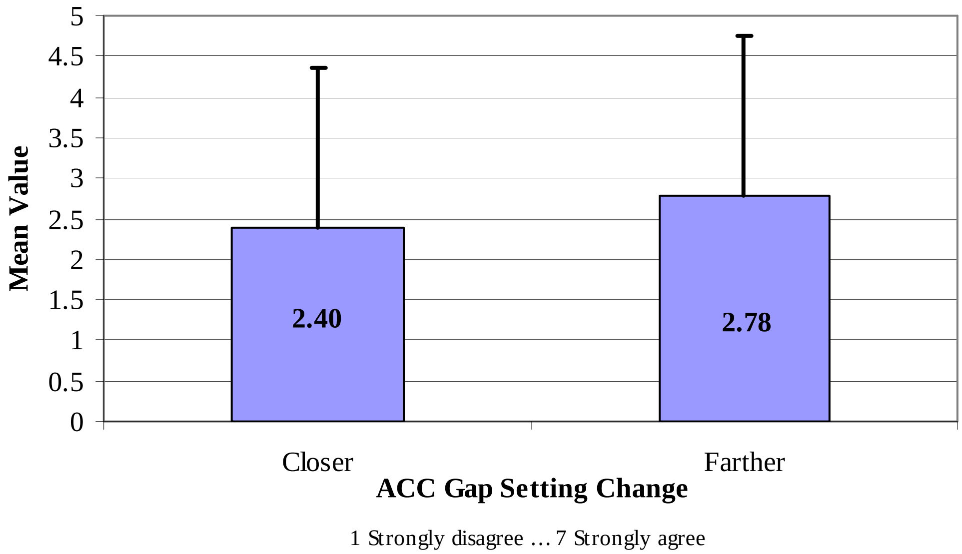


Figure 3-31. Subjective Response to Design Change of ACC Gap Setting Range

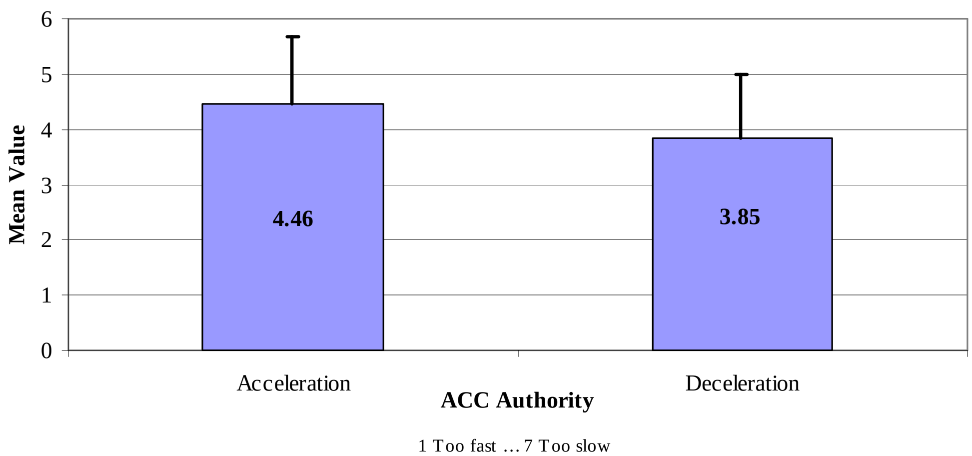


Figure 3-32. Subjective Evaluation of ACC Acceleration/Deceleration Authority

3.4 DRIVER-VEHICLE INTERFACE

This section evaluates the HUD readability and sound audibility of the DVI based on subjective judgment of FOT subjects in response to survey items. The DVI capability to effectively convey information to the driver in terms of HUD readability and alert sound audibility was subjectively captured by the following six questions:

1. How easy was it to drive and see the HUD at the same time?
2. How easy was it to see the HUD?

3. Overall, how easy was it to see all the information shown on the HUD?
4. How easily were you able to detect the visual crash alerts?
5. How easily were you able to recognize alerts from FCW?
6. How easily were you able to detect the audio crash alert?

Figure 3-33 displays the mean and standard deviation values for driver evaluation of the DVI. An overwhelming majority of subjects were able to see and hear text and audio messages transmitted by the DVI. All subjects (100%) easily (scales 5-7) drove and saw the HUD at the same time, 98.5 percent easily recognized alerts from FCW, 97 percent easily saw the HUD and detected the visual and audio crash alerts, and 96.5 percent saw all the information shown on the HUD overall.

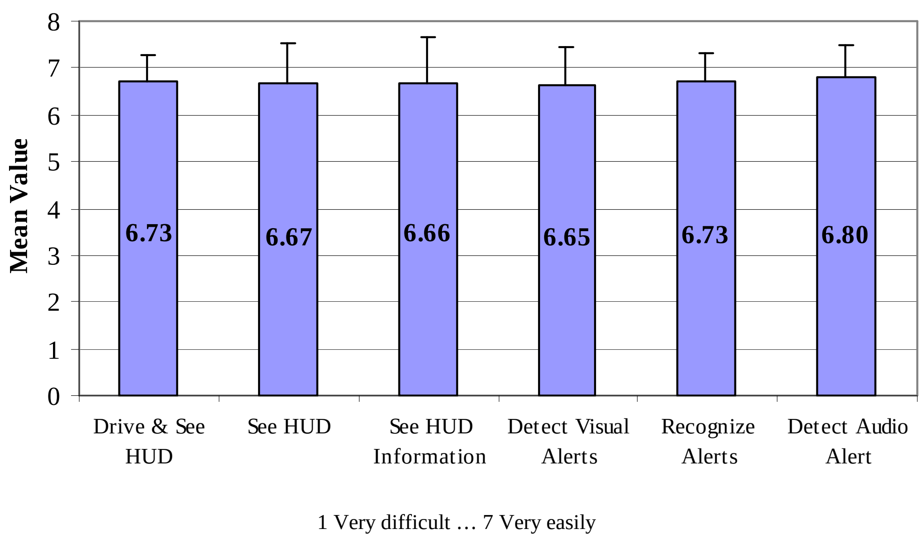


Figure 3-33. Subjective Evaluation of DVI Information Display Capability

3.5 SUMMARY OF SYSTEM CAPABILITY RESULTS

The analysis of 8-second video episodes triggered by the auditory crash-imminent alerts revealed the following:

– Subjects experienced 6.2 crash-imminent alerts per 1,000 km traveled overall during the FOT. However, this alert rate was 21.8 crash-imminent alerts per 1,000 km traveled when subjects were driving at vehicle speeds between 25 and 35 mph.

– In-path targets triggered 3.5 crash-imminent alerts per 1,000 km traveled. The majority of these alerts, or 3.4 alerts per 1,000 Km, was attributed to moving targets. Stationary vehicles triggered 14 alerts or 2.6 percent of all in-path target alerts – 2 of these were declared by the target selection algorithm as seen moving prior to stopping. About 0.4 crash-imminent alerts per 1,000 km traveled was issued for moving in-path targets due to host vehicle changing lanes, turning, or passing behind an in-path moving vehicle. In contrast, about 1.5 moving in-path target alerts per 1,000 km traveled were caused by a lead vehicle changing lanes, turning, or making left turn across the path of the host vehicle.

- Out-of-path targets caused 2.7 crash-imminent alerts per 1,000 km traveled. The majority of these alerts, or 2.3 alerts per 1,000 km traveled, were due to stationary targets. About 75 percent of these stationary out-of-path alerts occurred at vehicle speeds over 35 mph.
- In response to crash-imminent alerts for in-path targets during the ACAS-Enabled test period, subjects did nothing or simply eased up on the throttle in close to 40 percent of the episodes. Subjects braked in about 55 percent of the episodes. About 55 percent of the subjects had an average reaction time of 0.5 seconds or less after an in-path target alert. This suggests that subjects were attentive or were about to respond to the situation ahead when they received the crash-imminent alerts.
- The driver appeared to be distracted, within 5 seconds before the crash-imminent alert, in 38 percent of all alert episodes based on an analysis of recorded facial images.
- Driver eyes were away from the road ahead for at least 1.5 seconds before the crash-imminent alert in 3 percent of all alert episodes.
- Based on the judgment of the independent evaluator, FOT subjects received about 1.8 "true" alerts per 10,000 km traveled for a potential impending rear-end collision, near collision, or heavy braking event.

General results of the system characterization test were as follows:

- The forward-looking sensor suite was late in detecting 17 percent of the in-path targets (defined here by a speed independent 100/70 m), intermittently detected 28 percent of the targets, and lost detection of 22 percent of the targets on curves with radius below 500 m. In contrast, target detection loss was about 8 percent of all in-path targets on curves with radius over 500 m. Also on these curves, late detection and intermittent detection rates were estimated respectively at 14 percent and 24 percent of all in-path targets. It should be noted that late detection (defined here by a speed-independent 100/70 m criterion) does not necessarily imply lateness in warning availability for these targets.
- The threat assessment algorithm, correctly, did not generate crash-imminent alerts for 98 percent of the stationary out-of-path targets and for 99.5 percent of driving situations where the lead vehicle is traveling on a curve in the adjacent lane. Also, the system did not generate crash-imminent alerts for 98 percent of the cases when the host vehicle passed another vehicle or changed lanes and when the lead vehicle turned ahead. Overhead bridges or signs were all rejected by the system during the characterization test.
- The median time delay for ACC to release the auto-brakes after the lead vehicle is no longer a threat (range rate ≥ 0) was about 2 seconds.

Survey data provided a subjective evaluation of system capability. FOT subjects made the following remarks:

- FCW missed an alert at an average rating of 1.74 (1= never and 2= once or twice during the FOT). On the other hand, FCW issued an appropriate alert at an average rating of 2.77 (2= once or twice during the FOT and 3= once or twice per week).
- Lead vehicle turning or host vehicle passing by a sign, light pole, or guardrail were cited as the most likely sources for FCW inappropriate alerts.

- Acceleration authority and deceleration authority of the ACC were rated at an average of 4.46 and 3.85, respectively (1= too fast and 7= too slow). In corroboration with objective numerical data, FOT subjects thought ACC was slow to accelerate.
- HUD capability to clearly convey its information to drivers was rated very favorably by most subjects.

The following are some anecdotal comments about system capability and performance that were observed from FOT and system characterization test data:

- The system may issue crash-imminent alerts in rare instances when the brake pedal is pressed. The brake signal remains at zero. The ACAS is designed to suppress these alerts when the driver of the host vehicle steps on the brake pedal.
- The forward-looking sensor suite has intermittent detection problems in some cases where the lead vehicle is braking to a stop at an intersection. The lead vehicle is first declared as moving in-path target, then lost, and later reacquired at a shorter range.
- The forward-looking sensor suite "hangs on" lead vehicles after they change lanes, and switches back and forth between another lead vehicle and the vehicle that has just changed lanes.
- The forward-looking sensor suite is late sometimes in detecting a lead vehicle cutting in at short ranges.

Finally, some problems were identified with the data acquisition system, such as:

- The forward scene camera tilts down in some instances.
- The forward scene camera is out of focus.
- Data recording becomes "frozen" for some parameters for a period of time.
- Extreme value readings are generated from filtered parameters such as the acceleration level of the host vehicle.

4. SAFETY IMPACT OF ACAS

4.1 INTRODUCTION

This section presents the assessment of ACAS safety impacts. The assessment was performed in the following three areas:

1. *Driving Conflict Analysis* – This analysis is conducted at a global level examining all FOT driving conflicts to develop quantitative estimates of the overall safety impacts of ACAS. Results of this analysis are discussed in Section 4.2.
2. *Near-Crash Analysis* – This analysis is conducted on the subset of the most severe driving conflicts, referred to as near-crashes, using video and numerical episode data from the FOT, to assess the usefulness of ACAS in preventing crashes. Results of this analysis are discussed in Section 4.3.
3. *ACAS Driver Impact Analysis* – This analysis focuses on a detailed examination of driver performance data from the FOT to identify positive or unintended negative effects of ACAS on driving performance and behavior. Results of this analysis are discussed in Section 4.4.

This safety analysis focused on ACAS as an integrated package of FCW and ACC, and did not attempt to separate ACC and FCW effects because the two functions were coupled in the FOT vehicle and will typically be bundled together in production vehicles. The University of Michigan Transportation Research Institute and General Motors (2005) conducted separate analyses of FCW and ACC functions.

4.2 DRIVING CONFLICT ANALYSIS

The purpose of the Driving Conflict Analysis is to develop quantitative estimates of ACAS safety impacts. The estimates are based on quantifying how effectively ACAS accomplishes the two means by which it is intended to have an impact on safety: (1) ACAS will help drivers avoid conflicts that could lead to crashes and (2) if conflicts are encountered, ACAS will help drivers resolve the conflicts and thus prevent crashes. This analysis area consists of two major parts. The first part assesses the impact of ACAS on driver exposure to driving conflicts under different conditions of the driving environment. The second part estimates the safety benefits of ACAS in terms of the number of rear-end crashes that might be avoided with ACAS assistance.

The following equations describe a general approach for estimating the safety benefits of a crash avoidance system for a specific crash type, C. In this analysis, the crash type C represents rear-end crashes. System effectiveness, SE, denotes the percent reduction in crash type C resulting from deployment of ACAS:

$$SE = 1 - \left[\frac{P_w(C)}{P_{wo}(C)} \right] \qquad (1)$$

where,

$P_w(C) \equiv$ Probability of a crash type C with ACAS assistance
$P_{wo}(C) \equiv$ Probability of a crash type C without ACAS assistance

This approach also considers that crash type C is preceded by a specific driving conflict type S, which, for example, could be a lead vehicle decelerating. Given a driving conflict type S, Equation 1 can also be expressed as:

$$SE = 1 - \left[\frac{P_w(S)}{P_{wo}(S)}\right]\left[\frac{P_w(C\,|\,S)}{P_{wo}(C\,|\,S)}\right] \qquad (2)$$

where,

$P_w(S) \equiv$ Probability of an encounter with driving conflict S with ACAS assistance per VDT
$P_{wo}(S) \equiv$ Probability of an encounter with driving conflict S without ACAS assistance per VDT
$P_w(C|S) \equiv$ Probability of a crash of type C with ACAS assistance given that driving conflict S has been encountered
$P_{wo}(C|S) \equiv$ Probability of a crash of type C without ACAS assistance given that driving conflict S has been encountered

The ratio in the left pair of brackets in Equation 2 is referred to as the Exposure Ratio, ER, since it expresses the fractional decrease (or increase) in exposure of drivers to conflict type S as a result of driving with ACAS relative to driving without ACAS. The ratio in the right pair of brackets in Equation 2, referred to as the Prevention Ratio, PR, expresses the fractional decrease (or increase) in the likelihood of a crash type C, given an encounter with conflict type S. The Prevention Ratio thus reflects the ability of ACAS to help drivers prevent type C crashes by resolving type S conflicts. Equation 2 can be rewritten as follows:

$$SE = 1 - ER \times PR \qquad (3)$$

For a more complete discussion of this safety estimation methodology that considers multiple crash and conflict types, the reader is referred to Najm (2003).

Figure 4-1 provides an overview of the Driving Conflict Analysis process that consists of two major parts. The first part, Exposure to Driving Conflicts, examined driver exposure to driving conflicts in three stages. The first stage determined if drivers experienced differences in exposure to driving conflicts as they: (1) gained familiarity with the new ACAS vehicle, and (2) experimented with and learned how to use the FCW and ACC functions. The second stage determined rates of driver exposure to driving conflicts, with and without the assistance of ACAS, under different conditions of the driving environment. The third stage developed estimates of ACAS's ability to reduce driver exposure to driving conflicts under different driving conditions. This investigation yielded various estimates of the ACAS exposure effectiveness, EE, defined from Equation 3 as:

$$EE = 1 - ER \quad (4)$$

Thus, EE is simply SE by assuming PR = 1 in Equation 3. Results of the first part of the analysis are discussed in Section 4.2.1.

The second part of the Driving Conflict Analysis, Response to Driving Conflicts, was also conducted in three stages and is discussed in Section 4.2.2. The first stage determined the impact of ACAS on driver exposure to conflicts by specific dynamic scenarios and also determined the effectiveness of ACAS in reducing these exposures. The exposure rates were further analyzed by type of driver response and vehicle speed. These exposure rates were used to estimate the number of rear-end crashes that ACAS might prevent, as discussed in Section 4.2.2.3. The second stage developed characterizations of how drivers initiated responses to conflicts, with and without the assistance of ACAS, as well as how intense the responses were. The third stage employed Monte Carlo simulations to develop estimates of the Prevention Ratio in Equations 2 and 3 above; i.e., the effectiveness of ACAS in preventing crashes given that a particular rear-end crash conflict has occurred. This stage also projected estimates of overall safety benefits for ACAS.

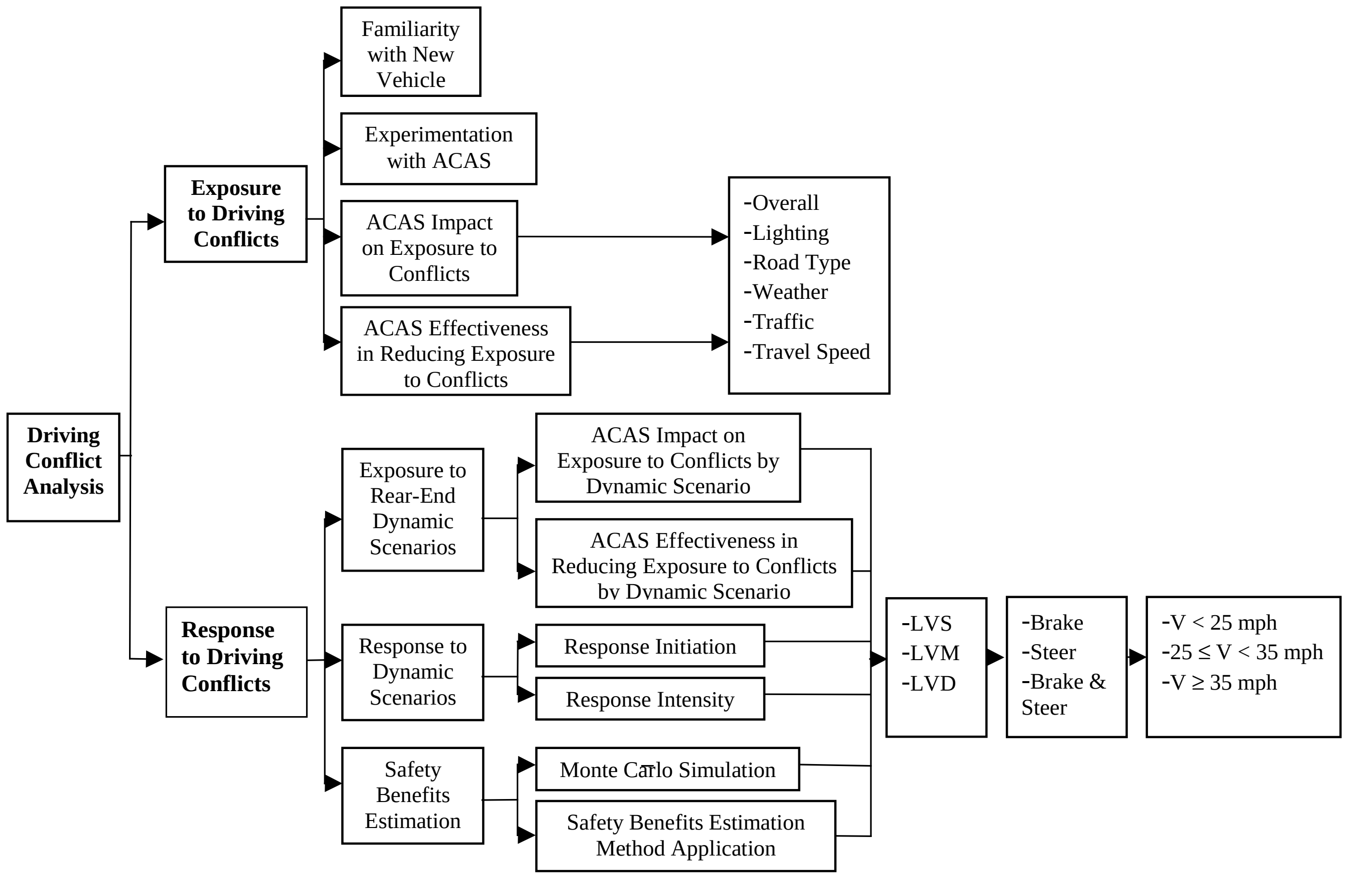


Figure 4-1. Conflict Analysis Flow Chart

4.2.1 Exposure to Driving Conflicts

In general, driving conflicts are situations where prompt driver intervention is required to avoid a crash. The ACAS evaluation is confined to the following four types of conflicts that have been reported to occur immediately prior to rear-end crashes:

1. Lead Vehicle Stopped (LVS),
2. Lead Vehicle Moving at lower constant speed (LVM),
3. Lead Vehicle Accelerating (LVA), and
4. Lead Vehicle Decelerating (LVD).

For the ACAS evaluation, exposure to any of these conflict types was determined by identifying situations where the ACAS vehicle exceeded defined levels of Time-To-Collision (TTC) (TTC= Range/Range rate) and range rate with a lead vehicle (closest in-path vehicle). Four such levels of conflict intensity were defined in terms of TTC and range rate thresholds. The four conflict intensity levels are based on results of test track studies conducted by the General Motors-Ford Crash Avoidance Metrics Partnership (CAMP) to characterize drivers' last-second braking and steering performance (Kiefer et al., 1999; Kiefer et al., 2003). These levels are based on driver's *preferred* last-second braking and steering levels. Using the CAMP data, two conflict types and two TTC-Range rate thresholds were defined which, together, establish the four conflict intensity levels. Appendix C defines these conflict intensity levels.

The following two conflict types were defined from CAMP data for the ACAS analysis:

1. *Conflicts*: CAMP scenarios where drivers were instructed to brake or steer at the last-second at a *comfortable* acceleration level.
2. *Near crashes*: CAMP scenarios where drivers were instructed to brake or steer at the last-second at a *hard* acceleration level. Near crashes are severe conflicts and are, thus, subsets of all conflicts.

The following two TTC-Range rate thresholds were defined from CAMP data for the ACAS analysis:

1. *Low intensity*: Quantified by TTC versus range rate diagrams derived from CAMP's 50 percentile data for LVS, LVM, LVA scenarios, and CAMP's 85 percentile data for the LVD scenario. The 85 percentile was selected for the LVD scenario in order to set consistent TTC boundary across the scenarios at closing speeds ≤ 5 m/s, as illustrated in Appendix C. The 50 percentile data of the LVD scenario yielded much higher values of the TTC boundary.
2. *High intensity*: Quantified by TTC versus range rate diagrams derived from CAMP's 95 percentile data for LVS, LVM, LVA, and LVD scenarios.

Combining the above definitions resulted in the following four conflict intensity levels, in order of increasing intensity, which were used for the ACAS safety analysis:

1. Low-intensity conflicts

2. High intensity conflicts
3. Low-intensity near-crashes
4. High intensity near-crashes

It should be noted that the low-and high-intensity levels of conflicts and near-crashes reflect the selection thresholds based on TTC and not the level or intensity of driver response to driving conflicts and near-crashes (e.g., reaction time, brake pressure).

To include a conflict in the analysis, the intensity level criteria must be met for a time period exceeding 1 second and the ACAS vehicle speed must be over 5 m/s (≈ 11 mph) at the time the criteria are met. In addition, there must be a driver/vehicle response to the conflict such as slow down (releasing accelerator), brake or autobrake, lane change, or combinations of these responses. A driver response was necessary to filter out targets picked up by the radar, which were not in the path of the ACAS vehicle. This criterion may result in missing some “conflicts” as defined in the report, such as cases where the driver does not react (or reacts late) and the “conflict” resolves itself (e.g., lane change by the lead vehicle) without a crash occurring. During a single approach to a target or lead vehicle, the host vehicle may cross in and out of a conflict boundary. This event is counted as a single driving conflict as long as the host vehicle is still closing in on the same target or lead vehicle. If the host vehicle first crosses the conflict boundary and later the near-crash boundary during a single approach to the same target or lead vehicle, then a conflict, and a near-crash are recorded. Thus, near-crashes are subsets of conflicts.

The following measures of performance (MOPs) were selected for analysis of driver exposure to driving conflicts:

1. MOP1: Number of high and low-intensity conflicts per 100 km traveled
2. MOP2: Number of high and low-intensity near-crashes per 100 km traveled

This part of the analysis of driver exposure to conflicts did not distinguish between the specific rear-end pre-crash scenarios (LVS, LVM, LVD, or LVA). Thus, the conflicts (and near-crashes) identified encompassed all rear-end scenarios. Subsequent analyses of driver response to conflicts in Section 4.2.2 examined conflicts by specific rear-end scenario. The driver exposure to conflicts analysis also did not examine the separate effects of FCW and ACC since they function as an integrated system. For instance, ACC incorporates a warning function (different alert timing from FCW alone) when it is operational. Moreover, the ACAS toggles between ACC, FCW, and manual mode as the driver intermittently brakes and re-engages ACC in response to various driving conflicts.

The conflict exposure analysis was conducted in three stages. The first stage of the analysis determined if drivers experienced differences in exposure to driving conflicts as they: (1) gained familiarity with the new ACAS vehicle, and (2) experimented with and learned how to use the FCW and ACC functions. This analysis was necessary to determine if early portions of the data were atypical of longer-range use patterns and therefore biased and not appropriate for the safety analysis. Results of the first stage of investigation are discussed in Section 4.2.1.1.

The second stage of investigation determined rates of driver exposure to driving conflicts, both with and without the assistance of ACAS, under different driving conditions. This investigation basically compared rates of conflict exposure between the first week of the FOT when ACAS was disabled and periods from the next three weeks when ACAS was enabled. Results of the second stage of investigation are discussed in Section 4.2.1.2.

The third stage of investigation developed estimates of ACAS's ability to reduce driver exposure to driving conflicts under different driving conditions. This investigation resulted in quantification of the ACAS exposure effectiveness, EE in Equation 4 above, for different conditions of the driving environment. These results are discussed in Sections 4.2.1.3 and 4.2.1.4.

4.2.1.1 Impact of New Vehicle Familiarity and ACAS Experimentation

Familiarity with New Vehicle

This analysis examines if the process of drivers' familiarization with the new ACAS vehicle affected their exposure to conflicts. The analysis is conducted by comparing the rate of driver exposure to conflicts between the first half and second half of the distance driven during the first week of experience with the new ACAS vehicle. The ACAS was disabled during the entire first-week period. The distances traveled for the two halves of the first week were computed by rounding to the nearest whole trip; thus, the two halves are not exactly equal. The period during which the first half of the distance was traveled with ACAS disabled is referred to as Period 1 and the second half as Period 2. The effects of driver age and gender on conflict exposure during Periods 1 and 2 were examined as well.

Table 4-1 shows the results of the familiarization analysis. Each cell contains the average and standard deviation values of the conflict rate (MOP1 and MOP2). The conflict rates for each category are computed by averaging the average conflict rate for each driver included in that category. This approach gives equal weight to each driver ensuring that individual drivers will not bias the results; however, the data set available for statistical analysis is more limited. The p-value is also provided for each pair of adjacent Period 1 and Period 2 cells using the 2-sided t-test for difference in mean values. Comparisons of conflict rates between Periods 1 and 2 that result in a p-value of .05 or less are considered statistically significant and are indicated in the table as shaded cells. It should be noted that the Low-Intensity Conflict (MOP1) category for *all* drivers contains the largest data set and is therefore considered the most robust indicator of overall driving performance. The table indicates no consistent significant difference in driver conflict rates between Periods 1 and 2. There are slightly higher conflict exposure rates during Period 2, which are reflected in those four categories that have significant differences. The slightly higher rates of conflicts in Period 2 might be due to an increased familiarization with the vehicle; drivers may be more comfortable with the ACAS vehicle and therefore more aggressive in their driving behavior. It was concluded, based on these results, that both Periods 1 and 2 were sufficiently similar that they should be used as a combined data set in subsequent analyses of driver exposure to conflicts.

Table 4-1. Conflict Exposure Rates for Period 1 versus Period 2

Age and Gender	*Low Intensity*										*High Intensity*									
	MOP1 (Conflicts/100Km)					**MOP2 (Near Crashes/100Km)**					**MOP1 (Conflicts/100Km)**					**MOP2 (Near Crashes/100Km)**				
	Period 1		***Period 2***			***Period 1***		***Period 2***			***Period 1***		***Period 2***			***Period 1***		***Period 2***		
	Avg	**Std Dev**	**Avg**	**Std Dev**	**p**	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**p**	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**p**	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**p**
All	33.0	19.0	36.7	23.6	0.14	10.4	7.7	12.5	10.9	0.04	17.5	11.2	20.3	14.9	0.06	2.7	3.0	2.7	2.5	0.97
Male	30.3	19.1	33.0	22.2	0.36	9.9	8.1	10.5	10.4	0.63	16.1	11.8	17.7	14.4	0.36	2.2	2.1	2.1	2.2	0.67
Female	35.6	18.8	40.5	24.6	0.26	11.0	7.4	14.5	11.1	0.02	18.8	10.6	23.0	15.2	0.10	3.2	3.7	3.3	2.7	0.83
Younger	33.2	21.8	35.7	24.3	0.55	10.2	8.3	12.6	12.9	0.17	16.8	11.9	19.7	16.1	0.26	2.3	2.7	2.8	3.2	0.37
Middle	33.5	16.2	44.5	20.4	0.03	11.3	7.5	14.9	8.6	0.08	18.1	10.2	24.3	12.7	0.04	2.5	1.8	3.2	1.9	0.08
Older	32.3	19.5	30.0	24.5	0.58	9.7	7.6	9.9	10.6	0.91	17.6	11.9	17.0	15.5	0.81	3.2	4.2	2.0	2.2	0.22

Experimentation and Learning with ACAS

This analysis examines if the process of drivers learning how to use ACAS, including possible experimentation with ACAS, affected driver exposure to conflicts. ACAS experimentation could include such behaviors as deliberately tailgating so as to provoke ACAS into issuing a warning and thereby acquiring a better understanding of when to expect future warnings. The analysis is conducted by comparing the rate of driver exposure to conflicts between the first half and second half of the distance driven during the final three weeks of the FOT when ACAS was enabled. The distances traveled for the two halves were computed in the same manner as the familiarization analysis discussed above. The period during which the first half of the distance was traveled is referred to as Period 3 and the second half as Period 4. The effects of driver age and gender on conflict exposure during Periods 3 and 4 were examined as well.

The results of the learning and experimentation analysis are shown in Table 4-2, which is constructed in a similar manner as Table 4-1. Results show a consistent decreased exposure to conflicts during Period 4 compared to Period 3 between all driver and conflict-level categories. This decrease is statistically significant for the category of *all* drivers as well as *male* drivers. It is also significant for the category of *younger* drivers for all but the most severe conflicts level (high intensity near-crashes). These results strongly indicate that drivers' behavior changed between Periods 3 and 4. The higher conflict exposure rate in Period 3 may be attributed to a combination of both learning and experimentation. Regarding the relative propensity of different age and gender groups to experiment with ACAS, it is noteworthy that only the subgroups of *males* and *younger* showed a significant difference between Periods 3 and 4. Based on these results, Period 3 was not considered representative of long-term driving behavior and was, therefore, not included in most subsequent analyses of driver exposure to conflicts. This is an important finding and should be considered in designing future FOTs. Possibly more free time is necessary to have the subjects experiment with these advanced systems before initiating data collection. On the other hand, if data were collected early in the treatment (with ACAS) period, caution should be exercised in analyzing the data collected in the early time frames.

Table 4-2. Conflict Exposure Rates for Period 3 versus Period 4

Age and Gender	*Low Intensity*										*High Intensity*									
	MOP1 (Conflicts/100Km)					**MOP2 (Near Crashes/100Km)**					**MOP1 (Conflicts/100Km)**					**MOP2 (Near Crashes/100Km)**				
	Period 3		***Period 4***			***Period 3***		***Period 4***			***Period 3***		***Period 4***			***Period 3***		***Period 4***		
	Avg	**Std Dev**	**Avg**	**Std Dev**	**p**	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**p**	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**p**	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**p**
All	33.9	19.2	28.4	17.2	0.01	11.0	7.3	9.1	6.1	0.02	18.4	11.0	15.4	9.6	0.02	2.5	2.0	2.1	1.5	0.05
Male	33.4	17.1	26.5	15.0	0.02	10.8	6.7	8.1	4.8	0.01	18.5	10.6	14.3	8.2	0.02	2.6	2.0	1.8	1.0	0.01
Female	34.4	21.3	30.2	19.3	0.23	11.1	7.9	10.1	7.1	0.36	18.4	11.6	16.5	10.9	0.32	2.4	2.0	2.3	1.9	0.77
Younger	37.5	17.4	28.8	18.8	0.02	12.4	7.4	9.8	6.6	0.03	20.2	10.1	15.6	10.2	0.02	2.7	2.2	2.2	1.6	0.16
Middle	35.0	20.3	32.9	13.2	0.61	11.4	7.8	10.5	4.7	0.53	19.1	11.5	17.6	7.3	0.53	2.8	2.2	2.5	1.2	0.51
Older	29.3	19.6	23.5	18.5	0.17	9.1	6.5	7.1	6.5	0.15	15.9	11.4	12.9	10.9	0.20	2.0	1.4	1.5	1.6	0.16

Summary – Impact of New Vehicle Familiarity and ACAS Experimentation

Period 2 has slightly higher conflict exposure rates than Period 1; however, it was concluded that Periods 1 and 2 are sufficiently similar that they should be combined for analyses of driver exposure to conflicts. The slightly higher rates in Period 2 are attributed to increased familiarization with the ACAS vehicle resulting in less conservative driving behavior.

Period 3 shows greater exposure to conflicts than Period 4 between all driver and conflict-level categories. These results strongly indicate that drivers' behavior changed between Periods 3 and 4. The change may be attributed to a combination of driver learning and experimentation with ACAS. Based on these results, Period 3 was not considered representative of long-term driving behavior and was not included in analyses of driver exposure to conflicts.

4.2.1.2 Impact of ACAS on Exposure to Driving Conflicts

Impact of ACAS on Overall Exposure to Driving Conflicts Independent of Driving Conditions

This analysis determines if ACAS reduced the overall exposure of subjects to driving conflicts independent of the different driving conditions characterized by lighting (ambient light), road type, weather, and traffic state. The analysis initially compares exposure to conflicts between the ACAS-Disabled test period (Periods 1 and 2) and the ACAS-Enabled test period (Periods 3 and 4). The analysis is then repeated by comparing driving with ACAS disabled (Periods 1 and 2) to driving with ACAS enabled in Period 4 only, the period considered most representative of long-term ACAS driving.

Table 4-3 shows the results of the Periods 1 and 2 versus Periods 3 and 4 comparisons. The results show a generally consistent lower exposure to conflicts during Periods 3 and 4. This lower exposure is statistically significant for the categories of *female* (high intensity near-crashes only) and *middle-age* (all conflicts except high-intensity near-crashes). The *male* (high intensity near-crash) is the only category that shows an insignificant increase in exposure.

Table 4-3. Conflict Exposure Rates for Periods 1 and 2 versus Periods 3 and 4

	Low Intensity										***High Intensity***									
	MOP1 (Conflicts/100Km)					**MOP2 (Near Crashes/100Km)**					**MOP1 (Conflicts/100Km)**					**MOP2 (Near Crashes/100Km)**				
	Periods 1 & 2 ACAS Disabled		***Periods 3 & 4 ACAS Enabled***			***Periods 1 & 2 ACAS Disabled***		***Periods 3 & 4 ACAS Enabled***			***Periods 1 & 2 ACAS Disabled***		***Periods 3 & 4 ACAS Enabled***			***Periods 1 & 2 ACAS Disabled***		***Periods 3 & 4 ACAS Enabled***		
Age and Gender	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**p**	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**p**	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**p**	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**p**
All	34.5	19.3	30.9	15.9	0.07	11.4	8.7	10.0	6.0	0.07	18.8	12.0	16.8	9.0	0.10	2.5	2.1	2.3	1.5	0.20
Male	31.8	19.2	29.7	13.7	0.41	10.2	8.6	9.4	5.1	0.46	17.0	12.3	16.2	8.1	0.64	2.1	1.9	2.2	1.3	0.78
Female	37.2	19.3	32.1	18.0	0.09	12.6	8.7	10.6	6.8	0.08	20.6	11.6	17.3	9.9	0.07	3.0	2.3	2.3	1.7	0.03
Younger	34.3	21.0	32.6	16.5	0.55	11.4	10.2	11.0	6.6	0.72	18.2	12.9	17.7	9.3	0.76	2.6	2.7	2.4	1.7	0.73
Middle	39.7	14.7	33.9	14.3	0.03	13.3	6.6	11.0	5.4	0.05	21.5	9.4	18.3	7.7	0.05	2.9	1.5	2.6	1.4	0.46
Older	29.6	20.9	26.3	16.5	0.46	9.5	8.9	8.0	5.7	0.36	16.6	13.3	14.4	9.8	0.42	2.2	2.0	1.7	1.2	0.32

Table 4-4 shows the results for the Periods 1 and 2 versus Period 4 only comparisons. The results are consistent with those presented above in Table 4-3; however, reduced driver exposure to conflicts when ACAS is enabled is consistent for all categories with no exceptions. Furthermore, the reduction in driver exposure to conflicts is statistically significant for the set of *all* drivers across all conflict severity levels. Assuming that Period 4 is the most representative of long-term ACAS driving behavior, these results indicate that use of ACAS will reduce exposure to conflicts for drivers and driving conditions overall.

Further illustrating the impact of ACAS on reducing exposure to conflicts, Figure 4-2 presents the distribution of conflict rates for all subjects with ACAS-Disabled and ACAS-Enabled. Figure 4-3 presents the same information as a cumulative distribution. The figures present rates for low-intensity conflicts for *all* subjects and all driving conditions. This information is the same as that summarized in Table 4-4 above for the *all* group, low-intensity conflicts. By observing Figure 4-2, it can be seen that the mean of the two distributions is approximately 30 conflicts per 100 Km, which agrees with the average rates presented in Table 4-4 for low-intensity conflicts (34.5 for ACAS-Disabled and 28.4 for ACAS-Enabled). As both figures show, the effect of ACAS is to shift the distribution of conflict rates to a lower average; i.e., with ACAS a larger percent of subjects have lower conflict rates. For example, as illustrated in the cumulative distribution, approximately 95.5 percent of subjects with ACAS-Disabled have rates lower than 70 conflicts per 100 Km; whereas, the same percent of subjects with ACAS-Enabled have rates lower than 60 conflicts per 100 Km. Expressed differently, no subjects with ACAS-Enabled have rates greater than 70 conflicts per 100 Km; whereas, with ACAS-Disabled 5 percent of subjects have rates greater than 70 conflicts per 100 Km. Similar distributions have been prepared for all intensity levels, subject groups, and driving conditions. These distributions are presented in Appendix D for reference.

Table 4-4. Conflict Exposure Rates for Periods 1 and 2 versus Period 4

	Low Intensity										*High Intensity*									
	MOP1 (Conflicts/100Km)					**MOP2 (Near Crashes/100Km)**					**MOP1 (Conflicts/100Km)**					**MOP2 (Near Crashes/100Km)**				
	Periods 1 & 2 ACAS Disabled		***Period 4 ACAS Enabled***			***Periods 1 & 2 ACAS Disabled***		***Period 4 ACAS Enabled***			***Periods 1 & 2 ACAS Disabled***		***Period 4 ACAS Enabled***			***Periods 1 & 2 ACAS Disabled***		***Period 4 ACAS Enabled***		
Age and Gender	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**p**	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**p**	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**p**	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**p**
All	34.5	19.3	28.4	17.2	0.01	11.4	8.7	9.1	6.1	0.01	18.8	12.0	15.4	9.6	0.02	2.5	2.1	2.1	1.5	0.05
Male	31.8	19.2	26.5	15.0	0.06	10.2	8.6	8.1	4.8	0.09	17.0	12.3	14.3	8.2	0.12	2.1	1.9	1.8	1.0	0.38
Female	37.2	19.3	30.2	19.3	0.07	12.6	8.7	10.1	7.1	0.07	20.6	11.6	16.5	10.9	0.07	3.0	2.3	2.3	1.9	0.07
Younger	34.3	21.0	28.8	18.8	0.13	11.4	10.2	9.8	6.6	0.31	18.2	12.9	15.6	10.2	0.22	2.6	2.7	2.2	1.6	0.41
Middle	39.7	14.7	32.9	13.2	0.07	13.3	6.6	10.5	4.7	0.06	21.5	9.4	17.6	7.3	0.09	2.9	1.5	2.5	1.2	0.26
Older	29.6	20.9	23.5	18.5	0.22	9.5	8.9	7.1	6.5	0.16	16.6	13.3	12.9	10.9	0.22	2.2	2.0	1.5	1.6	0.19

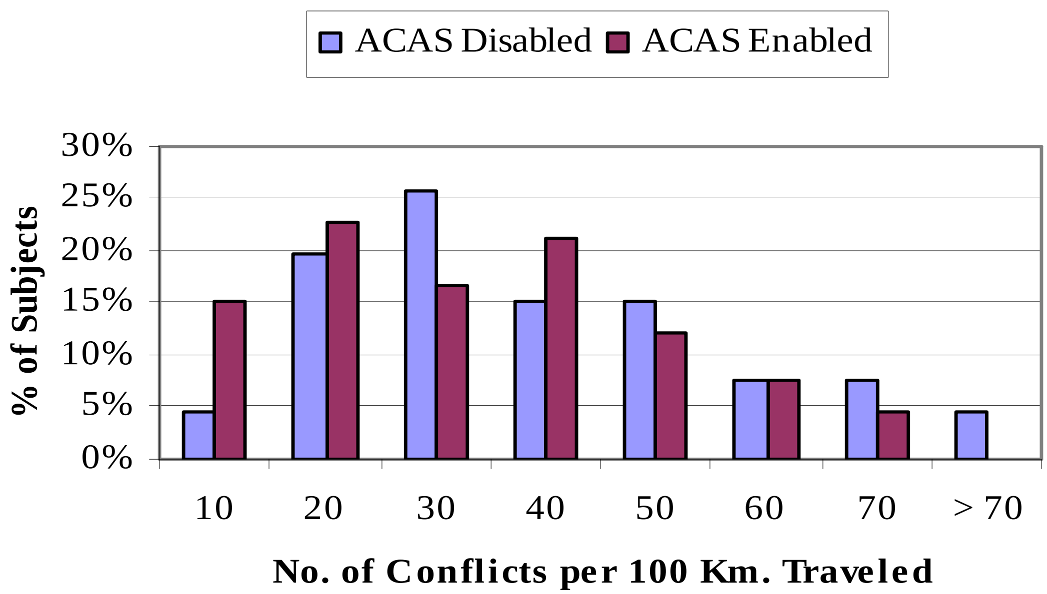


Figure 4-2. Distribution of Low-Intensity Conflicts, All Conditions, All Subjects, Periods 1 and 2 versus Period 4

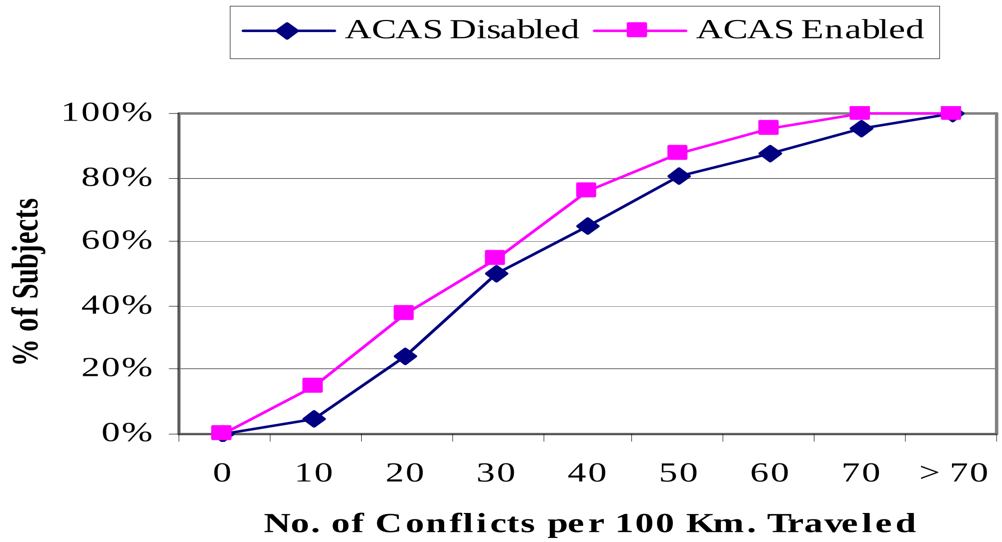


Figure 4-3. Cumulative Distribution of Low-Intensity Conflicts, All Conditions, All Subjects, Periods 1 and 2 versus Period 4

<u>Impact of ACAS on Exposure to Driving Conflicts by Ambient Light Conditions (Light and Dark)</u>

This analysis determines if ACAS reduces the exposure of subjects to driving conflicts in ambient light conditions of light and dark. Exposure with ACAS disabled (Periods 1 and 2) is compared to exposure with ACAS enabled (Period 4 only) for these two conditions. For this analysis and additional analyses of the other driving conditions discussed below, subjects were eliminated who did not encounter any conflict or near-crash while driving with either ACAS disabled or ACAS enabled. Also, subjects were excluded who did not travel at least 1 km in a trip under a driving condition being investigated. These exclusions ensured that very short trips, unlikely to experience typical exposures, did not bias the analysis. Moreover, the 1 km criterion was considered adequate for this analysis especially when examining driving conflicts in heavy traffic. Analyses conducted on data sets that contain less than 10 subjects are not considered statistically valid and are not shown in the results. The number of subjects analyzed for each subject group/conflict intensity level category is indicated in the “Subj” column in the following tables. The results for analyses of driving in ambient light conditions of light and dark are shown in Table 4-5 for low-intensity conflicts and Table 4-6 for high-intensity conflicts.

Table 4-5 and Table 4-6 both reflect lower exposure to conflicts with ACAS enabled than with ACAS disabled under both light and dark conditions. This lower exposure for light conditions is consistent for all subject groups and conflict intensity level categories. Furthermore, it is statistically significant for the *all* and *middle-age* subject groups for low-intensity conflicts and for the *all* subject group for high-intensity conflicts. The tendency of lower exposure for *dark* conditions is the same as for *light* conditions with one minor exception (*older* group, low-intensity conflicts). There are, however, no categories under dark conditions that have statistically significant results. Driving in dark conditions comprises only about 26 percent of driving and this lack of data likely contributes to the non-significance of the results for dark conditions. As shown in Table 4-5 and Table 4-6, the number of subjects for dark conditions is relatively few with *older* drivers having the fewest number of subjects (less than 10 subjects in the high-intensity near-crash category). This result is consistent with exposure analyses that show *older* drivers drove the least in dark conditions.

Compared to baseline results for the aggregate of all driving, independent of driving condition (see Table 4-4), the results for light conditions show consistent agreement in rates of exposure to conflicts. The exposure rates for light conditions, however, are slightly higher than for aggregate driving in all 47 subject group/conflict intensity level/ACAS Status categories for which sufficient data were available for analysis. This result is consistent with higher traffic densities being encountered during daytime, light conditions. For dark conditions, 19 out of the 23 subject group/conflict intensity level categories with ACAS disabled and 17 out of the 23 categories with ACAS enabled generally show slightly lower conflict levels than aggregate driving.

Comparing light conditions to dark conditions, it can be seen that the exposure rates for dark conditions are, expectedly, slightly lower in most subject group/conflict intensity level categories. In the 23 categories for which sufficient data were available for analysis of dark conditions, the exposure rates were lower in 21 with ACAS disabled and 22 ACAS enabled. For dark conditions, there is general reduction in exposure to conflicts with ACAS enabled; however, even for the most robust category of *all* subjects, the reduction is not statistically significant and there is an exception to this reduction in 1 of 23 categories. This contrasts with light conditions, which does have a statistically significant reduction in exposure to conflicts with ACAS enabled for *all* and *middle-age* subjects and there are no exceptions to this reduction in any categories. This suggests that ACAS might have less ability to reduce conflict exposure for dark conditions than for light conditions. This observation for dark conditions, not being based on statistically significant results, should, therefore, be interpreted with caution.

In conclusion, the results indicate that use of ACAS will reduce exposure to conflicts for drivers overall when driving in light conditions. For driving in dark conditions, ACAS also appears to have some ability to reduce exposure to conflicts; however, it is not possible to make reliable conclusions regarding this ability for all drivers. Thus, there is a need for more night driving in future FOTs with and without the assistance of crash avoidance systems.

Table 4-5. Low-Intensity Conflict Exposure Rates for ACAS Disabled versus ACAS-Enabled by Light and Dark Conditions

		LOW INTENSITY											
		MOP1 (Conflicts/100Km)						MOP2 (Near Crashes/100Km)					
		Periods 1 and 2 ACAS Disabled		*Period 4 ACAS Enabled*				*Periods 1 and 2 ACAS Disabled*		*Period 4 ACAS Enabled*			
	Age and Gender	Avg	Std Dev	Avg	Std Dev	Subj	p	Avg	Std Dev	Avg	Std Dev	Subj	p
Light	All	36.8	19.8	30.9	19.1	66	0.016	12.5	8.9	10.2	6.9	66	0.019
	Male	34.4	19.5	29.6	16.9	33	0.084	11.3	8.8	9.5	6.0	33	0.093
	Female	39.3	20.1	32.2	21.3	33	0.088	13.7	8.9	11.0	7.7	33	0.098
	Younger	36.7	21.0	33.2	21.8	22	0.354	12.4	10.1	11.3	7.7	22	0.485
	Middle	43.1	15.3	35.1	15.5	22	0.049	15.0	6.9	11.5	5.2	22	0.033
	Older	30.8	21.4	24.5	18.6	22	0.222	10.1	9.1	8.0	7.3	22	0.239
Dark	All	29.6	21.8	27.2	20.4	61	0.450	9.5	9.0	8.5	7.3	51	0.461
	Male	25.7	20.2	24.5	14.8	31	0.778	8.7	10.0	6.8	4.2	25	0.339
	Female	33.7	23.0	30.0	24.8	30	0.462	10.2	8.0	10.1	9.2	26	0.963
	Younger	33.2	25.5	26.5	24.6	21	0.206	11.1	11.4	10.0	9.3	18	0.700
	Middle	32.3	19.8	31.1	17.9	21	0.818	9.5	8.2	9.2	6.4	21	0.884
	Older	22.6	18.8	23.7	18.0	19	0.862	7.1	5.8	5.0	4.1	12	0.180

Table 4-6. High-Intensity Conflict Exposure Rates for ACAS-Disabled versus ACAS-Enabled by Light and Dark Conditions

	Age and Gender	HIGH INTENSITY											
		MOP1 (Conflicts/100Km)						MOP2 (Near Crashes/100Km)					
		Periods 1 and 2 ACAS Disabled		*Period 4 ACAS Enabled*				*Periods 1 and 2 ACAS Disabled*		*Period 4 ACAS Enabled*			
		Avg	Std Dev	Avg	Std Dev	Subj	p	Avg	Std Dev	Avg	Std Dev	Subj	p
Light	All	20.1	12.2	17.0	10.8	66	0.04	3.0	2.5	2.4	1.8	63	0.04
	Male	18.3	12.2	16.2	9.5	33	0.20	2.7	2.4	2.1	1.4	31	0.19
	Female	21.9	12.1	17.8	12.0	33	0.10	3.3	2.5	2.6	2.2	32	0.11
	Younger	19.3	12.8	17.8	11.3	22	0.49	3.2	3.2	2.7	2.3	21	0.39
	Middle	23.6	9.3	19.3	9.1	22	0.09	3.5	1.9	2.6	1.3	21	0.09
	Older	17.4	13.7	13.9	11.5	22	0.26	2.4	2.2	1.8	1.7	21	0.30
Dark	All	16.4	13.9	14.7	11.1	57	0.40	2.6	2.1	2.0	1.9	39	0.09
	Male	13.6	13.7	12.5	7.9	30	0.70	1.8	1.7	1.4	0.9	20	0.39
	Female	19.5	13.7	17.0	13.5	27	0.44	3.4	2.2	2.6	2.4	19	0.15
	Younger	19.3	15.7	15.6	13.5	19	0.30	2.6	2.4	2.0	2.3	16	0.23
	Middle	16.9	13.2	15.6	10.1	21	0.71	2.7	2.0	2.3	1.6	16	0.47
	Older	12.6	12.4	12.5	9.4	17	0.99						

Impact of ACAS on Exposure to Driving Conflicts by Road Type (Freeway and Non-Freeway)

This analysis determines if ACAS reduces the exposure of subjects to driving conflicts on freeways and non-freeways. The results are shown in Table 4-7 for low-intensity conflicts and Table 4-8 for high-intensity conflicts.

Both Table 4-7 and Table 4-8 generally reflect lower exposure to conflicts with ACAS enabled than with ACAS disabled for both freeway and non-freeway driving. Lower exposure for freeways is consistent for all subject groups and conflict intensity levels categories investigated. Furthermore, it is statistically significant for the *all* subject group, low-intensity conflicts (MOP1 and MOP2) and high-intensity conflicts (MOP1). These three conflict intensity levels are the only ones for which sufficient data were available to analyze. Lower exposure to conflicts on freeways is also significant for the *male* subject group, low-intensity conflicts (MOP1 only).

Lower exposure to conflicts for non-freeways is also generally consistent with ACAS enabled than with ACAS disabled, but this decreased in exposure is not statistically significant. There are also exceptions to the lower exposure observation in 3 of the 24 subject group/conflict intensity level categories, all involving *younger* drivers.

Compared to baseline results for the aggregate of all driving (see Table 4-4), freeway driving consistently shows lower exposures to conflicts in all 36 subject group/conflict intensity level/ACAS Status categories for which sufficient data were available for analysis. This result is consistent with lower traffic densities being encountered on freeways compared to all other road types. For non-freeway driving, the results show much higher exposures to conflicts. This result is consistent with higher traffic densities being encountered on non-freeways than freeways.

Comparing freeway driving to non-freeway driving, it can be seen that exposures to conflicts for freeways are, expectedly, much lower in all respective subject group/conflict intensity level/ ACAS Status categories. For non-freeway driving, there is general reduction in exposure to conflicts with ACAS enabled; however, even for the most robust category of *all* subjects, the reduction is not statistically significant and there is an exception to this reduction in 3 of 24 categories. This contrasts with freeway driving, which does have a statistically significant reduction in exposure to conflicts with ACAS enabled for *all* subjects and there are no exceptions to this reduction in any categories. This suggests that ACAS might have less ability to reduce conflict exposure for non-freeway driving than for freeway driving. This observation for non-freeways, not being based on statistically significant results, should, therefore, be interpreted with caution.

In conclusion, the results indicate that use of ACAS will reduce exposure to conflicts for drivers overall when driving on freeways. For driving on non-freeways, ACAS also appears to have some ability to reduce exposure to conflicts; however, it is not possible to draw reliable conclusions regarding this ability for all drivers.

Table 4-7. Low-Intensity Conflict Exposure Rates for ACAS-Disabled versus ACAS-Enabled by Road Type

		LOW INTENSITY											
		MOP1 (Conflicts/100Km)						MOP2 (Near Crashes/100Km)					
		Periods 1 and 2 ACAS Disabled		*Period 4 ACAS Enabled*				*Periods 1 and 2 ACAS Disabled*		*Period 4 ACAS Enabled*			
	Age and Gender	Avg	Std Dev	Avg	Std Dev	Subj	p	Avg	Std Dev	Avg	Std Dev	Subj	p
Freeway	All	4.7	5.3	3.3	3.2	49	0.04	1.5	1.7	1.0	0.9	30	0.04
	Male	4.4	4.9	2.5	2.3	26	0.05	1.2	1.3	0.9	0.7	16	0.28
	Female	5.0	5.8	4.2	3.9	23	0.42	1.8	2.0	1.1	1.0	14	0.08
	Younger	5.1	5.3	3.8	3.5	19	0.24	1.6	1.7	1.0	1.0	12	0.13
	Middle	6.0	6.8	4.5	3.6	15	0.33	2.1	1.9	1.2	0.9	11	0.13
	Older	3.0	3.0	1.6	1.3	15	0.12						
Non Freeway	All	61.3	29.0	58.3	28.9	66	0.34	20.6	14.8	19.3	12.2	66	0.34
	Male	55.6	25.6	53.9	20.3	33	0.69	18.0	13.2	16.9	7.9	33	0.59
	Female	67.0	31.5	62.6	35.3	33	0.37	23.3	15.9	21.7	15.2	33	0.43
	Younger	64.9	34.2	67.5	31.0	22	0.70	22.3	18.6	23.2	11.9	22	0.79
	Middle	66.8	25.6	59.8	28.2	22	0.10	23.5	13.1	20.7	14.3	22	0.12
	Older	52.1	25.5	47.5	24.8	22	0.42	16.1	11.2	13.9	8.3	22	0.30

Table 4-8. High-Intensity Conflict Exposure Rates for ACAS-Disabled versus ACAS-Enabled by Road Type

		HIGH INTENSITY											
		MOP1 (Conflicts/100Km)						MOP2 (Near Crashes/100Km)					
		Periods 1 and 2 ACAS Disabled		*Period 4 ACAS Enabled*				*Periods 1 and 2 ACAS Disabled*		*Period 4 ACAS Enabled*			
	Age and Gender	Avg	Std Dev	Avg	Std Dev	Subj	p	Avg	Std Dev	Avg	Std Dev	Subj	p
Freeway	All	2.1	1.9	1.4	1.4	31	0.04						
	Male	1.9	1.4	1.2	0.9	17	0.10						
	Female	2.4	2.5	1.7	1.8	14	0.22						
	Younger	2.2	1.7	1.9	2.0	12	0.46						
	Middle	2.5	2.5	1.3	1.0	12	0.10						
	Older												
Non Freeway	All	34.1	19.1	32.2	16.7	66	0.35	4.9	3.9	4.4	3.3	64	0.24
	Male	30.2	17.5	29.6	12.0	33	0.83	4.0	3.2	3.7	1.8	32	0.64
	Female	37.9	20.0	34.9	20.2	33	0.29	5.8	4.4	5.1	4.2	32	0.25
	Younger	36.0	23.1	37.1	16.9	22	0.79	5.5	5.4	5.1	3.2	21	0.63
	Middle	37.5	16.8	33.4	17.3	22	0.11	5.2	3.3	5.1	3.9	22	0.80
	Older	28.8	16.3	26.1	14.6	22	0.45	3.9	2.5	3.1	1.9	21	0.16

Impact of ACAS on Exposure to Driving Conflicts by Weather Conditions (Clear and Adverse)

This analysis determines if ACAS reduces the exposure of subjects to driving conflicts in clear and adverse weather conditions. Weather was classified as either clear or adverse as determined by activation of the windshield wipers. Table 4-9 and Table 4-10 show the results respectively for low-intensity and high-intensity conflicts.

Both Table 4-9 and Table 4-10 generally reflect lower exposure to conflicts with ACAS enabled than with ACAS disabled under clear conditions. This lower exposure for clear conditions is consistent for all subject groups and conflict intensity level categories. Furthermore, this result is statistically significant for the *all* subject group, low-intensity conflicts (MOP1 and MOP2), and high-intensity conflicts (MOP1 only).

Under adverse conditions, the rates of exposure to conflicts are higher with ACAS enabled than with ACAS disabled in 9 of the 13 subject group/conflict intensity level categories for which sufficient data were available to analyze. There are also no categories under adverse conditions that have statistically significant results. Driving in adverse conditions comprises only about 8 percent of driving and this lack of data likely contributes to the inconsistency and non-significance of the results for adverse conditions. As shown in Table 4-9 and Table 4-10, the number of subjects for adverse conditions is relatively few with 11 of 24 categories having less than 10 subjects.

Compared to baseline results for the aggregate of all driving, independent of driving condition (see Table 4-4), the rates of exposure to conflicts for clear conditions are generally similar; of the 48 subject group/conflict intensity level/ACAS Status categories, 29 are slightly higher, 7 are equal, and 12 are slightly less. For adverse conditions, the rates of exposure to conflicts are generally slightly higher than for aggregate driving; of 26 subject group/conflict intensity level/ACAS Status categories, 23 are slightly higher and 3 are slightly less.

Comparing clear to adverse driving conditions, it can be seen that exposures to conflicts for adverse are slightly higher in most (11 of 13) respective subject group/conflict intensity level/ ACAS Status categories.

For adverse conditions, there is no general reduction in exposure to conflicts with ACAS enabled. In fact, in 9 of 13 categories available for analysis, the conflict exposure rates increased with ACAS enabled under adverse conditions. In addition, even for the most robust category of *all* subjects, there is no reduction that is statistically significant. This contrasts with clear conditions, which does have a statistically significant reduction in exposure to conflicts with ACAS enabled for *all* subjects and there are no exceptions to this reduction in any categories. This suggests that ACAS might have less ability to reduce conflict exposure for adverse conditions than for clear conditions. This observation for adverse conditions, however, not being based on statistically significant results, should be interpreted with caution.

In conclusion, the results indicate that use of ACAS will reduce exposure to conflicts for drivers overall when driving in clear conditions. For driving in adverse conditions, reliable conclusions cannot be made regarding the ability of ACAS to reduce exposure to conflicts. Thus, it is desirable to obtain more driving in adverse weather conditions in future FOTs with and without crash avoidance systems even though it is hard to control for such conditions in FOT design.

Table 4-9. Low-Intensity Conflict Exposure Rates for ACAS-Disabled versus ACAS-Enabled by Weather Condition

		LOW INTENSITY											
		MOP1 (Conflicts/100Km)						**MOP2 (Near Crashes/100Km)**					
		Periods 1 and 2 ACAS Disabled		***Period 4 ACAS Enabled***				***Periods 1 and 2 ACAS Disabled***		***Period 4 ACAS Enabled***			
	Age and Gender	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**Subj**	**p**	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**Subj**	**p**
Clear	**All**	34.3	19.1	28.8	18.6	66	0.03	11.5	8.6	9.2	6.4	66	0.02
	Male	31.5	18.6	26.3	15.0	33	0.09	10.2	8.3	8.0	4.8	33	0.08
	Female	37.1	19.4	31.4	21.6	33	0.18	12.7	8.8	10.4	7.5	33	0.13
	Younger	35.0	21.6	27.6	18.8	22	0.07	11.9	10.5	9.3	6.7	22	0.15
	Middle	38.4	14.1	34.4	17.5	22	0.35	12.8	5.9	11.0	5.5	22	0.20
	Older	29.6	20.4	24.5	19.0	22	0.33	9.6	8.8	7.4	6.6	22	0.22
Adverse	**All**	37.4	28.2	41.7	39.9	40	0.49	15.0	15.5	16.8	19.9	23	0.73
	Male	34.8	28.2	36.3	30.7	24	0.83	14.5	18.2	13.2	12.6	14	0.81
	Female	41.4	28.8	49.7	50.9	16	0.48	15.8	11.0	22.4	27.8	9	0.49
	Younger	33.8	25.2	48.4	48.1	14	0.21	9.5	10.1	19.1	26.7	8	0.24
	Middle	46.6	31.2	42.2	38.5	17	0.68	19.5	19.6	17.4	17.6	11	0.81
	Older	25.8	23.5	30.1	28.6	9	0.57						

Table 4-10. High-Intensity Conflict Exposure Rates for ACAS-Disabled versus ACAS-Enabled by Weather Condition

		HIGH INTENSITY											
		MOP1 (Conflicts/100Km)						**MOP2 (Near Crashes/100Km)**					
		Periods 1 and 2 ACAS Disabled		***Period 4 ACAS Enabled***				***Periods 1 and 2 ACAS Disabled***		***Period 4 ACAS Enabled***			
	Age and Gender	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**Subj**	**p**	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**Subj**	**p**
Clear	**All**	18.9	12.0	15.7	10.2	66	0.03	2.7	2.4	2.1	1.5	64	0.06
	Male	17.0	11.9	14.3	8.5	33	0.16	2.2	1.8	1.8	1.0	32	0.38
	Female	20.8	11.9	17.0	11.6	33	0.12	3.2	2.8	2.4	1.9	32	0.09
	Younger	19.0	13.5	14.9	10.2	22	0.11	3.0	3.4	2.2	1.6	21	0.16
	Middle	21.0	8.9	18.4	8.5	22	0.26	2.8	1.5	2.6	1.3	22	0.55
	Older	16.7	13.2	13.7	11.4	22	0.33	2.3	2.1	1.7	1.6	21	0.27
Adverse	**All**	20.8	19.8	22.0	23.1	33	0.79	5.8	6.4	4.0	5.1	8	0.57
	Male	18.5	18.5	17.6	15.5	21	0.83						
	Female	24.8	22.1	29.7	31.9	12	0.66						
	Younger	18.1	22.3	26.5	27.7	14	0.33						
	Middle	19.7	19.8	19.9	20.2	17	0.97						
	Older												

ACAS Effect on Exposure to Driving Conflicts by Traffic Level (Low, Moderate, and Heavy)

This analysis determines if ACAS reduces the exposure of subjects to driving conflicts in low, moderate, and heavy traffic levels.

Both Table 4-11 and Table 4-12 generally illustrate lower exposure to conflicts with ACAS enabled than with ACAS disabled for low and moderate traffic levels. This lower exposure for low and moderate traffic is consistent for all subject groups and conflict intensity level categories. For low traffic levels, however, the lower exposure is not statistically significant. For moderate traffic levels, lower exposure is statistically significant for the following categories:

- *All* subject group, low-intensity conflicts (MOP1 and MOP2)
- *Female* subject group, low-intensity conflicts (MOP1 and MOP2) and high-intensity conflicts (MOP1 only)
- *Younger* subject group, low-intensity conflicts (MOP1 only)

Heavy traffic results are less consistent in terms of lower exposure to conflicts with ACAS enabled than with ACAS disabled. In 4 of the 19 subject group/conflict intensity level categories available for analysis, there are exceptions. However, there is statistically significant consistency with lower exposure for the category of *middle*-aged, low-intensity conflicts (MOP2 only) and high-intensity conflicts (MOP1 only). Driving in heavy traffic comprises only about 3 percent of driving and this lack of data resulted in 5 of the 24 categories having fewer than 10 subjects available for analysis.

Compared to baseline results for the aggregate of all driving, independent of driving condition (see Table 4-4), the results for low traffic generally show lower rates of exposure to conflicts with exceptions in 10 of 48 categories (all exceptions in the high-intensity near-crash category). The exposure rates for moderate traffic are higher than for aggregate driving in 47 of the 48 subject group/conflict intensity level/ACAS Status categories (one category is equal). For heavy traffic, the results show expected rates of exposure to conflicts that are much higher than aggregate driving in all categories available for analysis.

Comparing low, moderate, and heavy traffic results, it can be seen that, as expected, exposures to conflicts increase with increasing traffic levels for all respective subject group/conflict intensity level/ACAS Status categories. For low traffic levels, there is a consistent reduction in exposure to conflicts with ACAS enabled; however, even for the most robust category of *all* subjects, the reduction is not statistically significant. This lack of statistical significance may be attributed to the very low rates of exposure to conflicts encountered in low traffic levels. For moderate traffic levels, there are statistically significant reductions in exposure to conflicts with ACAS enabled for *all*, *female*, and *younger* subject groups and there are no exceptions to this reduction in any categories. For heavy traffic levels, there are also some statistically significant reductions in exposure to conflicts with ACAS enabled for *middle-age* subjects; however, there are exceptions to this reduction in 4 out of 19 categories involving *younger* and *older* drivers. These results suggest that ACAS has an ability to reduce conflict exposure for a wide range of traffic levels;

however, this ability might also vary by traffic level. Without statistically reliable results for all traffic levels, however, this observation should be interpreted with caution.

In conclusion, the results indicate that use of ACAS will reduce exposure to conflicts for drivers overall when driving in moderate traffic. The same conclusion can be made for low and heavy traffic levels, with somewhat less statistical confidence.

Table 4-11. Low-Intensity Conflict Exposure Rates for ACAS-Disabled versus ACAS-Enabled by Traffic Level

		LOW INTENSITY											
		MOP1 (Conflicts/100Km)						**MOP2 (Near Crashes/100Km)**					
		Periods 1 and 2 ACAS Disabled		***Period 4 ACAS Enabled***				***Periods 1 and 2 ACAS Disabled***		***Period 4 ACAS Enabled***			
	Age and Gender	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**Subj**	**p**	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**Subj**	**p**
Low Traffic	**All**	21.7	15.0	19.4	14.1	66	0.16	8.0	7.6	6.9	5.9	65	0.12
	Male	19.1	12.6	16.9	10.9	33	0.25	6.7	6.5	5.3	3.3	33	0.14
	Female	24.3	16.9	21.9	16.4	33	0.37	9.4	8.4	8.5	7.4	32	0.42
	Younger	21.8	17.5	20.1	16.4	22	0.51	8.3	10.0	7.7	7.1	22	0.69
	Middle	25.5	14.5	22.6	12.0	22	0.31	9.1	6.1	8.1	5.5	22	0.42
	Older	17.9	12.1	15.6	13.1	22	0.47	6.5	5.9	4.6	4.4	21	0.09
Moderate Traffic	**All**	53.7	27.0	45.1	29.1	66	0.02	17.7	11.3	14.0	10.3	64	0.01
	Male	49.2	23.3	45.4	22.9	33	0.40	15.6	11.0	13.9	9.2	32	0.38
	Female	58.3	30.0	44.8	34.5	33	0.02	19.8	11.4	14.1	11.4	32	0.01
	Younger	56.0	22.1	42.2	22.0	22	0.03	19.4	10.2	13.6	8.3	20	0.06
	Middle	55.9	30.3	50.3	28.9	22	0.21	18.6	11.1	15.8	8.7	22	0.13
	Older	49.2	28.6	42.7	35.3	22	0.44	15.3	12.5	12.5	13.1	22	0.30
Heavy Traffic	**All**	151.3	60.6	145.4	75.7	66	0.62	44.2	25.5	38.9	29.7	56	0.30
	Male	155.6	62.2	144.1	78.6	33	0.48	46.6	26.1	38.4	20.7	27	0.18
	Female	147.1	59.6	146.7	73.9	33	0.98	42.0	25.2	39.4	36.5	29	0.75
	Younger	133.5	49.9	163.5	89.4	22	0.20	40.6	29.3	42.9	22.0	17	0.78
	Middle	161.5	49.6	143.3	53.7	22	0.22	51.8	23.9	33.6	20.0	20	0.00
	Older	158.9	76.9	129.4	79.1	22	0.19	39.5	22.8	41.0	42.3	19	0.90

Table 4-12. High-Intensity Conflict Exposure Rates for ACAS-Disabled versus ACAS-Enabled by Traffic Level

		HIGH INTENSITY											
		MOP1 (Conflicts/100Km)						**MOP2 (Near Crashes/100Km)**					
		Periods 1 and 2 ACAS Disabled		***Period 4 ACAS Enabled***				***Periods 1 and 2 ACAS Disabled***		***Period 4 ACAS Enabled***			
	Age and Gender	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**Subj**	**p**	**Avg**	**Std Dev**	**Avg**	**Std Dev**	**Subj**	**p**
Low Traffic	**All**	13.4	10.7	11.7	9.0	66	0.12	2.7	2.4	2.2	1.9	60	0.07
	Male	11.3	9.0	9.7	6.0	33	0.19	2.1	1.6	1.7	1.1	31	0.20
	Female	15.4	11.9	13.7	10.9	33	0.36	3.4	2.8	2.8	2.4	29	0.20
	Younger	13.7	13.3	12.6	10.8	22	0.54	2.9	3.3	2.4	2.4	21	0.37
	Middle	15.3	9.5	13.4	7.4	22	0.28	2.8	1.5	2.6	1.7	22	0.57
	Older	11.0	8.7	9.1	8.1	22	0.36	2.4	2.0	1.6	1.4	17	0.11
Moderate Traffic	**All**	28.4	16.2	24.4	17.1	66	0.08	3.4	2.9	2.6	2.1	49	0.08
	Male	25.8	16.1	24.8	14.5	33	0.75	3.3	2.8	2.5	1.6	25	0.24
	Female	31.0	16.1	23.9	19.7	33	0.04	3.5	3.0	2.7	2.5	24	0.20
	Younger	28.1	12.9	22.1	13.0	22	0.12	3.2	3.3	2.2	1.6	15	0.30
	Middle	29.9	16.4	27.5	18.5	22	0.41	3.5	3.0	3.3	2.6	19	0.76
	Older	27.3	19.2	23.6	19.6	22	0.46	3.4	2.4	2.2	1.7	15	0.12
Heavy Traffic	**All**	62.4	31.8	59.6	36.6	62	0.68	10.7	8.1	6.3	4.4	12	0.17
	Male	63.9	30.0	59.5	31.0	30	0.58						
	Female	61.0	33.8	59.8	41.7	32	0.91						
	Younger	51.1	29.3	62.7	32.3	20	0.23						
	Middle	71.9	29.0	54.7	23.9	22	0.04						
	Older	63.3	34.9	62.0	50.8	20	0.93						

ACAS Effect on Exposure to Driving Conflicts by ACAS Vehicle Speed (< 25 mph, 25 mph to 35 mph, ≥ 35 mph)

This analysis determines if ACAS reduces the exposure of subjects to driving conflicts while driving at speeds of less than 25 mph, between 25 mph and 35 mph, and greater than or equal to 35 mph. The results are shown in Table 4-13 for low-intensity conflicts and Table 4-14 for high-intensity conflicts.

Table 4-13 and Table 4-14 indicate that ACAS has little effect on exposure to conflicts for vehicle speeds in the ranges of less than 25 mph, and between 25 mph and 35 mph. For the less than 25 mph speed range, the rate of conflicts decreases in only 11 of the 24 subject group/conflict intensity level categories with ACAS enabled. For the speed range between 25 mph and 35 mph, the rate of conflicts decreases in only 12 of the 24 subject group/conflict intensity level categories with ACAS enabled. An increase in exposure to conflicts with ACAS enabled is statistically significant for *younger* drivers for the less than 25 mph speed range. These results are not unexpected since ACAS is generally not functional below 25 mph and ACC is generally not used below 35 mph. The exposure analysis results of the previous section indicate that FCW is operational only 4 percent and 73 percent of vehicle distance traveled in the less than 25 mph, and the 25 mph and 35 mph speed ranges, respectively. The ACC system is used for only 1 percent of vehicle distance traveled in the 25 mph and 35 mph speed range.

For the 35 mph and greater speed range, the results show overall reduced exposure to conflicts with ACAS enabled. This reduction in exposure is statistically significant for the following categories:

- *All* subject group, low-and high-intensity conflicts (MOP1 and MOP2)
- *Female* subject group, low-intensity conflicts (MOP1 and MOP2) and high-intensity conflicts (MOP1 only)

Compared to baseline results for the aggregate of all driving, independent of driving condition (see Table 4-4), the results for the two lower speed ranges generally show considerably higher rates of exposure to conflicts. These higher rates of exposure may be attributed to higher traffic densities encountered at lower speeds. The opposite effect can be seen at speeds at or above 35 mph where the exposure rates are lower than for aggregate driving. These lower rates of exposure may be attributed to lower traffic densities encountered at higher speeds.

Comparing results for the three speed ranges, it can be seen that, as expected, exposures to conflicts decrease with increasing vehicle speed for all respective subject group/conflict intensity level/ACAS Status categories. There is a consistent reduction in exposure to conflicts with ACAS enabled only for the greater than or equal to 35-mph speed range. As noted above, these reductions are statistically significant for *all* and *female* subject groups. These results suggest that ACAS has an ability to reduce exposure to conflicts in driving situations that involve speeds of or greater than 35 mph. Comparing the less than 25-mph range to the 25-mph to 35-mph range, the results are similar and indicate that ACAS has little or no impact on exposure to conflicts. Since FCW is essentially not active in the less than 25-mph range, but is active about 73 percent of VDT in the 25-mph to 35-mph range, the results suggest that FCW has negligible ability to reduce exposure to conflicts in the 25-mph to 35-mph range (ACC is essentially not active in either speed range).

In conclusion, the results indicate that use of ACAS will reduce exposure to conflicts for drivers overall when driving in situations where speeds are greater than or equal to 35 mph. At speeds less than 25 mph, ACAS is essentially inactive and has no impact on exposure to conflicts. In the 25-mph to 35-mph range, the results suggest a negligible, but not statistically significant, ability of FCW to reduce exposure to conflicts.

Table 4-13. Low-Intensity Conflict Exposure Rates for ACAS-Disabled versus ACAS-Enabled by ACAS Vehicle Speed

	Age and Gender	*LOW INTENSITY*											
		MOP1 (Conflicts/100Km)						MOP2 (Near Crashes/100Km)					
		Periods 1 and 2 ACAS Disabled		*Period 4 ACAS Enabled*				*Periods 1 and 2 ACAS Disabled*		*Period 4 ACAS Enabled*			
		Avg	Std Dev	Avg	Std Dev	Subj	p	Avg	Std Dev	Avg	Std Dev	Subj	p
Less than 25 mph	All	188.6	62.1	193.7	59.0	66	0.54	59.6	33.2	61.6	32.1	66	0.63
	Male	186.9	68.3	192.4	47.5	33	0.65	58.3	35.4	63.2	32.9	33	0.50
	Female	190.3	56.2	195.1	69.2	33	0.69	60.8	31.2	60.0	31.6	33	0.85
	Younger	185.8	61.4	223.1	68.5	22	0.04	59.5	39.9	76.6	36.4	22	0.09
	Middle	210.2	52.1	196.0	41.7	22	0.15	67.7	27.4	62.8	27.8	22	0.29
	Older	169.8	67.6	162.1	48.7	22	0.59	51.5	30.4	45.5	24.0	22	0.34
25 mph to 35 mph	All	104.0	42.4	105.1	33.1	66	0.82	35.5	23.3	34.2	18.0	64	0.61
	Male	100.2	38.1	98.7	27.2	33	0.81	32.5	19.7	30.5	13.7	32	0.48
	Female	107.8	46.6	111.4	37.5	33	0.58	38.4	26.4	38.0	21.0	32	0.91
	Younger	113.1	48.9	119.8	33.0	22	0.50	39.8	29.5	40.4	18.2	22	0.92
	Middle	107.3	35.2	109.9	32.1	22	0.63	39.6	19.5	37.0	17.8	21	0.40
	Older	91.7	40.9	85.5	25.0	22	0.43	26.7	17.1	25.0	14.7	21	0.62
Greater than or equal to 35 mph	All	10.8	7.8	8.5	5.9	66	0.007	3.8	3.3	2.9	2.2	65	0.01
	Male	9.5	6.9	8.2	5.2	33	0.21	3.2	3.2	2.6	1.8	32	0.24
	Female	12.1	8.5	8.8	6.5	33	0.02	4.4	3.4	3.2	2.5	33	0.02
	Younger	11.6	9.0	9.1	4.7	22	0.08	3.8	3.7	3.2	2.4	22	0.35
	Middle	12.5	6.6	10.1	4.6	22	0.08	4.3	2.4	3.5	1.9	22	0.06
	Older	8.4	7.1	6.2	5.7	22	0.22	3.3	3.8	2.0	2.1	21	0.10

Table 4-14. High-Intensity Conflict Exposure Rates for ACAS-Disabled versus ACAS-Enabled by ACAS Vehicle Speed

		HIGH INTENSITY											
		MOP1 (Conflicts/100Km)						MOP2 (Near Crashes/100Km)					
		Periods 1 and 2 ACAS Disabled		*Period 4 ACAS Enabled*				*Periods 1 and 2 ACAS Disabled*		*Period 4 ACAS Enabled*			
	Age and Gender	Avg	Std Dev	Avg	Std Dev	Subj	p	Avg	Std Dev	Avg	Std Dev	Subj	p
Less than 25 mph	All	89.0	39.4	93.1	38.6	66	0.48	10.2	7.8	10.7	10.1	47	0.76
	Male	85.9	41.4	95.8	40.9	33	0.31	10.5	7.5	10.0	7.3	23	0.69
	Female	92.1	37.6	90.4	36.5	33	0.80	9.9	8.2	11.3	12.3	24	0.61
	Younger	89.0	40.4	111.9	48.8	22	0.10	9.5	7.7	13.2	14.4	16	0.38
	Middle	98.2	30.6	91.6	25.6	22	0.24	12.5	9.9	11.9	9.2	15	0.73
	Older	79.7	45.3	75.7	29.6	22	0.66	8.7	5.2	7.0	2.4	16	0.16
25 mph to 35 mph	All	59.0	27.6	59.0	21.1	65	0.98	8.0	6.8	9.1	10.3	51	0.51
	Male	55.1	25.1	53.7	15.6	33	0.69	6.9	5.3	9.3	10.4	24	0.25
	Female	63.1	29.7	64.4	24.6	32	0.78	9.0	7.9	8.9	10.5	27	0.94
	Younger	64.6	33.7	66.7	21.4	22	0.74	9.6	8.7	11.4	11.7	19	0.57
	Middle	60.2	22.6	61.2	18.0	22	0.77	7.2	5.1	7.0	4.9	19	0.84
	Older	52.0	24.9	48.5	20.2	21	0.48	6.9	5.9	8.8	13.7	13	0.68
Greater than or equal to 35 mph	All	6.8	5.0	5.2	3.7	66	0.01	1.7	1.4	1.3	1.0	60	0.05
	Male	5.9	4.8	5.1	3.3	33	0.28	1.4	1.3	1.1	0.8	29	0.35
	Female	7.7	5.1	5.4	4.0	33	0.01	1.9	1.4	1.4	1.1	31	0.08
	Younger	6.5	5.3	5.5	4.1	22	0.26	1.7	1.7	1.5	1.1	20	0.67
	Middle	7.9	4.2	6.2	2.9	22	0.06	1.8	1.0	1.4	1.0	20	0.13
	Older	5.9	5.4	3.9	3.6	22	0.10	1.5	1.4	0.9	0.7	20	0.05

Summary – Impact of ACAS on Driver Exposure to Conflicts

For the aggregate of all drivers and driving conditions, the results generally show a consistent reduction in driver exposure to conflicts when ACAS is enabled. This result is statistically significant. These results indicate that use of ACAS will reduce exposure to conflicts for drivers and driving conditions overall.

The effect of ACAS is to shift the distribution of conflict rates among all drivers to a lower average; e.g., no subjects with ACAS enabled have rates greater than 70 conflicts per 100 Km; whereas, 5 percent of subjects with ACAS disabled have rates greater than 70 conflicts per 100 Km.

The results indicate that use of ACAS will reduce exposure to conflicts for drivers overall under the following conditions:

- Light
- Freeways
- Clear
- Moderate traffic
- Speeds greater than or equal to 35 mph

ACAS also appears to have some ability to reduce exposure to conflicts in conditions of dark, non-freeways, adverse weather, and low and heavy traffic levels; however, the results are not reliable.

The results also suggest that that ACAS has an ability to reduce conflict exposure for a wide range of traffic levels; however, this ability might decline at higher traffic levels.

At speeds less than 25 mph, ACAS is essentially inactive and has no impact on exposure to conflicts. In the 25-mph to 35-mph range, the results suggest a negligible ability of FCW to reduce exposure to conflicts (this result is not statistically significant).

4.2.1.3 ACAS Effectiveness in Reducing Exposure to Driving Conflicts

The previous section investigated the ability of ACAS to reduce the exposure of drivers to conflicts by comparing the exposure rates (conflicts per VDT) between ACAS-Disabled and ACAS-Enabled test periods. The analysis in this section extends the previous section by quantifying the ability of ACAS to reduce exposure to conflicts. This section estimates the ACAS exposure effectiveness, EE in Equation 4. This metric is a useful and intuitive measure that facilitates comparisons of ACAS performance between subject groups, driving conditions, and conflict intensity levels. Results of ACAS exposure effectiveness are presented below based on aggregate data and based on driver average statistics.

Exposure Effectiveness Results Based on Aggregate Data

ACAS exposure effectiveness results based on aggregate data are presented following the same pattern as in the previous section. First, EE values are presented for overall driving, independent of driving condition. The overall results compare EE for ACAS disabled versus ACAS-enabled Periods 3 and 4 as well as Period 4 only. The EE values are further disaggregated by the 6 subject groups. Next, EE values are presented for the conditions of ambient light, road type, weather, traffic level, and travel speed by the 6 subject groups. The EE values presented here are computed on the basis of averaging overall population data; i.e., the underlying conflict exposure rates are computed by summing the conflicts for all drivers and dividing by the sum of distances traveled by all drivers. This approach provides the largest possible data set for analysis; however, it is more subject to bias by individual drivers.

Figure 4-4 through Figure 4-7 compare EE results using ACAS-Enabled Periods 3 and 4 versus Period 4 only for each of the four conflict intensity levels respectively. Each figure further breaks down the results by the six subject groups. Positive values of EE indicate a reduction in exposure to driving conflicts while negative values refer to an increase. It should be noted that the *all* group includes the largest data set and is most representative of overall driving.

Comparing the results for the two ACAS-Enabled periods shows that the EE for Period 4 only is generally higher than for both Periods 3 and 4 for all conflict intensity levels. This may be attributed to the negative effects of experimentation that appears to occur among drivers predominately during Period 3 as discussed in Section 4.2.1.1. The results for Periods 3 and 4 are therefore not considered representative of long-term driving behavior.

The *all* group, for Period 4, shows a consistent level of EE for all conflict intensity levels of 21 percent. Compared to the *all* group, the other subject groups show considerable variation in EE. The highest levels of EE are among *females*; the lowest levels of EE are among *males*. The level of EE increases with increasing age group.

Comparing the subject group results for different conflict intensity levels shows that the pattern of EE values is similar regardless of conflict intensity level for Period 4 only as well as Periods 3 and 4. The results for Periods 3 and 4 are generally lower than for Period 4 only and, in fact, are negative for *males* and *younger* drivers for the higher conflict intensity levels. As discussed earlier, the results for Periods 3 and 4 are not considered reliable indicator of long-term driving behavior.

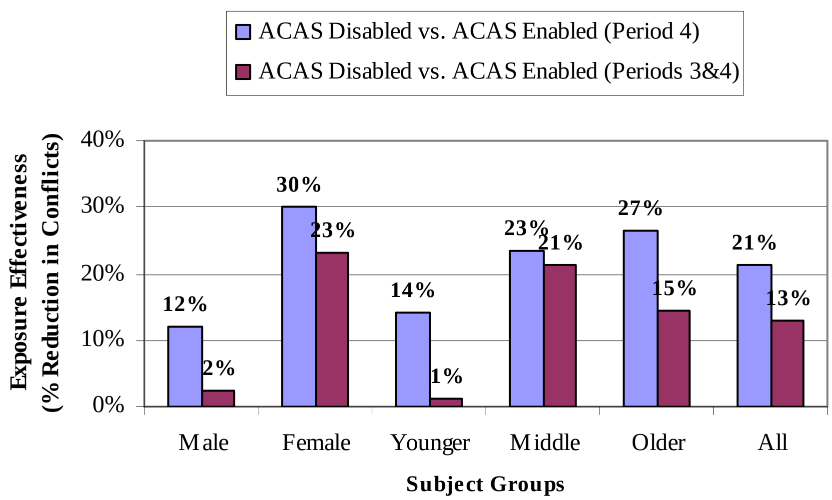


Figure 4-4. **Exposure Effectiveness, Low-Intensity Conflicts, Period 4 versus Periods 3 and 4**

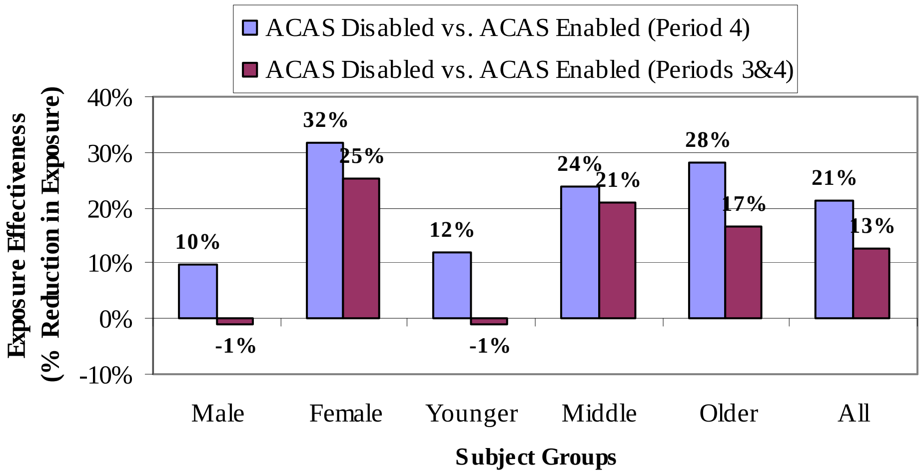


Figure 4-5. Exposure Effectiveness, High-Intensity Conflicts, Period 4 versus Periods 3 and 4

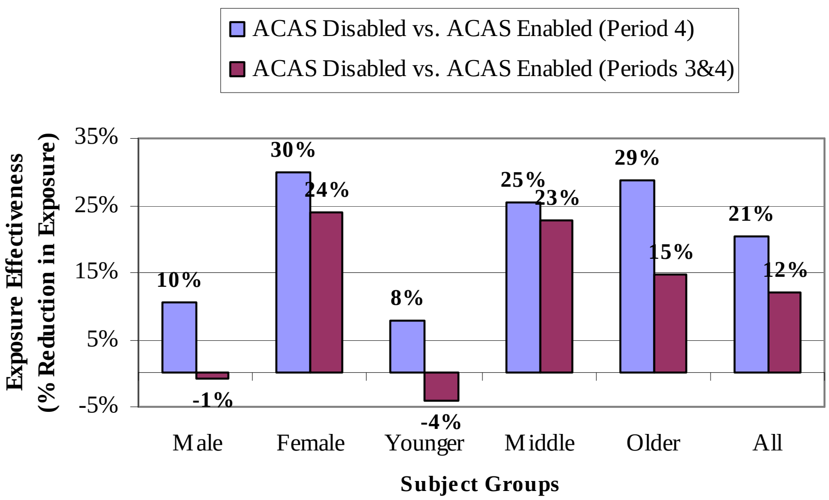


Figure 4-6. Exposure Effectiveness, Low-Intensity Near-Crashes, Period 4 versus Periods 3 and 4

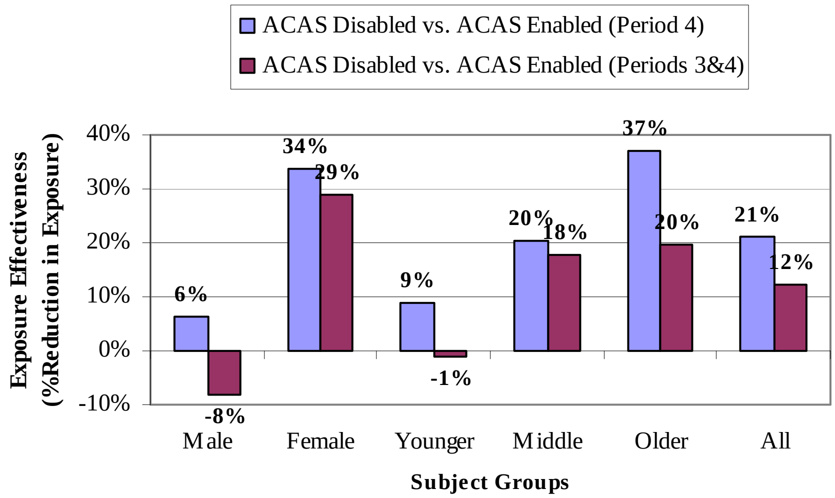


Figure 4-7. **Exposure Effectiveness, High-Intensity Near-Crashes, Period 4 versus Periods 3 and 4**

<u>Exposure Effectiveness Results by Ambient Light Conditions (Light and Dark)</u>:

Figure 4-8 through Figure 4-11 below compare EE results for driving in light and dark conditions for each of the four conflict intensity levels respectively (ACAS-Disabled versus ACAS-Enabled Period 4 only). EE results for light and dark show that, overall, there is generally higher EE for light than for dark conditions. EE for the *all* group is about 24 percent for light versus about 11 percent for dark and this is consistent for all intensity levels. There is, however, some variation in EE between light and dark for the subject groups. For all conflict intensity levels, the *younger* group has a much higher EE for dark than light and the *male* group has a much lower EE for dark than light. The *older* and *female* groups have a slightly higher EE for dark than light for some conflict intensity levels. Some of this variation by subject groups may be attributed to less data available for dark driving. Only about 26 percent of driving is done during dark conditions.

Comparing EE between the subject groups for light conditions shows a similar pattern for all conflict intensity levels. The *all* group shows a consistent level of EE for all conflict intensity levels of about 24 percent. Compared to the *all* group, the other subject groups show considerable variation in EE, but the pattern is consistent regardless of conflict intensity level. The highest levels of EE are among *females*; the lowest levels of EE are among *males*. The level of EE generally increases with increasing age group (a minor exception is *older* being about equal to *middle-age* for low-intensity near-crashes).

The EE results for light and dark conditions agree well with similar results for aggregate driving, independent of other conditions, as shown in Figure 4-4 through Figure 4-7 (ACAS-Enabled Period 4 only). In most cases, as expected, the EE values for light and dark bracket the corresponding EE value for the respective subject group and conflict intensity level. In those few cases where there are exceptions to this, the exceptions are minor and most likely due to an inability to sort all data by the condition being investigated.

The EE results show two anomalies that were noted above; namely, for all intensity levels, the *male* group has a much lower EE for dark conditions (in one case negative) and the *younger* group has a higher EE for dark conditions. The EE results suggest a much lower ability of ACAS to reduce exposure to conflicts for *male* drivers in dark conditions. These results also suggest a greater ability of ACAS to reduce exposure to conflicts for *younger* drivers in dark conditions.

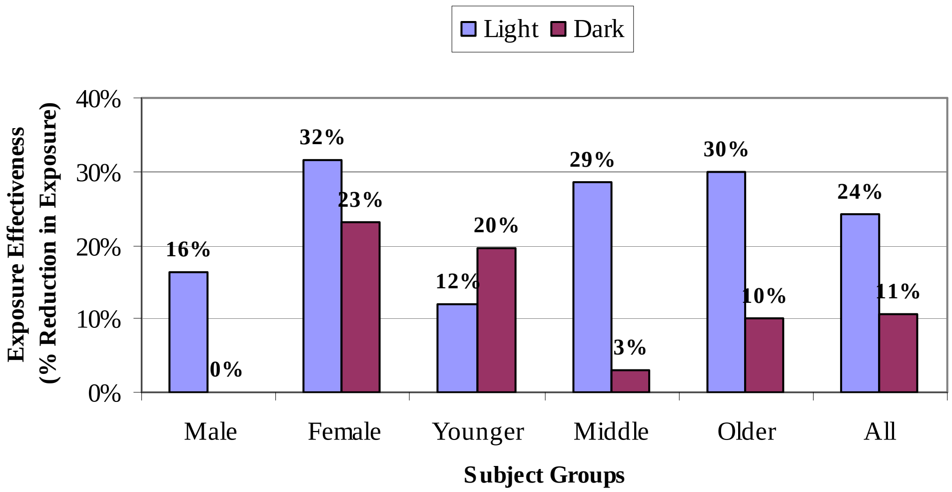


Figure 4-8. Exposure Effectiveness, Low-Intensity Conflicts, Light versus Dark

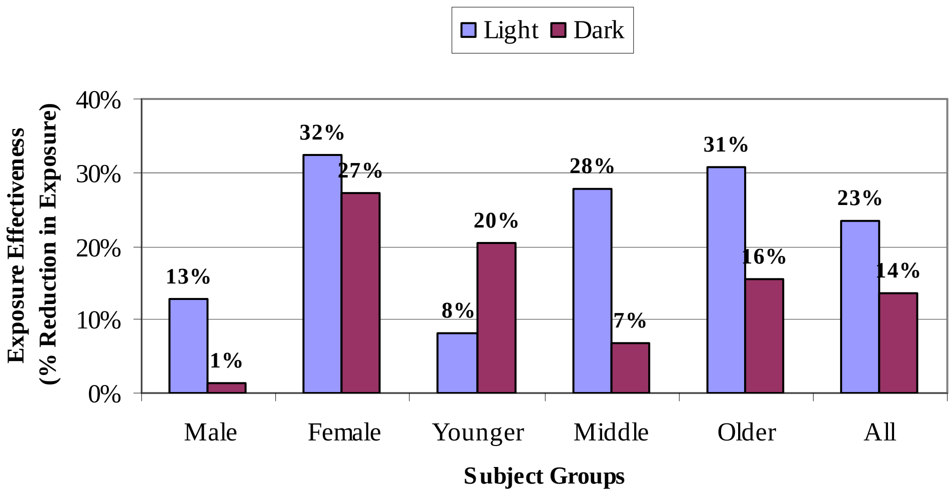


Figure 4-9. Exposure Effectiveness, High-Intensity Conflicts, Light versus Dark

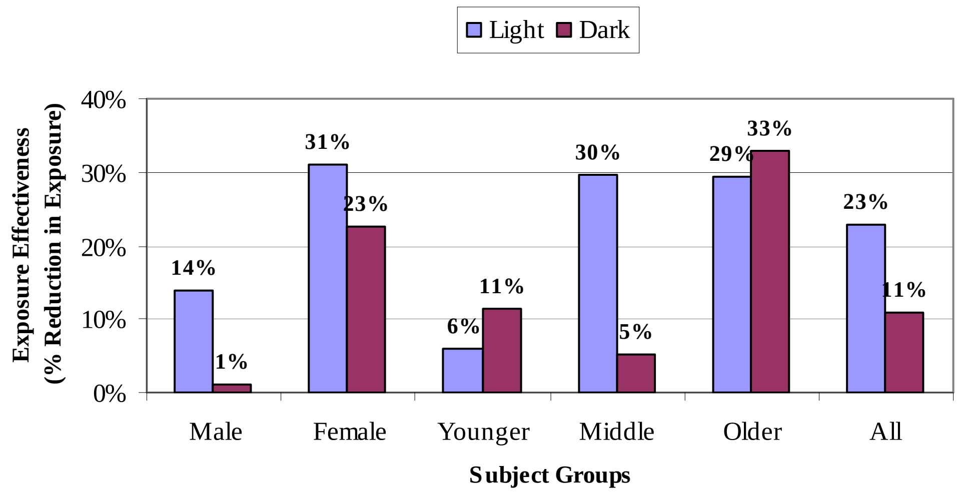


Figure 4-10. **Exposure Effectiveness, Low-Intensity Near-Crashes, Light versus Dark**

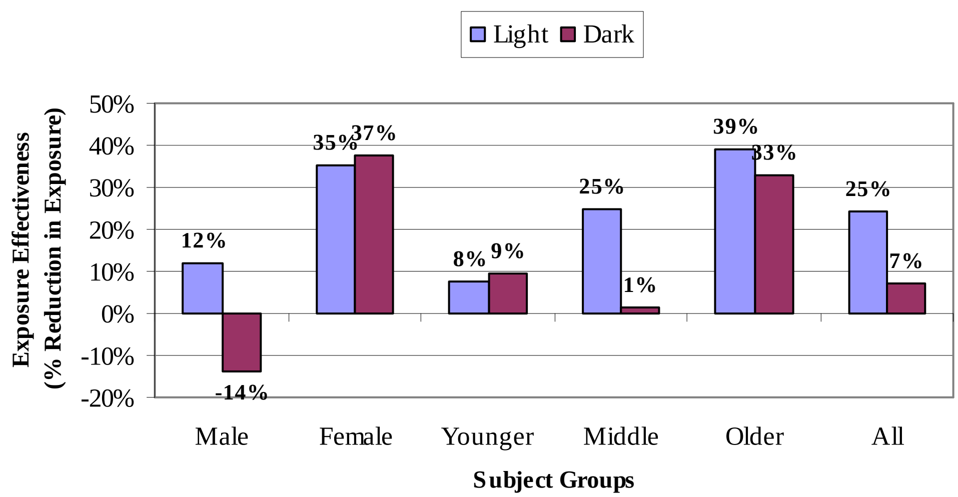


Figure 4-11. **Exposure Effectiveness, High-Intensity Near-Crashes, Light versus Dark**

Exposure Effectiveness Results by Road Type (Freeway and Non-Freeway):

Figure 4-12 through Figure 4-15 compare EE results for driving on freeways and non-freeways for each of the four conflict intensity levels respectively (ACAS-Disabled versus ACAS-Enabled Period 4 only). EE results for freeways and non-freeways show that, overall, there is generally a much higher EE for freeways than for non-freeways conditions. EE for the *all* group, across all conflict intensity levels, averages about 33 percent for freeways versus about 6 percent for non-freeways and these higher EE results are consistent for all intensity levels. There is, however, some variation between freeways and non-freeways for the subject groups. The *older* group has a much lower EE for freeways than non-freeways for all conflict intensity levels, the *male* group also has a lower EE (negative) for freeways for high-intensity near-crashes, and the *younger* group has much lower (negative) EE values for non-freeways for all conflict intensity levels. Some of this variation by subject group may be attributed to small data sets on freeways, especially for *older* drivers at all but the lowest conflict intensity level and for *males* at highest conflict intensity level.

Comparing EE results between the subject groups for freeways shows a similar pattern for all conflict intensity levels. The *all* group shows a consistent level of EE for all conflict intensity levels between 25 percent and 44 percent. The other subject groups show considerable variation in EE, but there is generally a consistent pattern regardless of conflict intensity level. The highest levels of EE are among *females* and *middle-age drivers*; *females* have a higher EE than *males*. The level of EE increases from *younger* to *middle age*, but the lowest levels of EE overall are among *older* drivers.

The EE results for freeways and non-freeways generally agree well with similar results for aggregate driving, independent of other conditions, as shown in Figure 4-4 through Figure 4-7 (ACAS-Enabled Period 4 only). In most cases, as expected, EE values for freeways and non-freeways bracket the corresponding EE value for the respective subject group and conflict intensity level. In two cases there are exceptions to this: the *older* group has a much lower than expected EE for freeways (in one case negative) and the *male* group has a lower than expected (negative) EE for freeways for high-intensity near-crashes. These exceptions may be attributed to very small data sets available for *older* drivers and *males* at the higher conflict intensity levels. This lack of data is due to very low exposure rates to higher intensity conflicts on freeways.

The EE results show three anomalies that were noted above; namely, for all intensity levels, the *older* group has a much lower EE (in one case negative) for freeways, the *male* group has a lower, negative EE for freeways for high-intensity near-crashes, and the *younger* group has much lower (negative) EE values for non-freeways for all conflict intensity levels. EE results suggest some ability of ACAS to reduce exposure to conflicts for *older* drivers on freeways for low-intensity conflicts. For all higher conflict intensity levels, however, there is insufficient *older* driver data to analyze. Similarly, in the one category where *male* drivers have a negative EE for freeways, there are insufficient data to analyze. As indicated above, this lack of data is likely due to very low conflict exposure rates on freeways. For *younger* drivers, EE results are consistent in suggesting a negative ability of ACAS to reduce exposure to conflicts at all but the highest conflict intensity level. These results for *younger* drivers should be viewed with some caution.

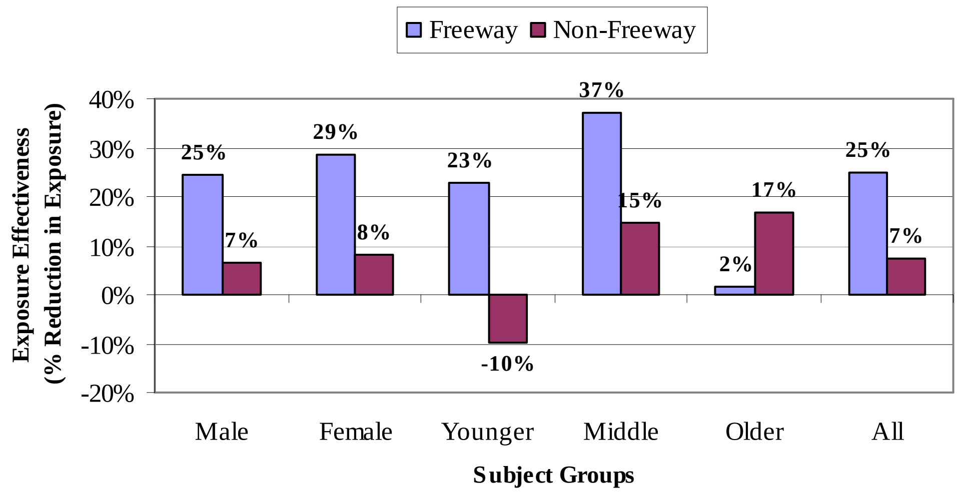


Figure 4-12. **Exposure Effectiveness, Low-Intensity Conflicts, Freeway versus Non-Freeway**

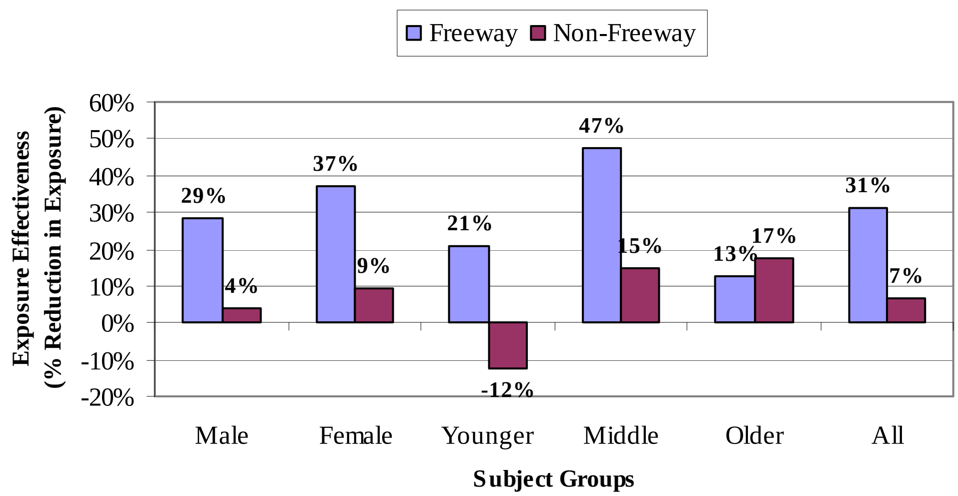


Figure 4-13. **Exposure Effectiveness, High-Intensity Conflicts, Freeway versus Non-Freeway**

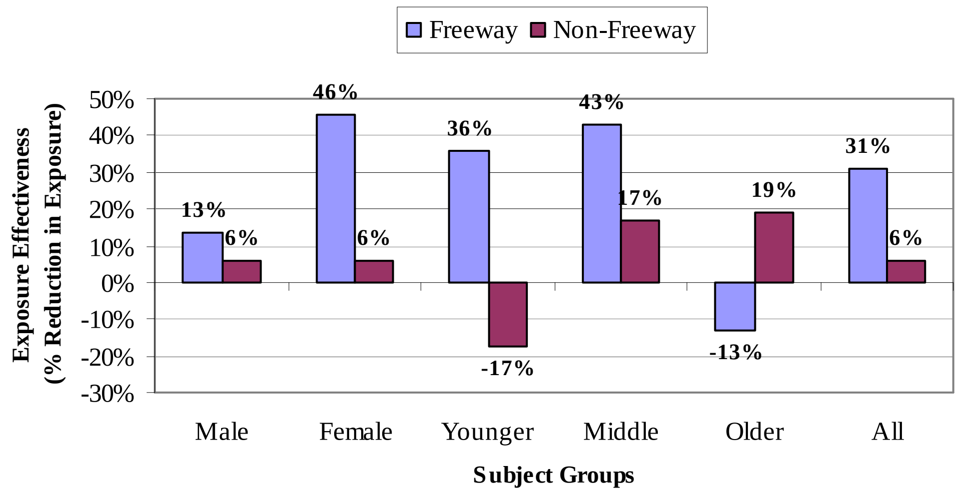


Figure 4-14. **Exposure Effectiveness, Low-Intensity Near-Crashes, Freeway versus Non-Freeway**

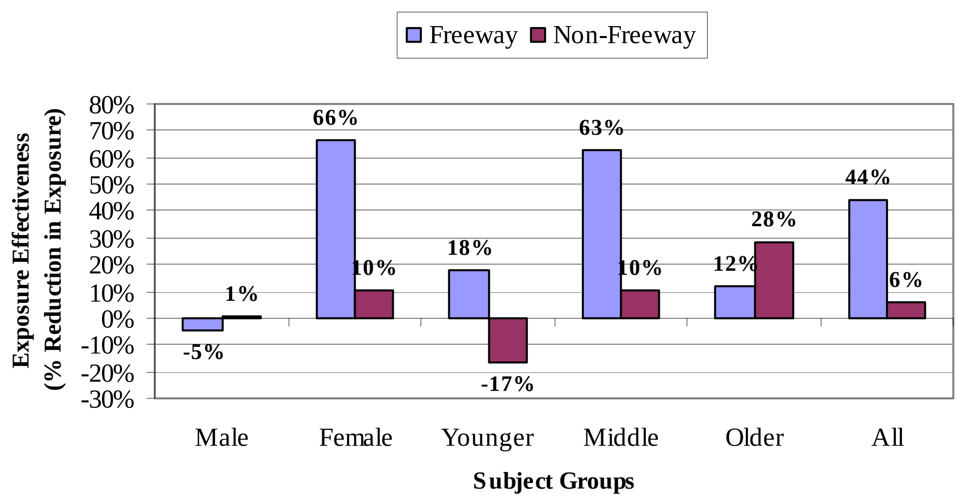


Figure 4-15. **Exposure Effectiveness, High-Intensity Near-Crashes, Freeway versus Non-Freeway**

Exposure Effectiveness Results by Weather Conditions (Clear and Adverse):

Figure 4-16 through Figure 4-19 compare EE results for driving in clear and adverse weather conditions for each of the four conflict intensity levels respectively (ACAS-Disabled versus ACAS-Enabled Period 4 only). Weather was classified as either clear or adverse as determined by activation of the windshield wipers. EE results for clear and adverse weather show that, overall, there are generally higher EE values for clear than for adverse weather for all conflict intensity levels. EE for the *all* group is about 21 percent for clear versus about 18 percent for adverse and this result is consistent for all intensity levels. There is, however, considerable variation between clear and adverse for the different subject groups. For all conflict intensity levels, the *younger* and *older* groups have a much lower EE for adverse than clear and the *middle-age* group has a much higher EE for adverse than clear. The *female* and *male* groups also have a higher EE for adverse than clear for several conflict intensity levels. Some of this variation by subject group may be attributed to less data available for driving in adverse weather. Only about 8 percent of driving is done during adverse weather.

Comparing EE results between the subject groups for clear weather shows a similar pattern for all conflict intensity levels. The *all* group shows a consistent level of EE for all conflict intensity levels of about 21 percent. Compared to the *all* group, the other subject groups show considerable variation in EE, but the pattern is consistent regardless of conflict intensity level. The highest levels of EE are among *females*; the lowest levels of EE are among *males*. The level of EE increases with increasing age group.

The EE results for clear and adverse generally agree well with similar results for aggregate driving, independent of other conditions, as shown in Figure 4-4 through Figure 4-7 (ACAS-Enabled Period 4 only). In all cases, as expected, the EE values for clear and adverse generally bracket the corresponding EE value for the respective subject group and conflict intensity level. In 6 of the 24 subject group/conflict intensity level categories, the EE value for clear approximately equals the corresponding EE value for aggregate driving. These cases are most likely due to the small amounts of data available for adverse driving.

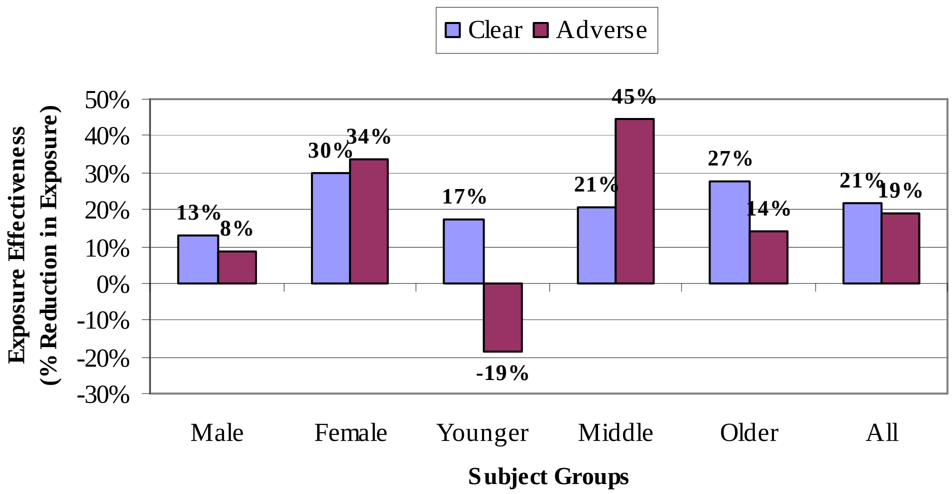


Figure 4-16. **Exposure Effectiveness, Low-Intensity Conflicts, Clear versus Adverse Weather**

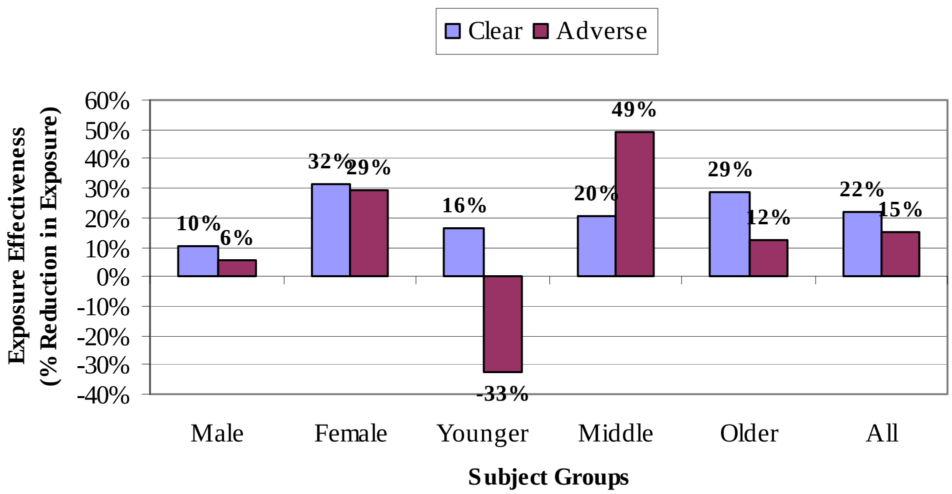


Figure 4-17. **Exposure Effectiveness, High-Intensity Conflicts, Clear versus Adverse Weather**

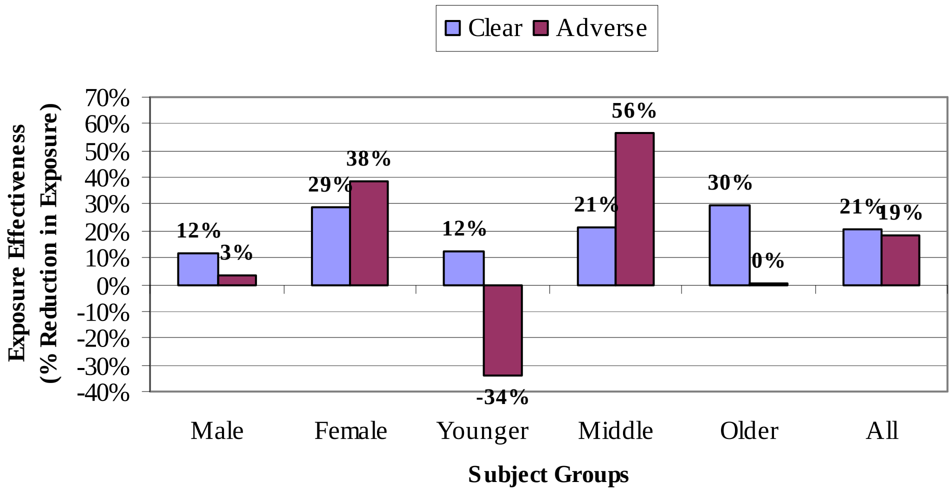


Figure 4-18. **Exposure Effectiveness, Low-Intensity Near-Crashes, Clear versus Adverse Weather**

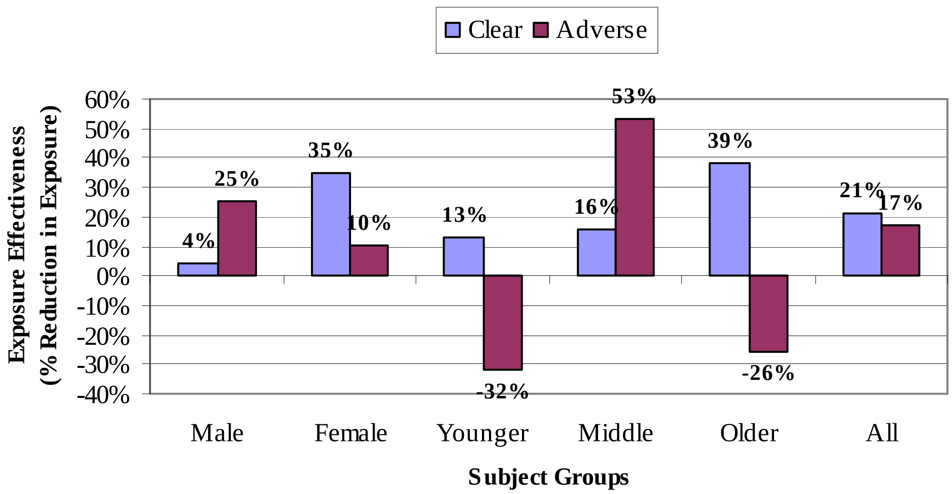


Figure 4-19. **Exposure Effectiveness, High-Intensity Near-Crashes, Clear versus Adverse Weather**

Exposure Effectiveness Results by Traffic Level (Low, Moderate, and Heavy):

Figure 4-20 through Figure 4-23 compare EE results for driving in low, moderate, and heavy traffic conditions for each of the four conflict intensity levels respectively (ACAS-Disabled versus ACAS-Enabled Period 4 only). EE results for low, moderate, and heavy traffic show that, overall, there are generally higher EE values for moderate than for low traffic for all conflict intensity levels. EE for the *all* group is about 21 percent for moderate versus about 16 percent for low traffic and this result is consistent for all intensity levels. The EE values for the *all* group for heavy traffic are generally about the same as for low traffic, 15 percent, but for high-intensity near-crashes, the value is 41 percent. The EE values for heavy traffic in the high-intensity near-crash category, however, are not considered reliable because very little data were available for analysis. There is considerable variation in EE results between traffic levels for the subject groups, most notably, for *younger* drivers who have a relatively low EE value for low traffic, a relatively high value for moderate traffic, and the lowest, negative values for heavy traffic. Some of this variation for the *younger* group may be attributed to less data available for driving in heavy traffic. Only about 3 percent of vehicle distance traveled is done in heavy traffic.

Comparing EE results between the subject groups for low and moderate traffic shows a similar pattern for most conflict intensity levels. The *all* group shows a consistent level of EE for all conflict intensity levels of about 16 percent for low traffic and 21 percent for moderate traffic. Compared to the *all* group, the other subject groups show considerable variation in EE, but the pattern is generally consistent regardless of conflict intensity level. The highest levels of EE are among *females* and *older* groups; the lowest levels of EE are among *males*. The level of EE increases with increasing age group for low traffic levels. For moderate traffic levels, *female* drivers have the highest EE values for all conflict intensity levels. The EE values for *younger* drivers for moderate traffic are relatively high (about 26 percent).

The EE results for low, moderate, and heavy traffic conditions generally agree with similar results for aggregate driving, independent of other conditions, as shown in Figure 4-4 through Figure 4-7 (ACAS-Enabled Period 4 only). In most cases, as expected, the EE values for low, moderate, and heavy traffic generally bracket the corresponding EE value for the respective subject group and conflict intensity level. There are a number of minor exceptions to this, however. These exceptions may be attributed to very small data sets available for heavy traffic, especially at the high-intensity near-crash level.

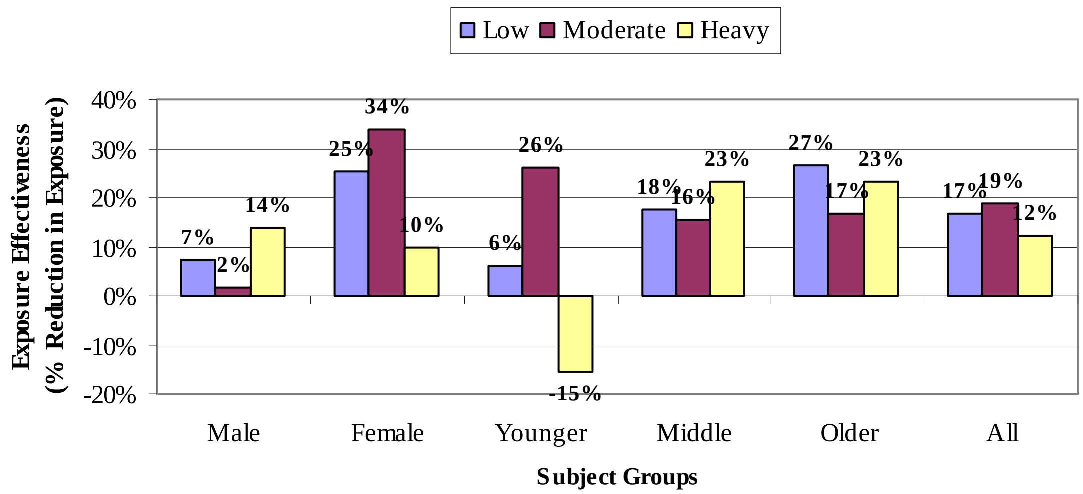


Figure 4-20. **Exposure Effectiveness for Low-Intensity Conflicts by Traffic Level**

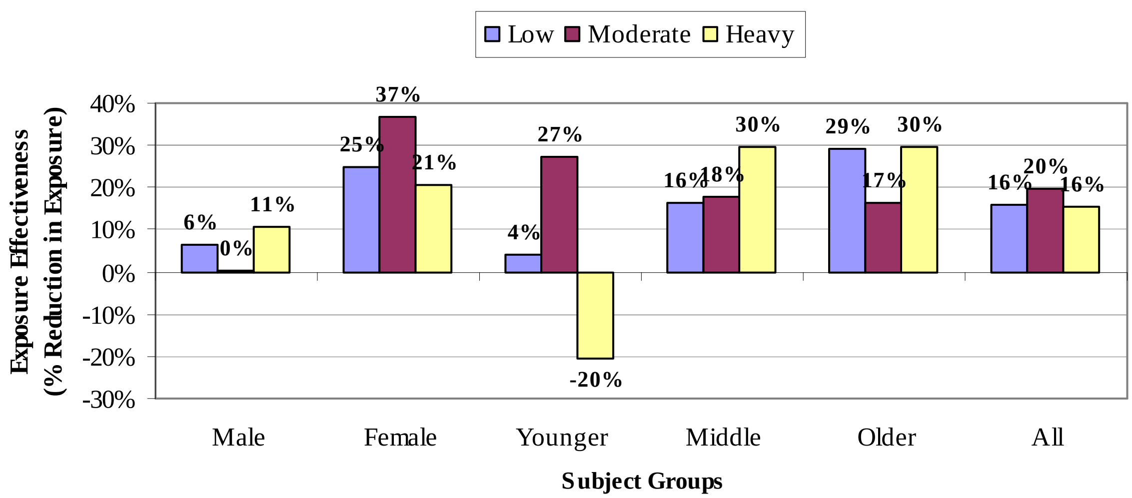


Figure 4-21. **Exposure Effectiveness for High-Intensity Conflicts by Traffic Level**

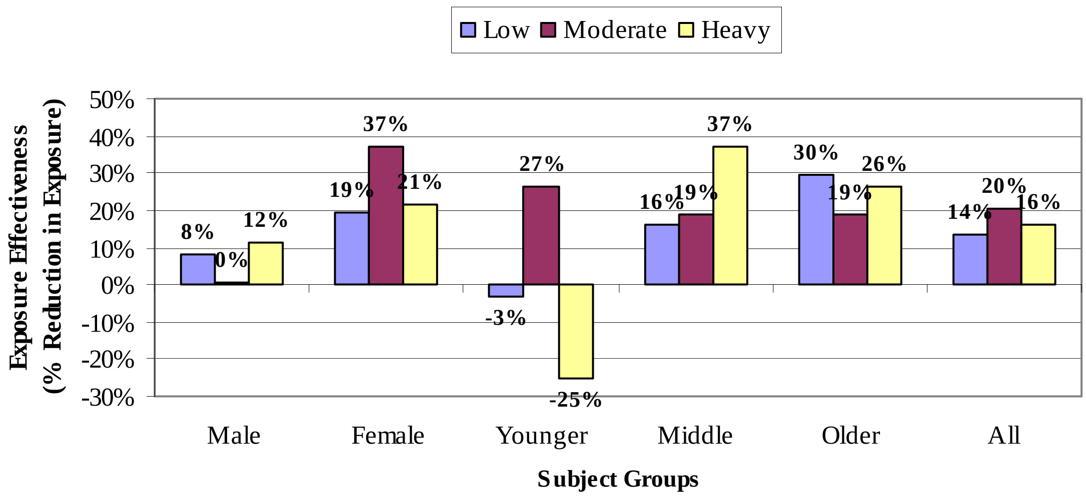


Figure 4-22. **Exposure Effectiveness for Low-Intensity Near-Crashes by Traffic Level**

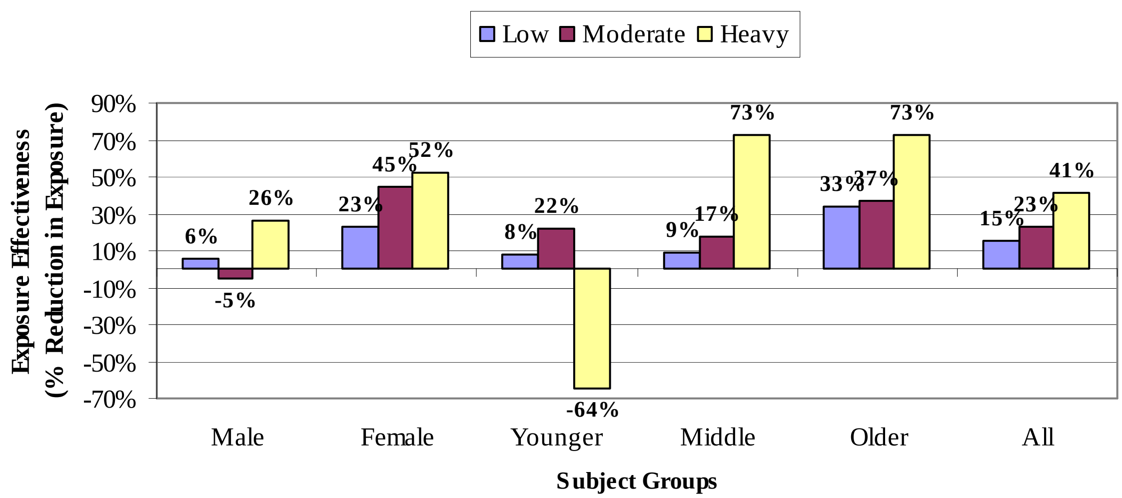


Figure 4-23. **Exposure Effectiveness for High-Intensity Near-Crashes by Traffic Level**

Exposure Effectiveness Results by ACAS Vehicle Speed:

Figure 4-24 through Figure 4-27 compare EE results for driving in the speed ranges of less than 25 mph, 25 mph to 35 mph, and greater than or equal to 35 mph for each of the four conflict intensity levels respectively (ACAS-Disabled versus ACAS-Enabled Period 4 only). EE results for vehicle speed show a large contrast between EE values for the two speeds ranges less than 35 mph and the speed range greater than or equal to 35 mph. In general, the EE values for the two speeds ranges less than 35 mph are predominantly negative; whereas, the EE values for speeds greater than or equal to 35 mph are all positive. For example, the EE for the *all* group, low-intensity conflicts, for speeds less than 25 mph, is about -3.6 percent; for speeds between 25 mph and 35 mph, about -3.2 percent; and, for speeds greater than or equal to 35 mph, about 24.6

percent. There is considerable variation in the EE values both between and within the speed ranges for the various subject groups and conflict intensity levels.

The EE results for the speed range below 25 mph provide little direct information for evaluating ACAS since the system is essentially non-functional in this speed range. In fact, Manual 2 is used 96 percent of VDT for speeds less than 25 mph. For this reason, however, the speed range below 25 mph does provide a useful baseline of performance during the ACAS-Enabled test period while the system was not functioning.

In the 25 to 35 mph speed range, ACAS is functional. The dominant ACAS mode in this range is FCW, which is used about 73 percent of VDT. Manual 2 driving occurs for about 26 percent of VDT and ACC is used for only about 1 percent of VDT. The EE results in this speed range are, therefore, applicable to evaluating FCW, but not ACC. In estimating the exposure effectiveness of FCW in the 25-mph to 35-mph range, it is useful to compare results with the less than 25-mph range. This range essentially represents a baseline of Manual 2 driving without the influence of ACAS. As noted above, the EE results for these two speed ranges are very similar; e.g., about -3.6 percent versus -3.2 percent for speeds less than 25 mph and speeds between 25 mph and 35 mph, respectively, for the *all* group, low-intensity conflicts. Thus, the addition of FCW use seems to have little impact on EE results over that of Manual 2. This suggests that the EE for FCW is negligible at least for driving in this speed range. However, the following confounding factors could influence results; hence, this observation of negligible EE for FCW should be viewed with caution:

- The analysis did not specifically separate the influence of Manual 2 and FCW driving in the 25-mph to 35-mph range. The influence of FCW is inferred by comparison of results with less than 25 mph driving. Any differences in driving conditions between the two speed ranges could therefore confound results.
- There are considerable variations in the results in the 25-mph to 35-mph range between and within subject groups; e.g., EE for the *older* group ranges from 5.0 percent for low-intensity near-crashes to -23.6 percent for high-intensity near-crashes.
- Driving in the 25-mph to 35-mph range likely includes significant amounts of high congestion and local roads with complex traffic patterns, intersections, and traffic signals.

Compared to the two lower speed ranges, the 35 mph and higher speed range shows a consistently positive level of EE for all conflict intensity levels. For example, the *all* group has EE values between about 22 percent for low-intensity near-crashes and 26 percent for high-intensity conflicts. Compared to the *all* group, the other subject groups show considerable variation in EE, but all the values are positive regardless of conflict intensity level. The highest levels of EE are among *females* (41.5% for high-intensity) and *older* groups (37.4% for high-intensity conflicts); the lowest levels of EE are among *males* (1.6% for low-intensity near-crashes). The level of EE consistently increases with increasing age group.

Since ACC was used for about 42 percent of VDT in the 35-mph and higher speed range and was essentially not used in the lower speed ranges, these results suggest a substantial level of EE for ACC. However, FCW was also used for about 54 percent of VDT in this range and, in spite of its apparent lack of EE in the lower speed range; it could also be contributing to overall ACAS

EE in the higher speed range. The driving environment for speeds greater than or equal to 35 mph is likely dominated by freeways, high speeds, and low to moderate traffic levels. In fact, a comparison of these results with those of driving by road type shows that they are most similar to freeway driving. Interestingly, a comparison of results with those for different traffic levels shows no consistent agreement. This suggests that it is the road type environment, and not traffic level, that has the greatest effect on ACAS EE. Specifically, freeway driving seems to be the environment where ACAS has the highest level of EE.

The EE results for the three speed ranges are generally consistent with the results for aggregate driving, independent of other conditions, as shown in Figure 4-4 through Figure 4-7 (ACAS-Enabled Period 4 only). The EE values for the three speed ranges, as expected, generally bracket the corresponding EE value for the respective subject group and conflict intensity level.

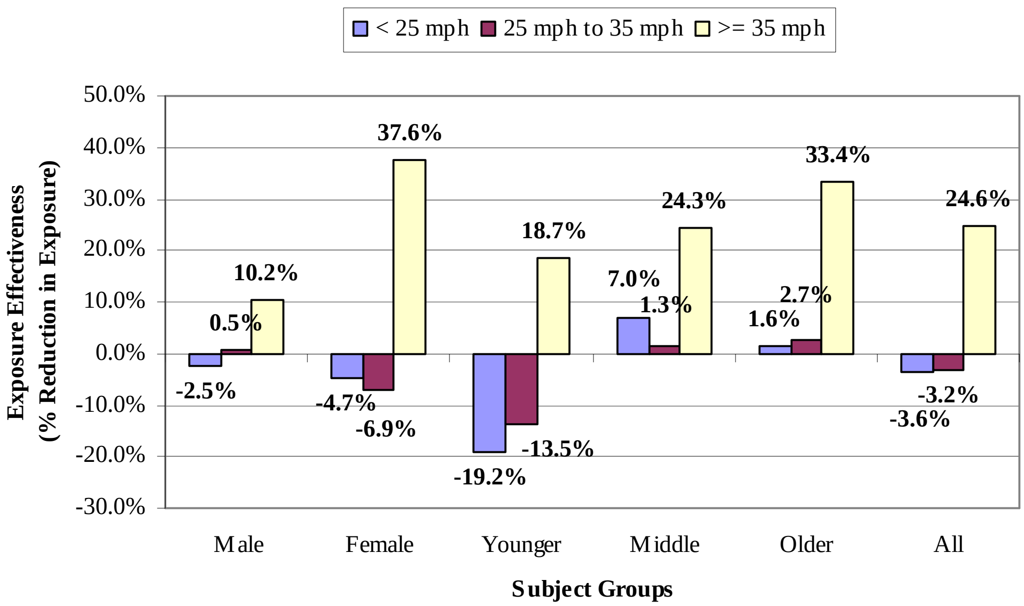


Figure 4-24. Exposure Effectiveness for Low-Intensity Conflicts by ACAS Vehicle Speed

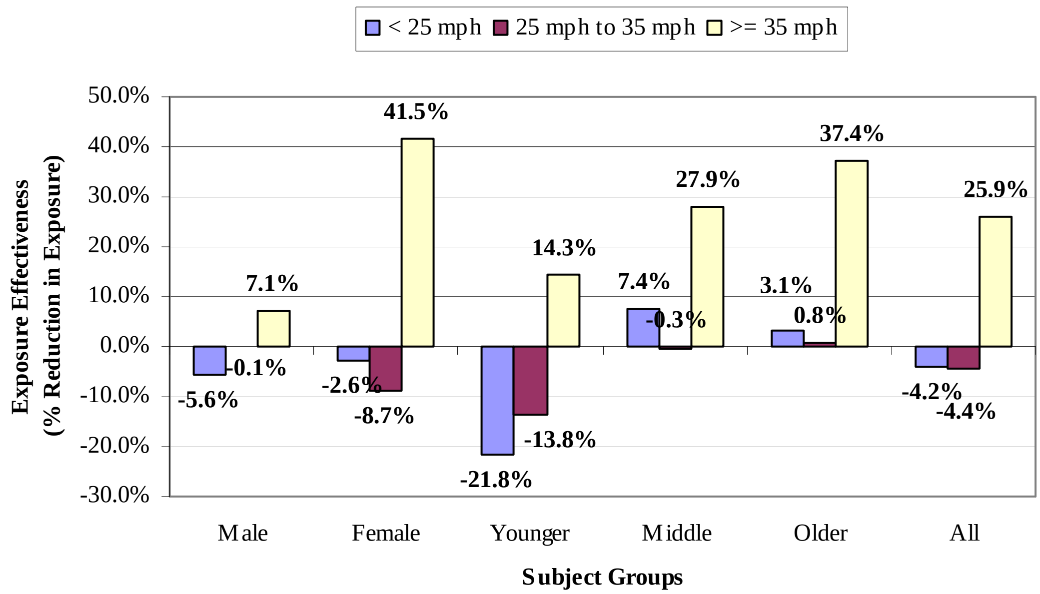


Figure 4-25. Exposure Effectiveness for High-Intensity Conflicts by ACAS Vehicle Speed

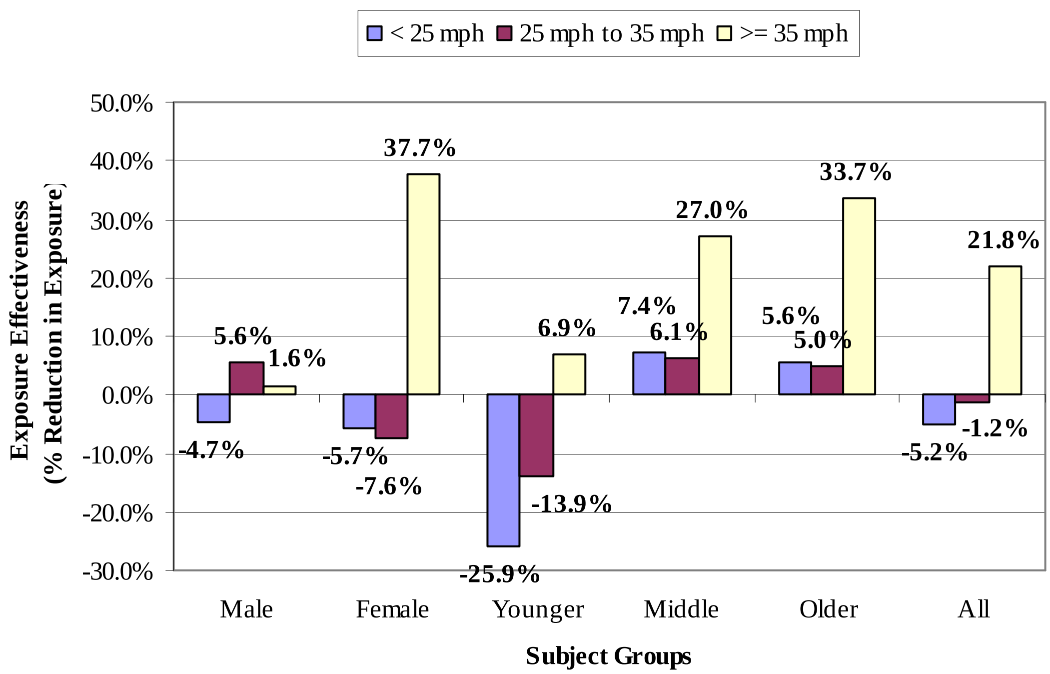


Figure 4-26. Exposure Effectiveness for Low-Intensity Near-Crashes by ACAS Vehicle Speed

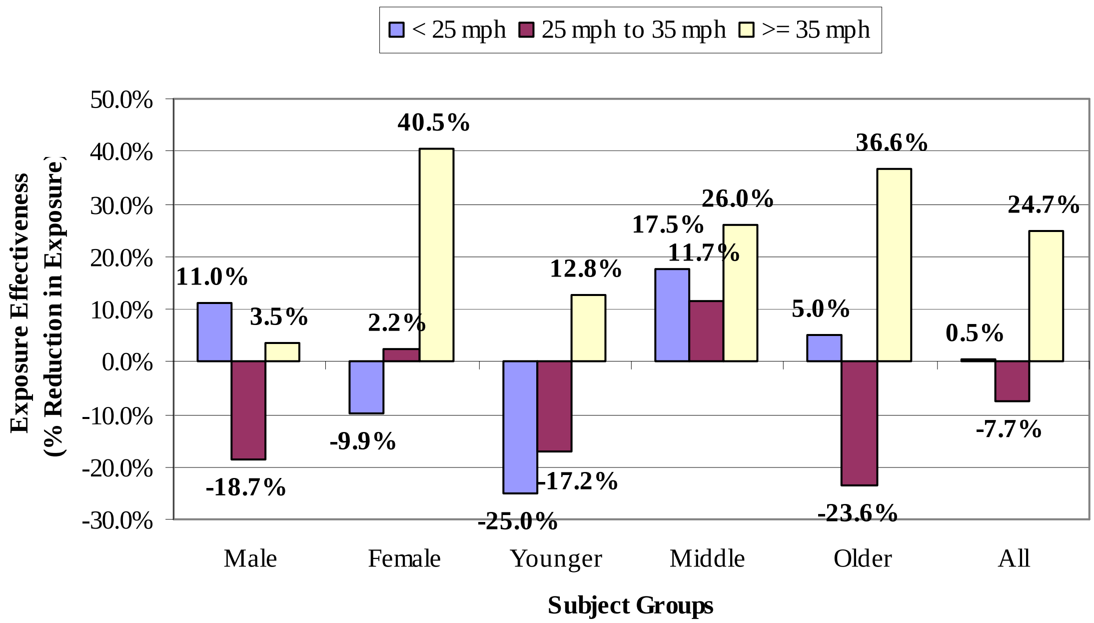


Figure 4-27. Exposure Effectiveness for High-Intensity Near-Crashes by ACAS Vehicle Speed

<u>Summary - Exposure Effectiveness Results Based on Aggregate Data</u>:

The exposure effectiveness results discussed above indicate that ACAS is about 21 percent effective in reducing the exposure of drivers to rear-end pre-crash conflicts for the aggregate of all drivers and driving conditions. This overall exposure effectiveness of ACAS is consistent regardless of the conflict intensity level metric used.

The EE of ACAS is also positive for the different subject groups. Using low-intensity conflicts as the metric for EE, the following results were obtained:

- EE is highest among *female* (30%) and *older* (27%) drivers
- EE is lowest among *male* (12%) drivers
- EE increases with age group from *younger* (14%) to *middle-age* (23%) to *older* (27%) drivers

Exposure effectiveness for ACAS is also positive for the different driving conditions of ambient light, road type, weather, and traffic level for *all* drivers. Again, using low-intensity conflicts as the metric for EE for *all* drivers, the following results were obtained:

- EE for light (24%) and dark (11%)
- EE for freeways (25%) and non-freeways (7%)
- EE for clear (21%) and adverse (19%) weather
- EE for low (17%), moderate (19%), and heavy (12%) traffic levels

The analysis of exposure effectiveness by ACAS vehicle speed found that the EE for ACAS was positive only for speeds at and above 35 mph (25%). The speed analysis concluded that the results for speeds less than 25 mph are not applicable to ACAS since the system essentially does not function at these speeds. It was also concluded that FCW has negligible EE for speeds between 25 mph and 35 mph. However, for speeds of 35 mph and above, ACC appears to have a substantial level of EE. FCW might also contribute to this EE for ACAS and ACC in the higher speed range. It was found that freeway driving seems to be the environment where ACAS has the highest level of EE.

It was found that the following combinations of subject group and driving condition produced EE values, for all conflict intensity levels, that varied considerably from the general results:

- *Younger* drivers have higher EE values for dark conditions (e.g., 20% for low-intensity conflicts).
- *Older* drivers have lower EE values for freeway driving (e.g., 2% for low-intensity conflicts).
- *Younger* drivers have lower, negative EE values for non-freeway driving (e.g., -10% for low-intensity conflicts).
- *Older* and *younger* drivers have atypically low EE values for adverse conditions (e.g., 14% for *older* drivers and -19% for *younger* drivers for low-intensity conflicts).
- *Middle-age* drivers have higher EE values for adverse conditions (e.g., 45% for low-intensity conflicts).
- *Younger* drivers have atypically low, negative EE values for driving in heavy traffic (e.g., -15% for low-intensity conflicts).

The unusual results obtained for some subject groups and conditions might be explained, at least in part, by limitations in the data. The results for particular subject groups and conditions should, therefore, be interpreted with some caution.

Exposure Effectiveness Results Based on Driver Average Statistics

This analysis examines the effectiveness of ACAS in reducing exposure to driving conflicts (EE) for selected low-intensity and high-intensity conflict levels. The driving conflict situations selected for this section were determined to be statistically significant from the exposure rate analyses presented previously in Sections 4.2.1.1 through 4.2.1.2. The analysis in this section is, furthermore, based on an alternative analytical approach, thus providing a more comprehensive assessment of exposure effectiveness.

The statistical significance of the driver conflict situations selected for this section is based on the difference of the means of conflict rates between the ACAS-Disabled test period and ACAS-Enabled test period (Period 4). Table 4-15 shows the 33 subject group, conflict intensity level, driving condition categories for which statistically significant values of EE were found. Of these 33 categories, the 20 indicated for the *all* subject group were selected for presentation in the following charts. The *all* group produces the largest data set and includes subjects chosen to be representative of age and gender and is, therefore, considered to be most representative of overall driving.

The EE values presented in the following charts were determined on the basis of averaging the mean EE value computed for each driver. Thus, these EE values are not directly comparable with the values presented in the previous section, which are based on population averages. The population average approach yields the largest data set for statistical analysis, but is most subject to the bias of individual drivers that might have extremes in driving behavior. The driver average approach, presented below, yields a smaller data set, but is less subject to driver bias; each driver is weighted equally. Given that the FOT had only 66 subjects and a wide variation in driving behavior was noted, the driver average values are considered most representative of overall driving. Figure 4-28 through Figure 4-33 show the mean values of EE along with standard error bars.

Figure 4-28 shows the mean EE values, along with standard error bars, for *all* drivers for all conditions. The mean EE values tend to decrease with increasing conflict intensity level. The highest EE of about 14 percent is associated low-intensity conflicts and the lowest EE value of about 8 percent is associated with high-intensity near-crashes. Since there is considerable overlap in the standard error bars, there is no statistically significant difference in the values. These EE values are consistently lower than the population average value of about 21 percent presented in the previous section for the same conditions.

Figure 4-29 shows the EE values for *all* drivers driving in lighted conditions. The mean EE values tend to decrease with increasing conflict intensity level. The highest EE value is about 14 percent and the lowest EE value is about 10 percent. These results are similar to the results for overall driving presented above which is expected since about 74 percent of all driving is in lighted conditions. These EE values are consistently lower than the population average value of about 21 percent presented in the previous section for lighted conditions.

Figure 4-30 shows the EE values for *all* drivers driving on freeways. The mean EE values tend to increase with increasing conflict intensity level. The highest EE value is about 22 percent and the lowest EE value is about 12 percent. These EE values are generally higher, especially for high-intensity conflicts and low-intensity near-crashes, than the corresponding values for driving overall (see Figure 4-28). This suggests that ACAS has a higher level of EE for freeway driving than for non-freeway driving and is consistent with the population average EE results presented in the previous section. These EE values for high-intensity conflicts and low-intensity near-crashes are about the same as the population average value of about 21 percent presented in the previous section for freeway driving.

Table 4-15. Categories of Statistically Significant Exposure Effectiveness

Statistically Significant Difference in MOP Means between ACAS Disabled and ACAS Enabled ($p < 0.05$)

			All	Younger	Middle	Older	Male	Female
Overall Driving	Low Intensity	Conflict	X					
		Near Crash	X					
	High Intensity	Conflict	X					
		Near Crash	X					
Clear Weather	Low Intensity	Conflict	X					
		Near Crash	X					
	High Intensity	Conflict	X					
		Near Crash						
Adverse Weather	Low Intensity	Conflict						
		Near Crash						
	High Intensity	Conflict						
		Near Crash						
Lighted Condition	Low Intensity	Conflict	X		X			
		Near Crash	X		X			
	High Intensity	Conflict	X					
		Near Crash	X					
Dark Condition	Low Intensity	Conflict						
		Near Crash						
	High Intensity	Conflict						
		Near Crash						
Freeway	Low Intensity	Conflict	X				X	
		Near Crash	X					
	High Intensity	Conflict	X					
		Near Crash						
Non-Freeway	Low Intensity	Conflict						
		Near Crash						
	High Intensity	Conflict						
		Near Crash						
Low Traffic	Low Intensity	Conflict						
		Near Crash						
	High Intensity	Conflict						
		Near Crash						
Moderate Traffic	Low Intensity	Conflict	X	X				X
		Near Crash	X					X
	High Intensity	Conflict						X
		Near Crash						
Heavy Traffic	Low Intensity	Conflict						
		Near Crash			X			
	High Intensity	Conflict			X			
		Near Crash						
< 25 mph	Low Intensity	Conflict		X				
		Near Crash						
	High Intensity	Conflict						
		Near Crash						
>= 25 mph & < 35 mph	Low Intensity	Conflict						
		Near Crash						
	High Intensity	Conflict						
		Near Crash						
>= 35 mph	Low Intensity	Conflict	X					X
		Near Crash	X					X
	High Intensity	Conflict	X					X
		Near Crash	X					

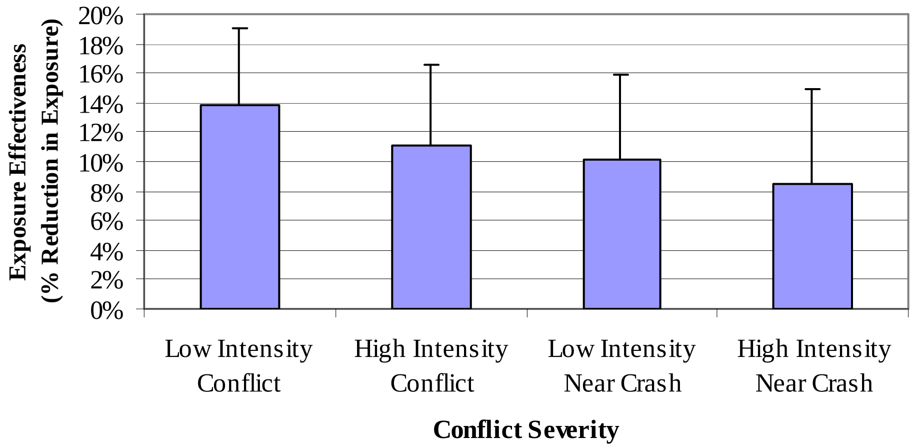


Figure 4-28. Exposure Effectiveness for *All* Drivers

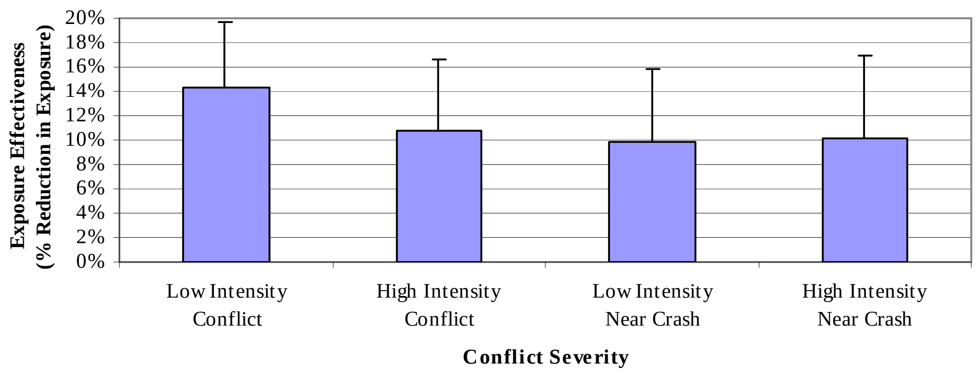


Figure 4-29. Exposure Effectiveness for *All* Drivers in Lighted Conditions

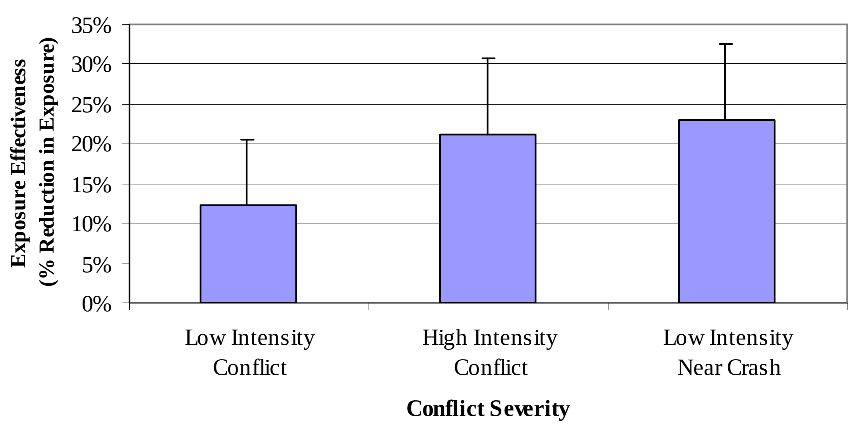


Figure 4-30. Exposure Effectiveness for *All* Drivers on Freeways

Figure 4-31 shows the EE values for *all* drivers driving in clear weather conditions. The mean EE values tend to decrease with increasing conflict intensity level. The highest EE value is about 13 percent and the lowest EE value is about 11 percent. These results are similar to the results for overall driving for the three corresponding conflict intensity levels, presented above. This result is expected since about 92 percent of all driving is in clear conditions. These EE values are consistently lower than the population average value of about 21 percent presented in the previous section for clear conditions.

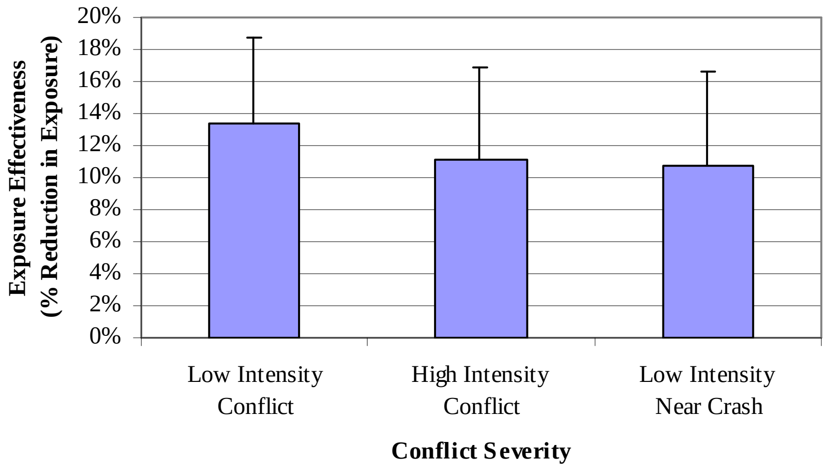


Figure 4-31. **Exposure Effectiveness for *All* Drivers in Clear Weather**

Figure 4-32 shows the EE values for *all* drivers driving in moderate traffic levels. The mean EE values increase slightly with increasing conflict intensity level. The highest EE value is about 16 percent and the lowest EE value is about 14 percent. The EE value for low-intensity near-crashes is higher than the corresponding value for overall driving presented above (16% versus 8% respectively). This suggests that ACAS has a higher level of EE for moderate traffic levels than for other traffic levels and is consistent with the population average EE results presented in the previous section for the three lower conflict intensity levels. These EE values are lower than the population average value of about 19 percent presented in the previous section for moderate traffic and the same conflict intensity levels.

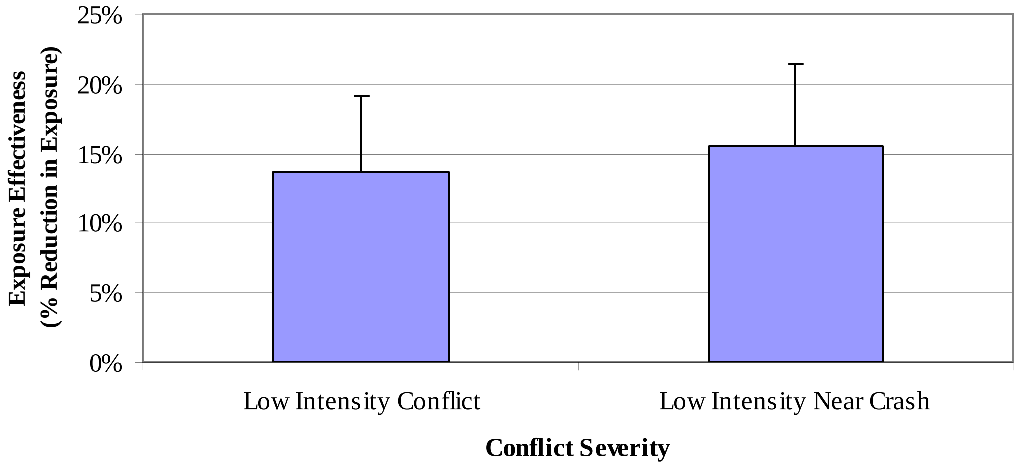


Figure 4-32. Exposure Effectiveness for *All* Drivers in Moderate Traffic

Figure 4-33 shows the EE values for *all* drivers driving at speeds greater than or equal to 35 mph. The mean EE values for low-and high-intensity conflicts are equal (16%) and slightly higher than the corresponding values for near-crashes, which are also equal (13%). The EE values for all four intensity levels are higher than the corresponding values for overall driving presented above. This suggests that ACAS has a higher level of EE for driving at speeds at and above 35 mph than for slower speed driving situations. This observation is consistent with the population average EE results presented in the previous section for all four intensity levels. The EE values presented here, however, are lower than the population average values that range from 21.8 percent and 25.9 percent depending on conflict intensity level.

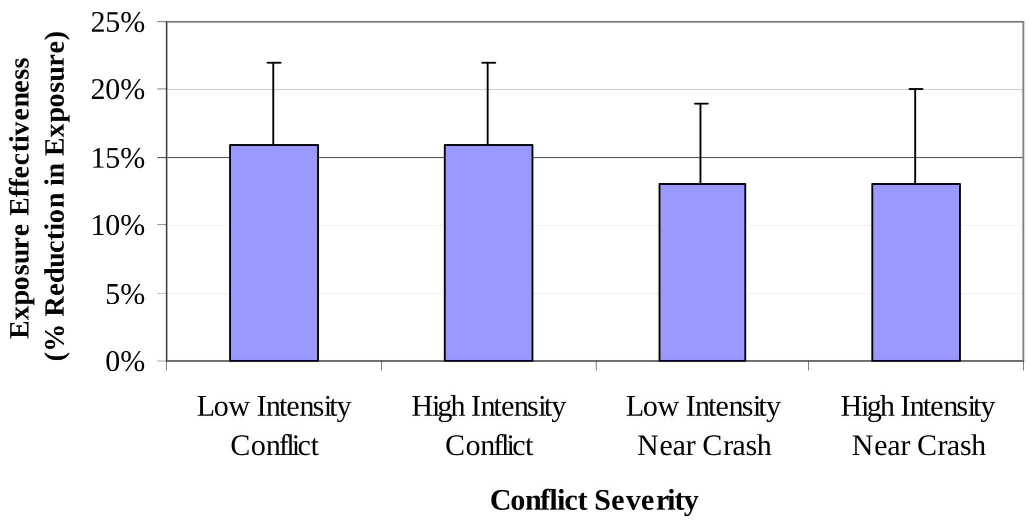


Figure 4-33. Exposure Effectiveness for *All* Drivers, Vehicle Speeds ≥ 35 mph

Summary - Exposure Effectiveness Results Based on Driver Average Statistics:

The EE results, based on driver averages, are consistently lower than the corresponding population average value of about 21 percent. There is no consistency in the variation of EE by conflict intensity level for the various conditions investigated. For all the conditions considered, the EE values are positive and range between a minimum and maximum value by conflict intensity level as follows:

- Light – min. 8 percent, high-intensity near-crashes; max. 14 percent, low-intensity conflicts
- Freeways – min. 12 percent, low-intensity conflicts; max. 22 percent, high-intensity near-crashes
- Clear – min.11 percent, high-intensity near-crashes; max. 13 percent, low-intensity conflicts
- Moderate traffic – min. 14 percent, low-intensity conflicts; max. 16 percent, high-intensity near-crashes
- Speeds greater than or equal to 35 mph – min. 13 percent, high-intensity near-crashes; max. 16 percent, low-intensity conflicts

4.2.2 Response to Driving Conflicts by Rear-End Dynamic Scenario

This analysis examined driver exposure to specific driving conflicts and near-crashes that involved a lead vehicle stopped (LVS), lead vehicle moving at slower constant speed (LVM), or lead vehicle decelerating (LVD). These three dynamic pre-crash scenarios accounted for 95 percent of all rear-end crashes that involved at least one light vehicle (i.e., passenger car, van, minivan, sport utility vehicle, or light truck) based on the 2000 General Estimates System (GES) (Najm and Sen et al., 2003). Moreover, driver/vehicle response to each of the three scenarios was also considered. The lead vehicle accelerating (LVA) scenario was removed from this analysis due to its very low frequency of occurrence in rear-end crashes and in conflicts during the FOT. Specifically, the following three response types were examined:

1. Brake/autobrake: Minimum deceleration of the host vehicle during the driving conflict is less than -0.1g ($-0.981\ m/s^2$).
2. Brake/autobrake and steer: Combined braking and steering (lane change) response in which minimum deceleration of the host vehicle during the driving conflict is less than -0.1g ($-0.981\ m/s^2$).
3. Steer: Lane change or combined lane change with a slow down in which minimum deceleration of the host vehicle during the driving conflict is greater than or equal to -0.1g ($-0.981\ m/s^2$).

The 0.1g threshold was selected to account for actual braking events and disregard other events in which the driver simply tapped on the brake pedal or eased on the throttle. Thus, the intent of this additional filtering was to analyze conflicts that required high response intensity from the driver and to remove low-risk conflicts. The examination of driver exposure and response to the three dynamic scenarios was conducted for the ACAS-Disabled test period and the ACAS-Enabled test period (Period 4 only). In addition, low-intensity and high-intensity driving conflicts and near-crashes were also considered. This analysis was focused on *all* drivers only since statistical significance in conflict exposure results between the ACAS-Disabled and ACAS-Enabled test periods was mostly observed at this level and not at the lower levels of subject groups.

4.2.2.1 Exposure to Rear-End Dynamic Scenarios

Figure 4-34 and Figure 4-35 provide a breakdown of the frequency and percentage of driving conflicts encountered during the ACAS-Disabled test period by dynamic scenario and driver response for low intensity and high-intensity levels, respectively. This breakdown was based on aggregate data from all subjects. These figures also show how many conflicts resulted in near-crashes according to driver/vehicle response. Figure 4-36 and Figure 4-37 present similar data about driving conflicts during the ACAS-Enabled test period (Period 4).

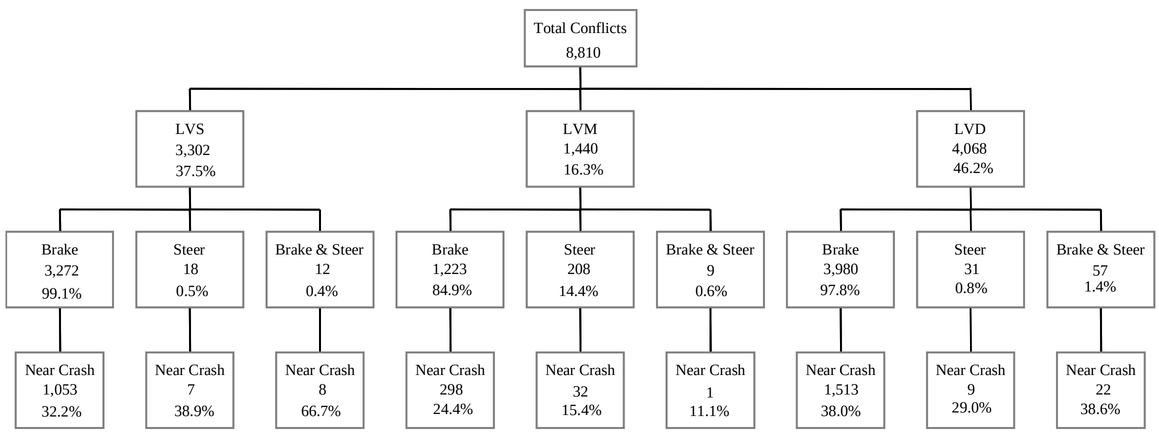


Figure 4-34. Breakdown of Low-Intensity Conflicts by Scenario, Response, and Near-Crash for ACAS-Disabled

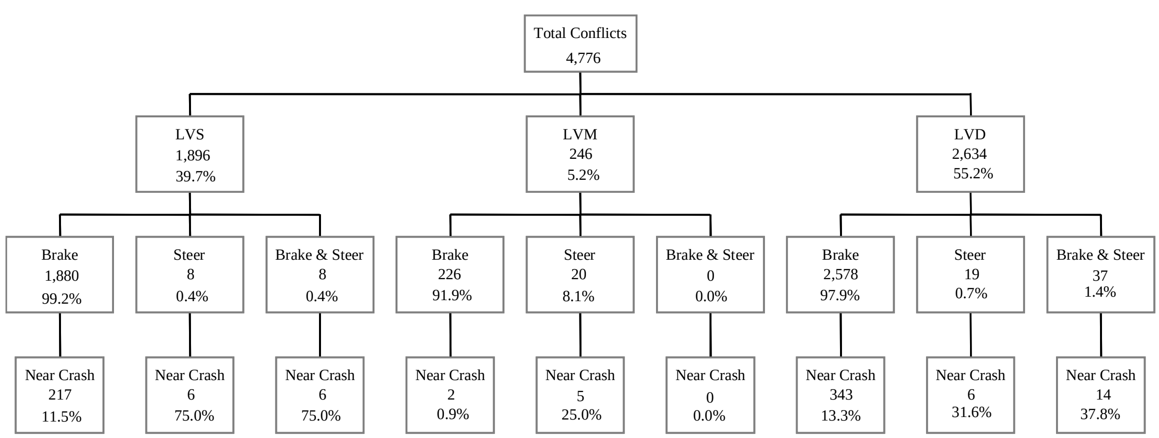


Figure 4-35. Breakdown of High-Intensity Conflicts by Scenario, Response, and Near-Crash for ACAS-Disabled

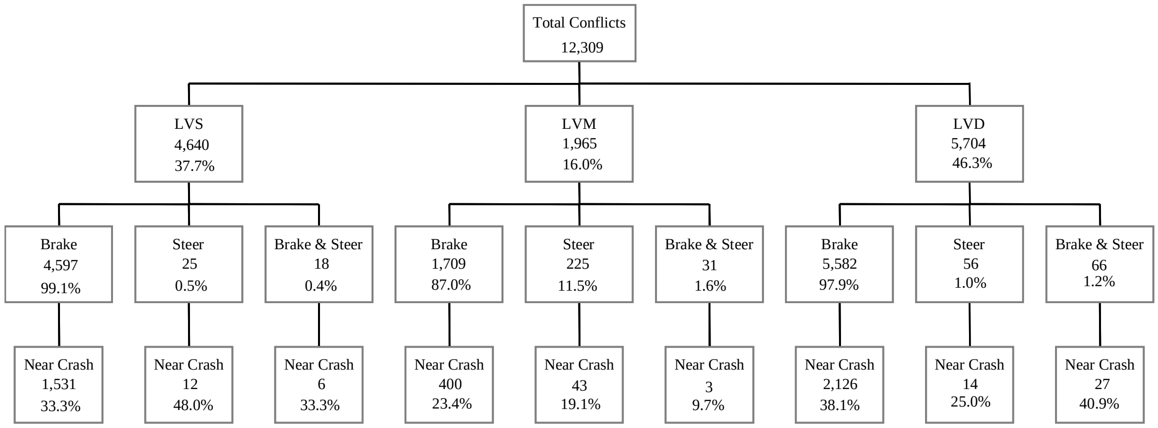


Figure 4-36. Breakdown of Low-Intensity Conflicts by Scenario, Response, and Near-Crash for ACAS-Enabled, Period 4

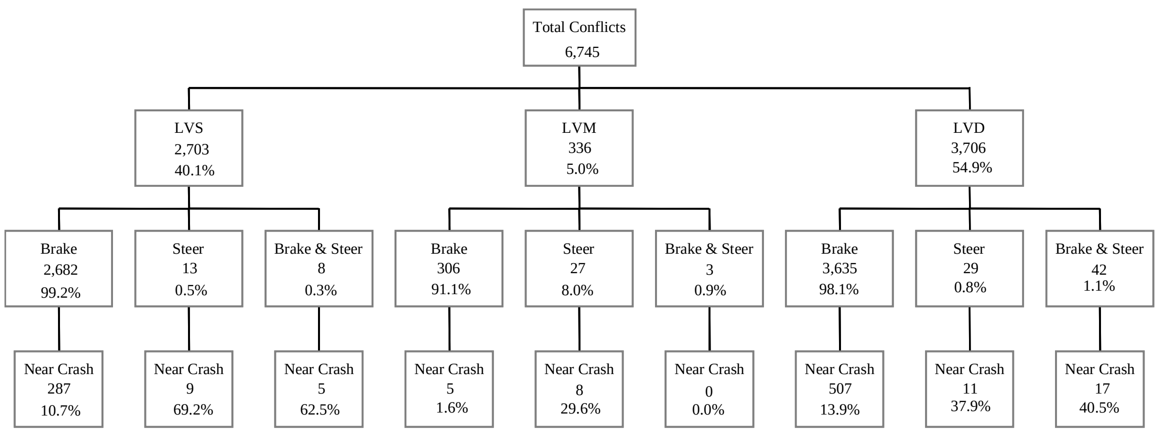


Figure 4-37. Breakdown of High-Intensity Conflicts by Scenario, Response, and Near-Crash for ACAS-Enabled, Period 4

Figure 4-34 through Figure 4-37 show similar results between ACAS-Disabled and ACAS-Enabled test periods at the low-and high-intensity conflict levels:

– At the low-intensity level, LVS, LVM, and LVD scenarios accounted respectively for 38 percent, 16 percent, and 46 percent of all driving conflicts in both test periods. On the other hand, LVS, LVM, and LVD scenarios amounted respectively to 40 percent, 5 percent, and 55 percent of all high-intensity driving conflicts in both test periods. It should be noted that the relative frequency of LVM scenarios is smaller at the high-intensity level as opposed to a larger relative frequency of LVD scenarios.

– Driver/vehicle response to each of the three scenarios was similarly distributed across the two test periods and the two levels of conflict intensity. Braking was the most dominant response across the three scenarios. The relative frequency of steering was higher in LVM scenario than in LVS and LVD scenarios.
– The ratio of near-crashes per conflicts also remained the same between the two test periods at the two levels of conflict intensity. At the low-intensity level, about 33 percent, 24 percent, and 38 percent of the conflicts resulted in near-crashes when braking was initiated respectively in response to LVS, LVM, and LVD scenarios. On the other hand, these near-crash percentages were respectively about 12 percent, 2 percent, and 14 percent of the high-intensity conflicts.

Data in Figure 4-34 through Figure 4-37 were further broken down by host vehicle speed. This analysis was conducted at three different speed bins: < 25 mph, ≥ 25 and < 35 mph, and ≥ 35 mph. Table 4-16, Table 4-17, and Table 4-18 present results from aggregate data about the number of conflicts and near-crashes encountered by 100 km traveled under different conditions respectively for brake, steer, and brake and steer responses. In addition, values of the exposure ratio are also provided to indicate either a decrease or an increase in exposure between ACAS-Disabled and ACAS-Enabled test periods (exposure ratio < 1 refers to a decrease in exposure to conflicts or near-crashes as a result of ACAS use).

Table 4-16. Number of Brake Events per 100 Km Traveled and Exposure Ratio by Scenario, Speed, Event, Driving Mode, and Intensity Level

Scenario	Speed Bin	Event	ACAS Disabled		ACAS Enabled		Exposure Ratio	
			Low Int.	High Int.	Low Int.	High Int.	Low Int.	High Int.
Lead Vehicle Stopped - Brake	< 25 mph	Conflict	78.64	45.53	83.13	48.90	1.06	1.07
		Near Crash	24.64	4.61	27.71	5.17	1.12	1.12
	>= 25 & < 35 mph	Conflict	33.27	18.35	33.46	18.39	1.01	1.00
		Near Crash	10.52	2.31	10.12	1.80	0.96	0.78
	>= 35 mph	Conflict	0.86	0.55	0.70	0.47	0.81	0.86
		Near Crash	0.35	0.10	0.31	0.07	0.89	0.71
Lead Vehicle Moving - Brake	< 25 mph	Conflict	30.56	6.33	31.17	5.60	1.02	0.88
		Near Crash	8.60		7.78		0.90	
	>= 25 & < 35 mph	Conflict	8.89	1.43	9.04	1.96	1.02	1.37
		Near Crash	1.82		2.29	0.07	1.26	
	>= 35 mph	Conflict	0.61	0.08	0.51	0.06	0.84	0.78
		Near Crash	0.10	0.01	0.08	0.004	0.82	0.54
Lead Vehicle Decelerating - Brake	< 25 mph	Conflict	45.12	24.35	48.01	26.73	1.06	1.10
		Near Crash	17.11	0.53	18.28	0.58	1.07	1.09
	>= 25 & < 35 mph	Conflict	41.55	27.84	43.94	29.16	1.06	1.05
		Near Crash	16.74	2.70	16.77	3.13	1.00	1.16
	>= 35 mph	Conflict	4.96	3.50	3.65	2.60	0.74	0.74
		Near Crash	1.79	0.79	1.39	0.62	0.78	0.78

Table 4-17. Number of Steer Events per 100 Km Traveled and Exposure Ratio by Scenario, Speed, Event, Driving Mode, and Intensity Level

Scenario	Speed Bin	Event	ACAS Disabled		ACAS Enabled		Exposure Ratio	
			Low Int.	High Int.	Low Int.	High Int.	Low Int.	High Int.
Lead Vehicle Stopped - Steer	< 25 mph	Conflict	0.41	0.25	0.34	0.24	0.82	0.99
		Near Crash	0.21	0.21	0.21	0.15	1.04	0.74
	>= 25 & < 35 mph	Conflict	0.03		0.18	0.07	5.93	
		Near Crash			0.07	0.04		
	>= 35 mph	Conflict	0.02	0.01	0.01	0.004	0.46	0.54
		Near Crash	0.01	0.003	0.004	0.004	0.54	1.08
Lead Vehicle Moving - Steer	< 25 mph	Conflict	0.78	0.16	0.43	0.06	0.55	0.37
		Near Crash	0.21	0.12	0.09	0.03	0.45	0.25
	>= 25 & < 35 mph	Conflict	0.52	0.12	0.49	0.04	0.96	0.37
		Near Crash	0.15	0.03	0.04	0.02	0.30	0.74
	>= 35 mph	Conflict	0.56	0.04	0.34	0.04	0.59	1.04
		Near Crash	0.07	0.003	0.07	0.01	0.93	3.25
Lead Vehicle Decelerating - Steer	< 25 mph	Conflict	0.45	0.41	0.58	0.31	1.29	0.74
		Near Crash	0.29	0.16	0.12	0.06	0.43	0.37
	>= 25 & < 35 mph	Conflict	0.30	0.09	0.25	0.11	0.82	1.24
		Near Crash	0.03	0.03	0.07	0.07	2.22	2.22
	>= 35 mph	Conflict	0.03	0.02	0.05	0.02	1.41	1.26
		Near Crash	0.003	0.003	0.01	0.01	3.79	3.25

Table 4-18. Number of Brake and Steer Events per 100 Km Traveled and Exposure Ratio by Scenario, Speed, Event, Driving Mode, and Intensity Level

Scenario	Speed Bin	Event	ACAS Disabled		ACAS Enabled		Exposure Ratio	
			Low Int.	High Int.	Low Int.	High Int.	Low Int.	High Int.
Lead Vehicle Stopped - Brake & Steer	< 25 mph	Conflict	0.37	0.25	0.34	0.12	0.91	0.50
		Near Crash	0.25	0.21	0.06	0.03	0.25	0.15
	>= 25 & < 35 mph	Conflict	0.09	0.06	0.13	0.09	1.48	1.48
		Near Crash	0.06	0.03	0.09	0.09	1.48	2.97
	>= 35 mph	Conflict			0.00			
		Near Crash						
Lead Vehicle Moving - Brake & Steer	< 25 mph	Conflict			0.24	0.06		
		Near Crash			0.06			
	>= 25 & < 35 mph	Conflict	0.15		0.16		1.04	
		Near Crash						
	>= 35 mph	Conflict	0.01		0.03	0.00	2.16	
		Near Crash	0.003		0.002		0.54	
Lead Vehicle Decelerating - Brake & Steer	< 25 mph	Conflict	0.41	0.33	0.37	0.28	0.89	0.84
		Near Crash	0.29	0.16	0.18	0.15	0.64	0.93
	>= 25 & < 35 mph	Conflict	0.58	0.39	0.54	0.47	0.94	1.20
		Near Crash	0.21	0.15	0.25	0.09	1.17	0.59
	>= 35 mph	Conflict	0.09	0.05	0.05	0.02	0.58	0.41
		Near Crash	0.03	0.02	0.02	0.01	0.68	0.87

Only seven scenarios from Table 4-16 through Table 4-18 were identified to have any statistically significant difference in the means of number of conflicts/ near-crashes per 100 km traveled between ACAS-Disabled and ACAS-Enabled test periods using t-test for two-paired samples as indicated in Table 4-19. Six of these scenarios correspond to host vehicle speed at or greater than 35 mph. Brake response was associated with 6 LVS and LVD scenarios and steer response was tied to only one LVM scenario. The last column of Table 4-19 provides results of ACAS effectiveness [1 – average exposure with ACAS enabled/average exposure with ACAS disabled] in reducing exposure to conflicts and near-crashes. Subjects who did not experience any conflicts or near-crashes in any of the two driving conditions were excluded from the statistical analysis. It should be noted that ACAS reduced the exposure to conflicts and near-crashes by 21 percent to 50 percent in these seven scenarios, considering the average values of conflicts/ near-crashes per 100 km traveled with and without ACAS use.

The reader is cautioned about the lack of robustness in the ACAS-Disabled versus ACAS-Enabled effects measured since only 7 out of the 108 tests performed were found to be statistically significant. These 7 effects might be spurious effects since one would have expected 5 of these 108 tests to have reached statistical significance by chance alone based on a p = 0.05 statistical significance criterion (this is referred to as "Type I" error).

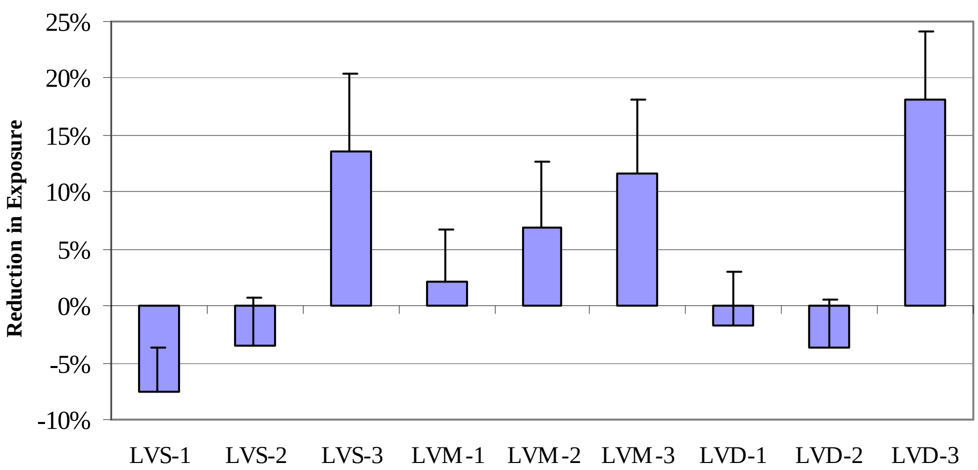
Table 4-19. Summary of Statistically Significant ($p < 0.05$) Results of Scenario Exposure by Intensity Level, Scenario, Response, Speed, and Driving Mode

Conflict Level	Dynamic Scenario	Driver Response	Speed Bin	*ACAS Disabled*		*ACAS Enabled*		No. Subj.	p-value	Effect.
				Avg.	StD.	Avg.	StD.			
Low Intensity Conflict	LVS	Brake	>= 35	1.3	1.5	1.0	0.7	56	0.05	22.7%
	LVM	Steer	>= 35	1.2	1.4	0.7	0.6	30	0.03	43.4%
	LVD	Brake	>= 35	6.3	4.2	5.0	3.6	66	0.01	21.0%
High Intensity Conflict	LVD	Brake	>= 35	4.5	3.3	3.6	2.6	65	0.01	21.3%
Low Intensity Near Crash	LVD	Brake	>= 35	2.6	2.3	2.0	1.0	61	0.02	23.2%
High Intensity Near Crash	LVS	Brake	>= 25 & < 35	5.9	5.3	3.0	2.1	27	0.003	49.7%
	LVD	Brake	>= 35	1.2	1	0.9	0.7	55	0.03	24.3%

Figure 4-38 through Figure 4-41 illustrate the effectiveness of ACAS in reducing driver exposure to driving conflicts and near-crashes by dynamic scenario and vehicle speed as a result of brake response. Mean values and concomitant standard errors are displayed in these figures. These statistics are based on effectiveness values of individual drivers who experienced at least one driving conflict or near-crash in each of the two driving modes (with ACAS disabled or ACAS enabled). It is noteworthy that positive mean values indicate a decrease in exposure and negative values imply an increase in exposure to conflicts and near-crashes as a result of ACAS use.

Considering statistically significant scenarios from Table 4-19, ACAS has the potential to reduce driver exposure by:

- 14 percent to low-intensity conflicts with lead vehicle stopped resolved with braking at speeds greater than or equal to 35 mph (0 – 27% range at 95% confidence levels)
- 29 percent to high-intensity near-crashes with lead vehicle stopped resolved with braking at speeds greater than or equal to 25 mph and less than 35 mph (12 – 46% range at 95% confidence levels)
- 18 percent to low-intensity conflicts with lead vehicle decelerating resolved with braking at speeds greater than or equal to 35 mph (6 – 30% range at 95% confidence levels)
- 15 percent to high-intensity conflicts with lead vehicle decelerating resolved with braking at speeds greater than or equal to 35 mph (2 – 27% range at 95% confidence levels)
- 9 percent to low-intensity near-crashes with lead vehicle decelerating resolved with braking at speeds greater than or equal to 35 mph (-5 – 23% range at 95% confidence levels)
- 11 percent to high-intensity near-crashes with lead vehicle decelerating resolved with braking at speeds greater than or equal to 35 mph (-4 – 26% range at 95% confidence levels)
- 21 percent to low-intensity conflicts with lead vehicle moving at slower constant speed resolved with braking at speeds greater than or equal to 35 mph (0 – 43% range at 95% confidence levels)



LV*-x: x= 1, v < 25 mph; x= 2, 25 ≤ v < 35 mph; x= 3, v ≥ 35 mph
Standard error bars are shown

Figure 4-38. ACAS Effectiveness in Reducing Exposure to Low-Intensity Conflicts with Brake Response

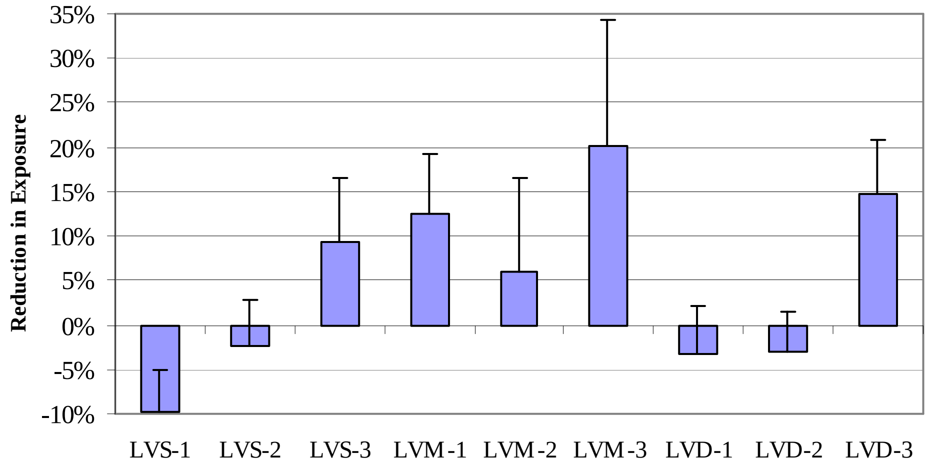


Figure 4-39. ACAS Effectiveness in Reducing Exposure to High-Intensity Conflicts with Brake Response

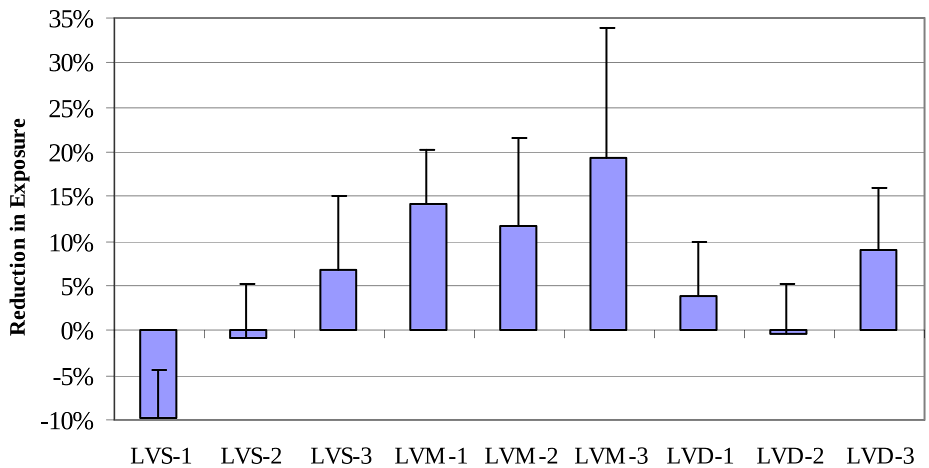


Figure 4-40. ACAS Effectiveness in Reducing Exposure to Low-Intensity Near-Crashes with Brake Response

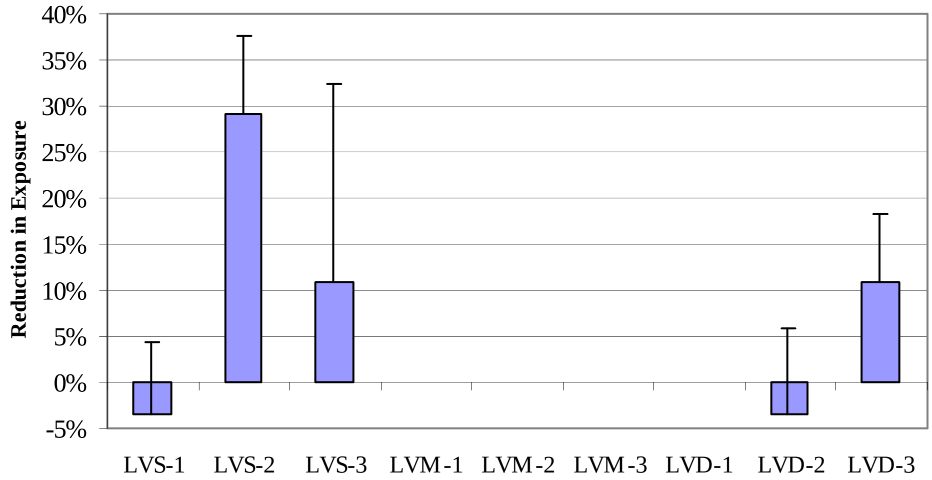


Figure 4-41. ACAS Effectiveness in Reducing Exposure to High-Intensity Near-Crashes with Brake Response

The effect of conflict and near-crash intensity levels on ACAS effectiveness estimates listed above was examined for the lead vehicle decelerating scenario with braking at speeds greater than or equal to 35 mph. There was statistically significant difference between low-intensity conflict level and low-intensity near-crash level ($p= 0.036$), and between high-intensity conflict level and low-intensity near-crash level ($p= 0.044$) based on t-test paired two samples for means. No difference was found in the remaining four combinations ($p > 0.17$).

ACAS Effectiveness results are not shown for steer response and brake and steer response because the number of subjects in each speed bin cell was under 8 subjects except for low-intensity conflicts with lead vehicle moving resolved with steering at speeds of 35 mph and higher, and for low-intensity conflicts with lead vehicle decelerating resolved with combined braking and steering at speeds greater than or equal to 35 mph. There was not statistically significant difference in the means of exposure between ACAS-Disabled and ACAS-Enabled test periods in the latter scenario.

Summary Results of Exposure to Rear-End Pre-Crash Scenarios

Based on aggregate data of all drivers, the breakdown of driving conflicts by specific scenarios was similar overall between the ACAS-Disabled and ACAS-Enabled (Period 4) test periods. Distributions of LVS, LVM, and LVD scenarios were observed to be similar between the two test periods. Moreover, driver/vehicle response to each of the three scenarios was similarly distributed across the two test periods and the two levels of conflict intensity. In addition, the ratio of near-crashes per conflict also remained the same between the two test periods at each of the two levels of conflict intensity.

Driver exposure was investigated for 108 combinations of scenarios (4 conflict levels × 3 dynamic scenarios × 3 driver responses × 3 speed bins). Statistically significant difference of exposure between ACAS-Disabled and ACAS-Enabled test periods was found in only 7 of the 108 combinations. The remaining 101 combinations had no statistically significant difference or fewer than 8 subjects per combination. Table 4-20 lists the 7 scenarios and provides their concomitant EE values based on aggregate data and driver average statistics. In 6 of these 7 scenarios, ACAS was effective in reducing exposure to driving conflicts at travel speeds greater than or equal to 35 mph. About 54 percent of the VDT at these travel speeds during the ACAS-Enabled test period was driven with active FCW compared to 42 percent with ACC. On the other hand, ACAS was effective in reducing exposure to driving conflicts with statistical significance in only one scenario at travel speeds between 25 and 35 mph. FCW was active in 73 percent of the VDT at this speed range, as opposed to only 1 percent by ACC and 26 percent in manual control. As seen in Table 4-20, EE values based on aggregate data fall between the mean and upper bound (95% confidence bound) values based on driver average statistics in 66 of the 7 scenarios (travel speed ≥ 35 mph). Moreover, Table 4-20 shows a large variability in EE results based on driver average statistics.

Table 4-20. Statistically Significant Estimates of ACAS Exposure Effectiveness in Specific Rear-End Pre-Crash Dynamic Scenarios

				ACAS Disabled vs ACAS Enabled P4		
Conflict Level	Dynamic Scenario	Driver Response	Speed Bin (mph)	Aggregate	Driver Average Statistics	
					Mean	Upper Bound
Low Intensity Conflict	LVS	Brake	>= 35	19%	14%	27%
	LVM	Steer	>= 35	39%	21%	42%
	LVD	Brake	>= 35	26%	18%	30%
High Intensity Conflict	LVD	Brake	>= 35	26%	15%	27%
Low Intensity Near Crash	LVD	Brake	>= 35	22%	9%	23%
High Intensity Near Crash	LVS	Brake	>= 25 & < 35	22%	29%	46%
	LVD	Brake	>= 35	22%	11%	26%

4.2.2.2 Response to Rear-End Pre-Crash Dynamic Scenarios

The initiation time and intensity of driver response to rear-end pre-crash dynamic scenarios were investigated at different speed bins. Response initiation was measured by time-to-collision or TTC (range/range rate) for LVS and LVM scenarios, and by time headway TH (range/host vehicle speed) for LVD scenario.

Table 4-21 throough Table 4-23 provide the average and standard deviation values of TTC and TH for each of the three scenarios at three speed bins for ACAS-Disabled and ACAS-Enabled (Period 4) test periods, which are associated respectively with brake, steer, and brake and steer responses. In addition, these tables list p values from two-sample t tests with equal variances so as to observe differences in driver performance with and without ACAS assistance. Some cells in these tables were left blank because fewer than 8 observations were collected under corresponding conditions. There were only two conditions in which a statistically significant difference ($p \leq 0.05$) in response initiation was observed between the two test periods. In response to low-intensity LVM conflicts at less than 25 mph, subjects initiated braking at TTC of about 4.0 seconds with ACAS enabled as opposed to 3.9 seconds with ACAS disabled. It should be noted that ACAS is not active under 20 mph and only active between 20 and 25 mph if host vehicle speed initially passed the 25 mph mark. The other condition also involved low-intensity LVM conflicts but with steering response at speeds between 25 and 35 mph. In this case, subjects initiated steering at longer TTC with ACAS disabled than with ACAS enabled. In both driving modes though, TTC was quite large (≥ 8 seconds). By considering confidence levels higher than 85 percent ($p < 0.15$), there were statistically significant differences in response initiation times between the two test periods in four other scenarios as indicated in Table 4-24. Again, the reader is cautioned about the lack of robustness in the ACAS-Disabled versus ACAS-Enabled effects measured since only very few cases out of many tests performed were found to be statistically significant. These might be spurious effects.

Measures of response initiation would have a great impact on the outcome of Monte Carlo simulations used for estimation of safety benefits, especially if benefits estimates were based on FOT data with very few severe near-crashes. Based on the results shown in Table 4-24, Monte Carlo simulations were run on only six conditions with statistically significant differences in the mean values between ACAS-Disabled and ACAS-Enabled (Period 4) test periods.

Table 4-21. TTC/TH (sec) and p-Values at Brake Onset by Scenario, Speed, Event, Driving Mode, and Intensity Level

Scenario	Speed Bin	Event	ACAS Disabled				ACAS Enabled				p-value	
			Low Int.		High Int.		Low Int.		High Int.		Low Int.	High Int.
			Avg	Std	Avg	Std	Avg	Std	Avg	Std		
Lead Vehicle Stopped - Brake (TTC)	< 25 mph	Conflict	3.5	1.0	2.9	0.7	3.4	1.0	2.9	0.7	0.29	0.29
		Near Crash	2.6	0.6	2.2	0.5	2.6	0.7	2.2	0.6	0.56	0.41
	>= 25 & < 35 mph	Conflict	4.3	1.0	3.9	0.9	4.2	1.0	3.8	0.9	0.20	0.55
		Near Crash	3.6	1.0	3.0	0.9	3.5	0.9	2.8	0.7	0.13	0.16
	>= 35 mph	Conflict	4.4	0.9	4.2	0.9	4.3	0.7	4.1	0.8	0.15	0.53
		Near Crash	4.0	0.9	3.3	0.7	4.0	0.8	3.7	0.9	0.56	0.07
Lead Vehicle Moving - Brake (TTC)	< 25 mph	Conflict	3.9	1.4	2.7	0.7	4.0	1.5	2.8	0.8	0.05	0.53
		Near Crash	3.0	1.6			3.0	0.9			0.68	
	>= 25 & < 35 mph	Conflict	4.7	1.5	3.6	1.1	4.6	1.4	3.5	1.1	0.38	0.73
		Near Crash	3.7	1.1			3.7	1.2	1.7	0.2	0.83	
	>= 35 mph	Conflict	5.1	1.4	4.3	1.6	5.0	1.4	4.3	1.7	0.45	0.93
		Near Crash	4.2	1.6			4.3	1.6	3.0	1.2	0.94	
Lead Vehicle Decelerating - Brake (TH)	< 25 mph	Conflict	1.9	0.8	2.0	0.8	1.8	0.7	1.9	0.8	0.09	0.62
		Near Crash	1.8	0.7	1.7	0.6	1.8	0.7	2.0	0.7	0.48	0.12
	>= 25 & < 35 mph	Conflict	2.4	1.2	2.6	1.2	2.4	1.2	2.6	1.2	1.00	0.43
		Near Crash	2.2	0.9	2.9	1.0	2.3	0.9	2.9	0.9	0.43	0.75
	>= 35 mph	Conflict	2.9	1.4	3.2	1.4	2.8	1.4	3.1	1.3	0.28	0.36
		Near Crash	2.8	1.2	4.0	1.2	2.8	1.2	3.8	1.1	0.77	0.26

Table 4-22. TTC/TH (sec) and p-Values at Steer Onset by Scenario, Speed, Event, Driving Mode, and Intensity Level (highlighted cells refer to $p < 0.15$)

Scenario	Speed Bin	Event	ACAS Disabled				ACAS Enabled				p-value	
			Low Int.		High Int.		Low Int.		High Int.		Low Int.	High Int.
			Avg	Std	Avg	Std	Avg	Std	Avg	Std		
Lead Vehicle Stopped - Steer (TTC)	< 25 mph	Conflict	3.9	1.6			3.8	1.2	3.0	0.6	0.87	
		Near Crash										
	>= 25 & < 35 mph	Conflict					3.8	1.1				
		Near Crash										
	>= 35 mph	Conflict										
		Near Crash										
Lead Vehicle Moving - Steer (TTC)	< 25 mph	Conflict	8.1	4.5			11.1	8.7			0.22	
		Near Crash										
	>= 25 & < 35 mph	Conflict	10.3	3.7			8.0	3.1			0.05	
		Near Crash										
	>= 35 mph	Conflict	8.7	5.5	9.9	11.3	8.5	4.3	7.5	4.3	0.80	0.37
		Near Crash	9.9	10.7			7.4	3.9			0.20	
Lead Vehicle Decelerating - Steer (TH)	< 25 mph	Conflict	1.9	1.0	1.8	1.0	2.3	1.5	2.2	1.2	0.48	0.47
		Near Crash										
	>= 25 & < 35 mph	Conflict	1.5	0.9			1.4	1.0			0.70	
		Near Crash										
	>= 35 mph	Conflict	1.3	0.8			2.1	1.4	1.9	1.4	0.11	
		Near Crash										

Table 4-23. TTC/TH (sec) and p-Values at Brake and Steer Onset by Scenario, Speed, Event, Driving Mode, and Intensity Level (highlighted cells refer to p < 0.15)

Scenario	Speed Bin	Event	ACAS Disabled				ACAS Enabled				p-value	
			Low Int.		High Int.		Low Int.		High Int.		Low Int.	High Int.
			Avg	Std	Avg	Std	Avg	Std	Avg	Std		
Lead Vehicle Stopped - Brake & Steer (TTC)	< 25 mph	Conflict	4.4	1.6			4.1	1.2			0.58	
		Near Crash										
	>= 25 & < 35 mph	Conflict										
		Near Crash										
	>= 35 mph	Conflict										
		Near Crash										
Lead Vehicle Moving - Brake & Steer (TTC)	< 25 mph	Conflict					7.3	2.8				
		Near Crash										
	>= 25 & < 35 mph	Conflict										
		Near Crash										
	>= 35 mph	Conflict					9.0	5.2				
		Near Crash										
Lead Vehicle Decelerating - Brake & Steer (TH)	< 25 mph	Conflict	2.2	0.8	2.2	0.7	2.3	1.2	2.5	1.2	0.82	0.54
		Near Crash										
	>= 25 & < 35 mph	Conflict	2.3	1.2	2.1	1.1	2.6	1.3	2.4	1.2	0.40	0.38
		Near Crash					2.5	1.1				
	>= 35 mph	Conflict	2.7	1.1	2.8	1.2	2.9	1.3	2.8	1.4	0.75	0.89
		Near Crash	2.7	0.7			2.4	1.2	2.5	1.3	0.54	

Table 4-24. Summary of Statistically Significant (p < 0.15) Results of Response Initiation by Scenario, Speed, Event, Driving Mode, and Intensity Level

Conflict Level	Dynamic Scenario	Driver Response	Speed Bin (mph)	Mean TTC/TH (sec)		p-value
				ACAS Disabled	*ACAS Enabled*	
Low Intensity Conflict	LVD (TH)	Brake	< 25	1.89	1.84	0.09
		Steer	>= 35	1.31	2.09	0.11
	LVM (TTC)	Brake	< 25	3.9	4.04	0.05
		Steer	>= 25 & < 35	10.26	8.03	0.05
Low Intensity Near Crash	LVS (TTC)	Brake	>= 25 & < 35	3.61	3.51	0.13
High Intensity Near Crash	LVS (TTC)	Brake	>= 35	3.26	3.65	0.07

The onset of brake response to the LVD scenario was also examined using the TTC measure that accounts for the deceleration level of the lead vehicle. Statistically significant differences ($p < 0.05$) were found in the mean values of this TTC between the ACAS-Disabled and ACAS-Enabled (Period 4) test periods only at vehicle speeds greater than or equal to 35 mph. The results at this speed range are as follows:

- Low-intensity conflict – ACAS-Disabled: Mean TTC= 5.2 seconds and standard deviation= 1.4 seconds; ACAS-Enabled: Mean TTC= 5.1 seconds and standard deviation= 1.4 seconds; p= 0.02.
- High intensity conflict – ACAS-Disabled: Mean TTC= 5.3 seconds and standard deviation= 1.4 seconds; ACAS-Enabled: Mean TTC= 5.2 seconds and standard deviation= 1.4 seconds; p= 0.04.
- Low-intensity near-crash – ACAS-Disabled: Mean TTC= 5.0 seconds and standard deviation= 1.4 seconds; ACAS-Enabled: Mean TTC= 4.9 seconds and standard deviation= 1.3 seconds; p= 0.02.
- High intensity near-crash – ACAS-Disabled: Mean TTC= 5.1 seconds and standard deviation= 1.3 seconds; ACAS-Enabled: Mean TTC= 4.9 seconds and standard deviation= 1.2 seconds; p= 0.04.

Even though the mean TTC is higher in the ACAS-Disabled test period, this difference is less than or equal to 0.1 seconds between the two test periods. This same difference is also reflected in the TH measure (not statistically significant) at the onset of brake response.

The intensity of driver response to rear-end pre-crash dynamic scenarios was analyzed at two different speed bins: < 25 mph and ≥ 25 mph. Given the number of conditions and measures, as well as preliminary analysis of data, the two speed bins were deemed appropriate to compare driver performance with and without ACAS assistance. Three measures of response intensity during the conflict/ near-crash event were examined for each of the three driver responses:

- Brake:
  - Minimum TTC
  - Maximum longitudinal deceleration
  - Average longitudinal acceleration
- Steer:
  - Minimum TTC
  - Maximum lateral acceleration
  - Average lateral acceleration
- Brake and steer:
  - Minimum TTC
  - Maximum acceleration $[((\text{maximum longitudinal acceleration})^2 + (\text{maximum lateral acceleration})^2)^{1/2}]$
  - Average acceleration $[((\text{average longitudinal acceleration})^2 + (\text{average lateral acceleration})^2)^{1/2}]$

Table 4-25, Table 4-26, and Table 4-27 provide the average and standard deviation values of minimum TTC (TTCmin) for each of the three scenarios at two speed bins for ACAS-Disabled and ACAS-Enabled (Period 4) test periods, which are associated respectively with brake, steer, and brake and steer responses. In addition, these tables list p values from two-sample t tests to find any statistically significant differences in the means of minimum TTC between the two test periods. There were only three conditions in which a statistically significant difference ($p \leq 0.05$) in minimum TTC was observed between the two test periods: one from brake response and two from steer response. In response to low-intensity LVM conflicts at less than 25 mph, the average minimum TTC due to braking was 3.3 seconds with ACAS enabled as compared to 3.2 seconds with ACAS disabled, a difference of only 0.1 second. Significant differences in the means of minimum TTC between the two test periods were much larger in steering response to lead vehicle decelerating conflict at low-and high-intensity levels. In both levels, the average minimum TTC values were smaller with ACAS enabled than with ACAS disabled by a difference of 0.4 and 0.6 seconds respectively for low-and high-intensity levels. This suggests that ACAS might increase the safety risk of drivers when steering in response to the LVD scenario at speeds greater than or equal to 25 mph. No statistically significant difference was observed in average value of minimum TTC between the two driving modes with brake and steer response due mostly to the low number of events in each condition.

Table 4-28 provides statistically significant results of differences in minimum TTC between ACAS-Disabled and ACAS-Enabled test periods, considering confidence levels higher than 85 percent ($p \leq 0.15$). Again, the reader is cautioned about the lack of robustness in the ACAS-Disabled versus ACAS-Enabled effects measured since only very few cases out of many tests performed were found to be statistically significant.

In addition to the three situations of $p \leq 0.05$ discussed above, there were three more cases with travel speeds below 25 mph. At this speed range, ACAS is generally not active. In two of the new cases, drivers with ACAS enabled had higher minimum TTC than with ACAS disabled. This suggests that ACAS had some positive safety impact in this speed range.

Table 4-25. TTCmin (sec) and p-Values during Brake Response by Scenario, Speed, Event, Driving Mode, and Intensity Level (highlighted cells refer to $p \leq 0.05$)

Scenario	Speed Bin	Event	ACAS Disabled				ACAS Enabled				p-value	
			Low Int.		High Int.		Low Int.		High Int.		Low Int.	High Int.
			Avg	Std	Avg	Std	Avg	Std	Avg	Std		
Lead Vehicle Stopped - Brake	< 25 mph	Conflict	2.7	0.9	2.1	0.4	2.6	0.8	2.1	0.4	0.11	0.22
		Near Crash	1.8	0.3	1.4	0.2	1.8	0.3	1.4	0.2	0.55	0.26
	>= 25 mph	Conflict	2.8	0.8	2.2	0.4	2.8	0.8	2.2	0.4	1.00	0.62
		Near Crash	1.9	0.3	1.5	0.3	1.9	0.3	1.5	0.3	0.31	0.39
Lead Vehicle Moving - Brake	< 25 mph	Conflict	3.2	0.7	2.3	0.3	3.3	0.7	2.3	0.3	0.02	0.21
		Near Crash	2.4	0.3			2.4	0.3			0.19	
	>= 25 mph	Conflict	3.6	0.7	2.4	0.4	3.5	0.7	2.3	0.4	0.17	0.29
		Near Crash	2.5	0.4			2.4	0.4			0.36	
Lead Vehicle Decelerating - Brake	< 25 mph	Conflict	3.0	0.8	2.6	0.6	3.0	0.8	2.6	0.6	0.53	1.00
		Near Crash	2.3	0.5	1.5	0.4	2.3	0.5	1.7	0.6	0.74	0.30
	>= 25 mph	Conflict	3.6	1.2	3.3	1.1	3.6	1.2	3.3	1.1	1.00	1.00
		Near Crash	2.6	0.6	3.1	1.1	2.6	0.6	3.1	1.1	0.69	0.61

Table 4-26. TTCmin (sec) and p-Values during Steer Response by Scenario, Speed, Event, Driving Mode, and Intensity Level

Scenario	Speed Bin	Event	ACAS Disabled				ACAS Enabled				p-value	
			Low Int.		High Int.		Low Int.		High Int.		Low Int.	High Int.
			Avg	Std	Avg	Std	Avg	Std	Avg	Std		
Lead Vehicle Stopped - Steer	< 25 mph	Conflict	2.7	1.3			2.7	1.1			0.92	
		Near Crash										
	>= 25 mph	Conflict	3.1	0.9			2.7	1.1			0.38	
		Near Crash										
Lead Vehicle Moving - Steer	< 25 mph	Conflict	3.6	1.1			3.7	0.6			0.76	
		Near Crash										
	>= 25 mph	Conflict	3.7	0.7	2.3	0.3	3.6	0.7	2.2	0.4	0.24	0.35
		Near Crash	2.5	0.3			2.5	0.5			0.77	
Lead Vehicle Decelerating - Steer	< 25 mph	Conflict	3.1	0.6	2.8	0.3	3.5	0.6	3.0	0.4	0.08	0.26
		Near Crash										
	>= 25 mph	Conflict	3.6	0.5	3.2	0.3	3.2	0.7	2.6	0.5	0.05	0.01
		Near Crash										

Highlighted cells refer to $p \leq 0.05$

Table 4-27. TTCmin (sec) and p-Values during Brake and Steer Response by Scenario, Speed, Event, Driving Mode, and Intensity Level

Scenario	Speed Bin	Event	ACAS Disabled				ACAS Enabled				p-value	
			Low Int.		High Int.		Low Int.		High Int.		Low Int.	High Int.
			Avg	Std	Avg	Std	Avg	Std	Avg	Std		
Lead Vehicle Stopped - Brake & Steer	< 25 mph	Conflict	2.4	1.0			3.0	0.7			0.15	
		Near Crash										
	>= 25 mph	Conflict										
		Near Crash										
Lead Vehicle Moving - Brake & Steer	< 25 mph	Conflict										
		Near Crash										
	>= 25 mph	Conflict	3.3	0.6			3.6	0.6			0.16	
		Near Crash										
Lead Vehicle Decelerating - Brake & Steer	< 25 mph	Conflict	2.7	0.6	2.5	0.2	2.5	0.8	2.5	0.6	0.66	0.96
		Near Crash										
	>= 25 mph	Conflict	3.1	0.7	2.7	0.6	3.0	0.7	2.8	0.5	0.25	0.75
		Near Crash	2.3	0.4	2.1	0.3	2.3	0.4	2.1	0.4	0.55	0.73

Table 4-28. Summary of Statistically Significant ($p \leq 0.15$) Results of Minimum TTC by Scenario, Speed, Event, Driving Mode, and Intensity Level

Conflict Level	Dynamic Scenario	Driver Response	Speed Bin (mph)	Mean TTCmin (sec)		p-value
				ACAS Disabled	*ACAS Enabled*	
Low Intensity Conflict	LVS	Brake	< 25	2.7	2.6	0.11
		Brake & Steer	< 25	2.4	3.0	0.15
	LVD	Steer	< 25	3.1	3.5	0.08
			>= 25	3.6	3.2	0.05
	LVM	Brake	< 25	3.2	3.3	0.02
High Intensity Conflict	LVD	Steer	>= 25	3.2	2.6	0.01

The analysis of response intensity using measures other than minimum TTC yielded few statistically significant differences between ACAS-Disabled and ACAS-Enabled (Period 4) test periods. Other measures encompassed peak and average accelerations for brake, steer, and brake and steer responses. Table 4-29 lists a summary of statistically significant results of these measures for $p \leq 0.05$, which all belong to brake response only. Even though the results are statistically significant, these differences in mean values between the two driving modes are almost negligible – difference < 0.2 m/s2. The results shown in Table 4-28 and Table 4-29 suggest that drivers would exhibit similar response intensity with and without the assistance of ACAS once they encountered a driving conflict. It should be noted, however, that the majority of conflicts encountered during the FOT was of benign nature based on the mean values of response intensity measures (minimum TTC > 1.5 seconds, average deceleration < 0.2 g, and peak deceleration < 0.25 g).

Table 4-29. Summary of Statistically Significant ($p \leq 0.05$) Results of Acceleration by Scenario, Speed, Event, Driving Mode, and Intensity Level

Conflict Level	Dynamic Scenario	Driver Response	Speed Bin (mph)	Measure	Mean Value (m/s^2)		p-value
					ACAS Disabled	*ACAS Enabled*	
Low Intensity Conflict	LVS	Brake	>= 25	Average Deceleration	-1.7	-1.7	0.04
	LVM	Brake	>= 25	Peak Deceleration	-1.9	-2.0	0.02
High Intensity Conflict	LVS	Brake	>= 25	Peak Deceleration	-2.3	-2.4	0.002
Low Intensity Near Crash	LVS	Brake	< 25	Peak Deceleration	-2.3	-2.2	0.002
			>= 25	Peak Deceleration	-2.4	-2.5	0.02
			>= 25	Average Deceleration	-2.0	-2.2	0.001
	LVD	Brake	>= 25	Peak Deceleration	-2.2	-2.3	0.002

Summary Results of Response to Rear-End Pre-Crash Scenarios

Overall, driver response to driving conflicts was similar between ACAS-Disabled and ACAS-Enabled (Period 4) test periods with few exceptions. The analysis of response initiation measures (TTC or TH) revealed only 6 statistically significant ($p \leq 0.15$) differences in mean values between the two driving modes – 6 out of 108 combinations of scenarios (4 conflict levels × 3 dynamic scenarios × 3 driver responses × 3 speed bins). There were only two statistically significant ($p \leq 0.05$) differences in mean TTC values between the two driving modes in response to LVM scenarios at speeds below 35 mph. The examination of TTC for the LVD scenario, taking into account the deceleration level of the lead vehicle, identified statistically significant differences ($p < 0.05$) between the means of the two test periods at vehicle speeds greater than or equal to 35 mph. However, this difference was only 0.1 seconds or less in each of the four conflict-intensity levels.

The analysis of response intensity measures identified few cases where differences were found between ACAS-Disabled and ACAS-Enabled (Period 4) test periods. These differences however were very small. There were only three statistically significant ($p \leq 0.05$) differences in mean values of minimum TTC between the two test periods – three out of 72 combinations (4 conflict levels × 3 dynamic scenarios × 3 driver responses × 2 speed bins). Moreover, there were 7 statistically significant ($p \leq 0.05$) differences in mean values of peak and average deceleration between the two test periods – 7 out of 144 combinations (4 conflict levels × 3 dynamic scenarios × 3 driver responses × 2 speed bins × 2 measures).

4.2.2.3 Safety Benefits Estimation

This section estimates potential safety benefits of ACAS based on driver/vehicle performance data in driving conflicts encountered during the FOT with ACAS disabled and ACAS enabled. The safety benefits are projected in terms of the number of rear-end crashes that ACAS might prevent annually. This is a nonclassical approach to predict safety benefits of a crash countermeasure system using noncrash data. The number of preventable rear-end crashes, B, is expressed as follows:

$$B = N_{wo} \times SE \tag{5}$$

where,

$N_{wo} \equiv$ Annual number of rear-end crashes prior to ACAS deployment
$SE \equiv$ Total ACAS effectiveness in mitigating rear-end crashes

Based on 2002 GES statistics, light vehicles were involved in 1,791,000 police-reported rear-end crashes in the United States. The number of rear-end crashes not reported to the police is estimated at about 1.2 times police-reported rear-end crashes. Thus, an estimate of N_{wo} is approximately 3,940,000 crashes annually. Generally, SE can be estimated from the following equation:

$$SE = \sum_{i=1}^{3} P_{wo}(S_i \mid C) \times E(S_i) \tag{6}$$

where,

$P_{wo}(S_i|C) \equiv$ Probability of an encounter with driving conflict scenario S_i prior to a crash given that a rear-end crash has happened *without* ACAS assistance
$E(S_i) \equiv$ ACAS effectiveness in scenario S_i

The values of $P_{wo}(S_i|C)$ are obtained from the GES for LVD, LVS, and LVM scenarios preceding rear-end crashes. Based on GES statistics, these values are 0.61, 0.28, and 0.08, respectively. The values of $E(S_i)$ are computed from FOT data using Equation 2. To compute $E(S_i)$, values of the Exposure Ratio and Prevention Ratio were estimated from FOT data as explained below.

Based on statistically significant results of Section 4.2.2.1, ACAS was effective in reducing the exposure of drivers to 7 combinations of rear-end pre-crash dynamic scenarios. Values of their Exposure Ratio are derived from Table 4-20. In Section 4.2.2.2, the difference in response initiation between ACAS-Disabled and ACAS-Enabled test periods was statistically significant ($p < 0.15$) in 6 combinations of scenarios. The reader is again cautioned about the lack of robustness in the ACAS-Disabled versus ACAS-Enabled effects measured since only very few cases out of many tests performed were found to be statistically significant. These might be spurious effects. Since ACAS is intended to warn inattentive drivers of an impending rear-end crash, its main goal then is to speed up driver response to driving conflicts ahead. Monte Carlo simulations were executed on these 6 scenarios using distributions of response initiation measures as well as other distributions to estimate the probability of a crash with and without ACAS assistance ($P_w(C|S)$ and $P_{wo}(C|S)$). These estimates of the probability of a crash were used to compute values of the Prevention Ratio in Table 4-30 as discussed below. Table 4-30 lists the scenarios, provides values for relevant exposure ratios, and identifies those that require estimates of prevention ratios for safety benefits estimation. Values of $E(S_i)$ are computed from estimates in Table 4-30.

Table 4-30. Scenario Data as a Basis for Estimating Safety Benefits

Dynamic Scenario	Driver Response	Speed Bin (mph)	Low Intensity Conflict		High Intensity Conflict		Low Intensity Near Crash		High Intensity Near Crash	
			Prev. Ratio	Exp. Ratio	Prev. Ratio	Exp. Ratio	Prev. Ratio	Exp. Ratio	Prev. Ratio	Exp. Ratio
LVS	Brake	>= 25 & < 35					*			0.71
		>= 35		0.86					*	
LVM	Brake	< 25	*							
	Steer	>= 25 & < 35	*							
		>= 35		0.79						
LVD	Brake	< 25	*							
		>= 35		0.82		0.85		0.91		0.89
	Steer	>= 35	*							

Prev. Ratio= Prevention Ratio
Exp. Ratio= Exposure Ratio
*: To be estimated by Monte Carlo simulations

Prevention Ratio Estimation Using Monte Carlo Simulations

Monte Carlo simulations were executed to estimate the prevention ratios for the scenarios denoted with an asterisk in Table 4-30. Table 4-31 lists the variables and their concomitant values used in the simulations. Data for initial conditions of each scenario and response initiation (TTC) variables were drawn from the FOT, which vary between the ACAS-Disabled and ACAS-Enabled test periods. Data for response intensity (a_F and a_{Lat}), representing evasive maneuvers, were selected by the independent evaluator based on data from different experiments in the literature. Distributions of the response intensity were assumed to be normal and the same for the ACAS-Disabled and ACAS-Enabled test periods. Thus, estimates of the prevention ratio were influenced by the initial conditions of the scenario and response initiation. One million iterations were exercised to compute the probability of a crash in each scenario with ACAS disabled ($P_{wo}(C|S)$) and then with ACAS enabled ($P_w(C|S)$). The values of $P_{wo}(C|S)$ and $P_w(C|S)$ were based on the average of 10 runs for each set of iterations. The "Prevention Ratio" is simply $P_w(C|S)/P_{wo}(C|S)$.

The simulation of the low-intensity conflict LVM scenario with steer response at speeds between 25 and 35 mph yielded no crashes due to the high TTC values at response initiation in the ACAS-Disabled and ACAS-Enabled test periods. The simulation of the low-intensity conflict LVD scenario with brake response at speeds below 25 mph produced positive results with ACAS enabled even though the mean value of TH at brake onset was slightly less with ACAS enabled than with ACAS disabled. This was due to higher closing speeds at brake onset in the ACAS-Disabled test period than the ACAS-Enabled test period. It should be noted that the results of response initiation were statistically significant at $p \leq 0.05$ in only one scenario in Table 4-31:

low-intensity conflict LVM scenario with brake response at speeds below 25 mph. The results of response initiation for other scenarios in Table 4-31 were statistically significant at $p \leq 0.15$.

Table 4-31. Monte Carlo Simulation Data and Results

Scenario	Speed	Variable	Distribution	ACAS Disabled		ACAS Enabled		Prevention Ratio
				Mean	Std. Dev.	Mean	Std. Dev.	
Low Intensity Near Crash: LVS - Brake	25 - 35 mph	TTC (s)	Lognormal	3.6	1.0	3.5	0.9	**1**
		a_F (g)	Normal	0.6	0.1	0.6	0.1	
High Intensity Near Crash: LVS - Brake	>= 35 mph	TTC (s)	Lognormal	3.3	0.7	3.7	0.9	**0.73**
		a_F (g)	Normal	0.6	0.1	0.6	0.1	
Low Intensity Conflict: LVM - Brake	< 25 mph	TTC (s)	Lognormal	3.9	1.5	4.0	1.5	**0.27**
		v_L (mph)	Normal	8.3	4.3	8.7	4.5	
		a_F (g)	Normal	0.4	0.1	0.4	0.1	
Low Intensity Conflict: LVD - Brake	< 25 mph	TH (s)	Lognormal	1.9	0.8	1.8	0.7	**0.78**
		v_L (mph)	Normal	14.1	4.4	14.5	4.3	
		a_L (g)	Normal	0.17	0.05	0.17	0.05	
		a_F (g)	Normal	0.6	0.1	0.6	0.1	
Low Intensity Conflict: LVD - Steer	>= 35 mph	TH (s)	Lognormal	1.3	0.8	2.1	1.4	**0.79**
		v_L (mph)	Normal	34.2	15	34.2	15	
		a_L (g)	Normal	0.17	0.06	0.2	0.09	
		ILCD (ft)	Normal	12.0	2.5	12	2.5	
		aLat (g)	Normal	0.2	0.1	0.2	0.1	

ILCD= Intended lane change distance
aLat= Lateral acceleration
$g = 9.81\ m/s^2$ 1 m = 3.281 ft

Table 4-32 lists estimates of ACAS effectiveness in specific scenarios, $E(S_i)$, based on results presented in Table 4-30 and Table 4-31. These estimates were computed from values of "Exposure Ratio" and "Prevention Ratio" as indicated in Equation 2. All but one of the seven estimates were derived from driver/vehicle performance in low-intensity conflicts during the FOT. The remaining one was based on driver/vehicle performance in high-intensity near-crash LVS scenarios with brake response between 25 and 35 mph. There were two estimates of ACAS effectiveness in LVS scenarios with brake response at speeds greater than or equal to 35 mph. One estimate is based on the exposure ratio in low-intensity conflicts and the other is based on the prevention ratio in high-intensity near-crashes. The low-intensity conflict estimate was selected for safety benefits estimation because the exposure ratio is more statistically reliable than the prevention ratio in this case.

Table 4-32. Estimates of ACAS Effectiveness in Specific Scenarios

Dynamic Scenario	Driver Response	Conflict Level	Speed Bin (mph)	E(S_i)		
				E	E_L	E_U
LVS	Brake	High Intensity Near Crash	>= 25 & < 35	0.29	0.12	0.46
		Low Intensity Conflict	>= 35	0.14	0.00	0.27
LVM	Brake	Low Intensity Conflict	< 25	0.73		
	Steer	Low Intensity Conflict	>= 35	0.21	0.00	0.43
LVD	Brake	Low Intensity Conflict	< 25	0.22		
		Low Intensity Conflict	>= 35	0.18	0.06	0.30
	Steer	Low Intensity Conflict	>= 35	0.21		

E_L= Lower bound of E estimate based on 95% confidence level

E_U= Upper bound of E estimate based on 95% confidence level

Projection of Safety Benefits:

As indicated in Equation 6, total ACAS effectiveness in preventing rear-end crashes, SE, is calculated using estimates of E(S_i) as well as estimates of corresponding baseline crash data $P_{wo}(S_i|C)$. Table 4-33 provides a distribution of rear-end crashes by pre-crash scenario and attempted avoidance maneuver prior to the crash based on the 1996-1997 Crashworthiness Data System (CDS). Pre-crash scenarios are identified in the GES and CDS from coded qualitative data that distinguish between vehicle dynamic states but do not provide any quantitative information, for instance, about the deceleration value of the decelerating lead vehicle or how long the lead vehicle was stopped prior to impact. The CDS is a better source than the GES to obtain data on avoidance maneuvers attempted by drivers prior to rear-end collisions. CDS files are based on a detailed investigation of the crash and contain fewer unknowns about the avoidance maneuver. Table 4-34 provides a distribution of rear-end crashes by pre-crash scenario and vehicle speed based on the 2000 GES. Both travel speed and speed limit data are presented. Ideally, travel speed crash data are the better source to estimate the safety benefits. Unfortunately, over 60 percent of the travel speed data in both the GES and CDS are coded as "unknown." Thus, speed limit crash data with very few coded unknowns might provide an alternative or surrogate source to travel speed. It should be noted that distributions of baseline crash data by scenario, speed, or attempted avoidance maneuver usually remain constant through the years.

Table 4-33. Percent Distribution of Rear-End Crash Data by Scenario and Attempted Avoidance Maneuver (Based on 1996-1997 CDS)

	Pre-Crash Scenario		
Maneuver	**LVS**	**LVD**	**LVM**
Brake	58	64	71
Steer	10	1	3
Brake & Steer	20	10	2
None	12	25	24

Table 4-34. Percent Distribution of Rear-End Crash Data by Scenario and Vehicle Speed (Based on 2000 GES)

Scenario	mph	Travel Speed*	Speed Limit
LVS	< 25	49	1
	>= 25 & < 35	21	17
	>= 35	30	83
LVD	< 25	56	1
	>= 25 & < 35	15	17
	>= 35	30	82
LVM	< 25	27	1
	>= 25 & < 35	14	16
	>= 35	59	84

*: > 60% coded as "unknown"

Figure 4-42 displays a range of estimates for ACAS effectiveness in preventing rear-end crashes (SE) based on different types of crash data applied to Equation 6 for combinations of scenarios, maneuvers, and vehicle speeds. It should be noted that ACAS effectiveness in low-intensity LVD conflict at speeds below 25 mph (Table 4-32) was excluded from safety benefits estimation due to a non statistically significant difference in mean TTC values accounting for lead vehicle deceleration between the two test periods at this speed range. Upper and lower bound estimates for ACAS effectiveness are also provided based on 95 percent confidence level. Mean SE estimates vary between 6 and 15 percent, lower bound SE estimate might be as low as 3 percent, and upper bound SE estimate could be as high as 26 percent. Applying these SE estimates to Equation 5, ACAS might avoid between approximately 133,000 (lowest 95% confidence bound) and 1,039,000 (highest 95% confidence bound) rear-end crashes in the United States annually if fully deployed in the light-vehicle fleet. Based on mean SE estimates, the number of preventable rear-end crashes with ACAS assistance varies between 254,000 and 593,000 crashes depending on crash statistics used in Equation 6.

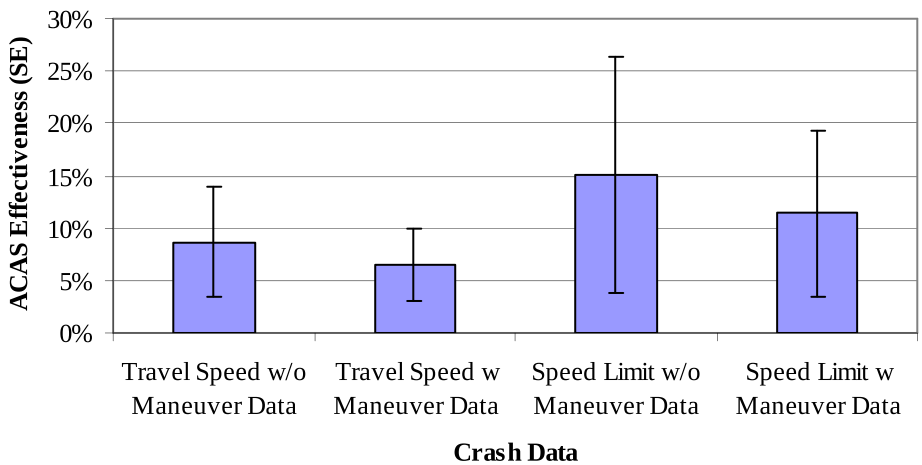


Figure 4-42. Estimates of ACAS Effectiveness in Preventing Rear-End Crashes

Summary Results of Safety Benefits Estimation:

ACAS, as an integrated system of FCW and ACC functions, has the potential to prevent about 6 to 15 percent of all rear-end crashes depending on the source of crash data used for safety benefits estimation. This system effectiveness ranges between 3 and 26 percent according to 95 percent confidence bounds. By averaging estimates from the four sources of crash data, ACAS might prevent about 10 percent of all rear-end crashes with variability between 3 and 17 percent based on 95 percent confidence bounds. As a result, ACAS might avoid between approximately 133,000 and 687,000 rear-end crashes in the United States annually. About 17 percent of these benefits based on travel speed rear-end crash data are accrued from response to driving conflicts at vehicle speeds below 25 mph, 20 percent of these benefits are attributed to less exposure to driving conflicts at vehicle speeds between 25 and 35 mph, and the remaining 63 percent of these benefits are also attributed to less exposure to driving conflicts at speeds greater than or equal to 35 mph. On the other hand, 9 percent of the benefits based on speed limit rear-end crash data are due to vehicle speeds between 25 and 35 mph while the remaining 91 percent are found at speeds greater than or equal to 35 mph. It should be noted that FCW was active in only 4 percent of the VDT below 25 mph. At speeds between 25 and 35 mph, FCW and ACC accounted respectively for 73 percent and 1 percent of all VDT at this speed range. FCW and ACC accounted respectively for 54 percent and 42 percent of all VDT at speeds greater than or equal to 35 mph. These projections of safety benefits are conservative estimates due to the exclusion of system effectiveness in some scenarios represented by fewer than 8 subjects (Section 4.2.2.1), and a "best guess" given the nature of data collected during this FOT. There were no crashes in this FOT, and subjects generally experienced few severe near-crashes as discussed below.

4.3 NEAR CRASH ANALYSIS

This section examines driver exposure and response to severe near-crashes at low and high-intensity levels from FOT numerical data (numerical episodes). Severe near-crashes were defined based on the following criteria imposed on two measures of response intensity: minimum TTC must be less than or equal to 3 seconds and peak deceleration/acceleration must be greater than 0.3g. This analysis was conducted for *all* drivers at the aggregate data level. In addition, this section identifies video episodes triggered by ACAS crash-imminent alerts that might have prevented a crash, near-crash, or heavy braking by the host vehicle. These episodes were judged based on driver distraction immediately prior to the crash-imminent alert, or on high peak deceleration exerted by the driver after the alert in response to the driving conflict.

4.3.1 Analysis of Numerical Near-Crash Episodes

This analysis examines and compares near-crashes between ACAS-Disabled and ACAS-Enabled (Period 4) test periods. LVS, LVM, and LVD scenario near-crashes were considered at low-and high-intensity levels. Severe near-crashes were identified from all near-crashes based on the following criteria imposed on each of the three response types:

- Brake:
  - Minimum TTC is less than or equal to 3 seconds, and
  - Maximum longitudinal acceleration is less than –0.3g

- Steer:
  - Minimum TTC is less than or equal to 3 seconds, and
  - Maximum lateral acceleration is greater than 0.2g
- Brake and Steer:
  - Minimum TTC is less than or equal to 3 seconds, and
  - Maximum acceleration is greater than 0.3g

The minimum TTC criterion above was selected to encompass most near-crashes as defined in Appendix C, and the associated acceleration criteria were imposed to ensure that a considerable action was taken by the driver to resolve the near-crash. Table 4-35 provides the counts of all and severe near-crashes at low-and high-intensity levels by driver response and ACAS test periods. Moreover, the ratio of the count of severe near-crashes over the count of all near-crashes is also included in Table 4-35. This ratio is slightly higher with ACAS enabled than with ACAS disabled for total near-crashes at the low-intensity level. On the other hand, this ratio is the same between ACAS-Disabled and ACAS-Enabled (Period 4) test periods for total near-crashes at the high-intensity level. Thus, ACAS does not appear to have an impact on the ratio of severe near-crashes over all near-crashes. It should be noted that no statistical tests were performed to support these observations.

Table 4-36 lists the number of all and severe near-crashes per 1,000 km traveled at low-and high-intensity levels by driver response and ACAS test periods. Overall, the data show lower exposure rates to severe low-intensity near-crashes with ACAS enabled than with ACAS disabled except for the steer response. In contrast, ACAS effectiveness was prevalent in all severe high-intensity near-crash scenarios. Figure 4-43 and Figure 4-44 illustrate the effectiveness of ACAS in reducing exposure to all and severe near-crashes respectively at low- and high-intensity levels. The data show that ACAS is more effective in reducing overall exposure to severe near-crashes at the high-intensity level than at the low-intensity level. These results suggest positive safety impact by ACAS in mitigating the occurrence of severe near-crashes by about 20 percent based on aggregate FOT data from all subjects.

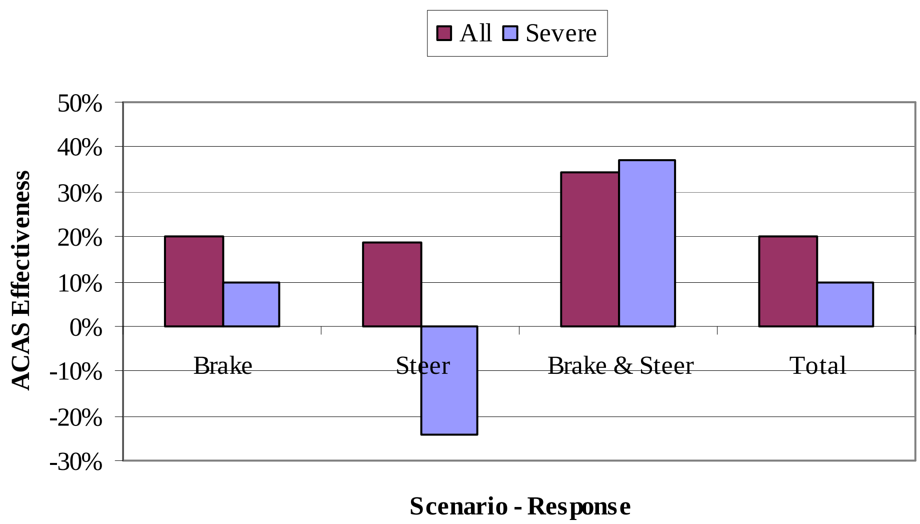
Table 4-35. Breakdown of All and Severe Near-Crash Counts and Ratios

		Low Intensity Near Crash			High Intensity Near Crash		
Response	ACAS	All	Severe	Ratio	All	Severe	Ratio
Brake	Disabled	2,864	403	0.14	562	108	0.19
	Enabled	4,057	642	0.16	799	153	0.19
Steer	Disabled	48	6	0.13	17	4	0.24
	Enabled	69	14	0.20	28	7	0.25
Brake & Steer	Disabled	31	9	0.29	20	8	0.40
	Enabled	36	10	0.28	22	8	0.36
Total	Disabled	2,943	418	0.14	599	120	0.20
	Enabled	4,162	666	0.16	849	168	0.20

Ratio= Severe near crashes/All near crashes

Table 4-36. Number of All and Severe Near-Crashes per 1,000 Km Traveled

Response	ACAS	Low Intensity Near Crash: All	Low Intensity Near Crash: Severe	High Intensity Near Crash: All	High Intensity Near Crash: Severe
Brake	Disabled	79	11	16	3
	Enabled	63	10	12	2
Steer	Disabled	1.3	0.17	0.5	0.11
	Enabled	1.1	0.22	0.4	0.11
Brake & Steer	Disabled	0.9	0.25	0.6	0.22
	Enabled	0.6	0.16	0.3	0.12
Total	Disabled	81	12	17	3.3
	Enabled	65	10	13	2.6



Negative percentage refers to an increase in exposure.

Figure 4-43. ACAS Effectiveness in Reducing Encounters with Low-Intensity Near-Crashes

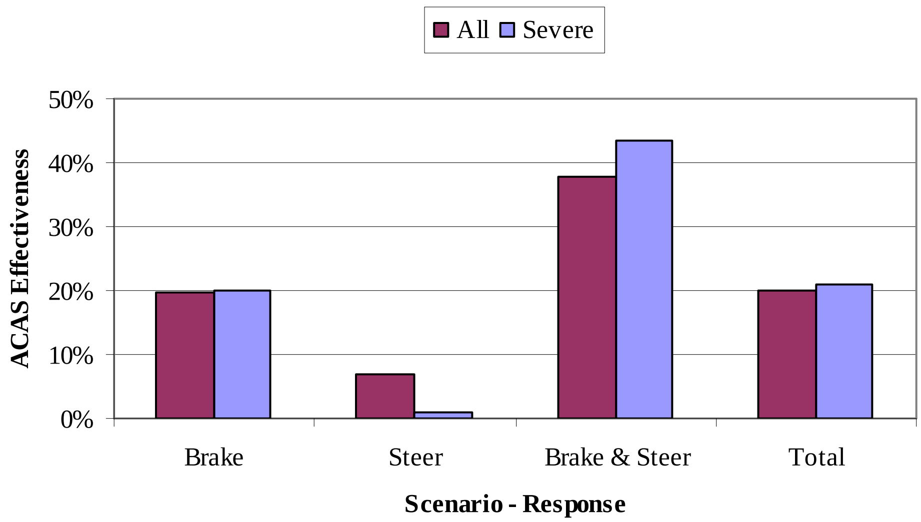


Figure 4-44. ACAS Effectiveness in Reducing Encounters with High-Intensity Near-Crashes

ACAS settings for FCW and ACC were examined in all and severe near-crashes at low-and high-intensity levels. Figure 4-45 and Figure 4-46 display the distributions of all and severe near-crashes by FCW sensitivity settings respectively at low-and high-intensity levels. It should be noted that FCW sensitivity setting only controls the visual alert scheme and not the crash-imminent alert. The data show minor differences in the distributions between all and severe near-crashes by FCW sensitivity settings. The three highest settings – S1, S3, and S6 – observed in near-crashes correspond to the same highest settings selected by FOT subjects in their overall VDT with FCW in Period 4. Figure 4-47 and Figure 4-48 illustrate the distributions of all and severe near-crashes by ACC gap settings respectively at low-and high-intensity levels. There are minor differences with ACC in the distributions between all and severe near-crashes at the low-intensity level. In contrast, there is an observable difference with ACC at the high-intensity level. The majority of severe high-intensity near-crashes with ACC occurred at 1-second gap setting. The reader is cautioned about this observation because high-intensity level distributions with ACC were based on a very small number of cases. It should be noted that the distributions presented in Figure 4-47 and Figure 4-48 do not parallel ACC gap setting choices set by FOT subjects in their overall VDT with ACC in Period 4 (highest settings were 1.4 and 2 seconds).

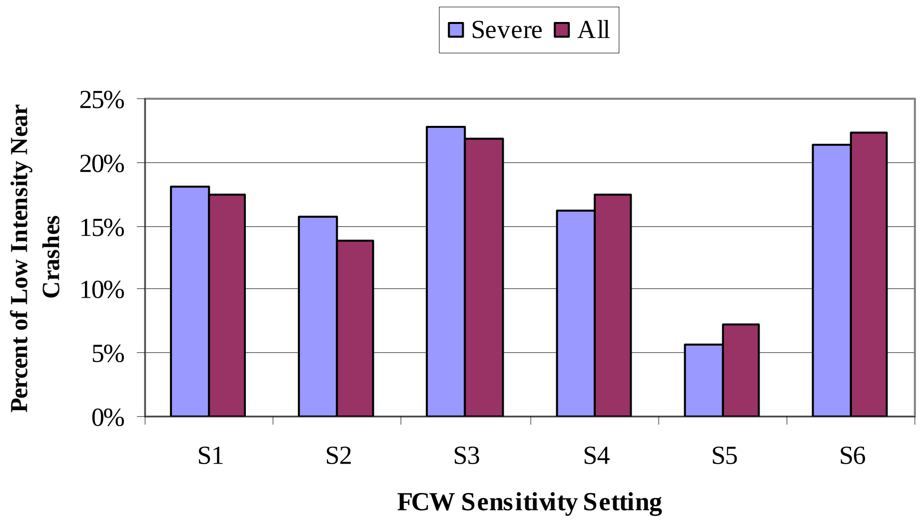


Figure 4-45. Distribution of Low-Intensity Near-Crashes by FCW Sensitivity Setting

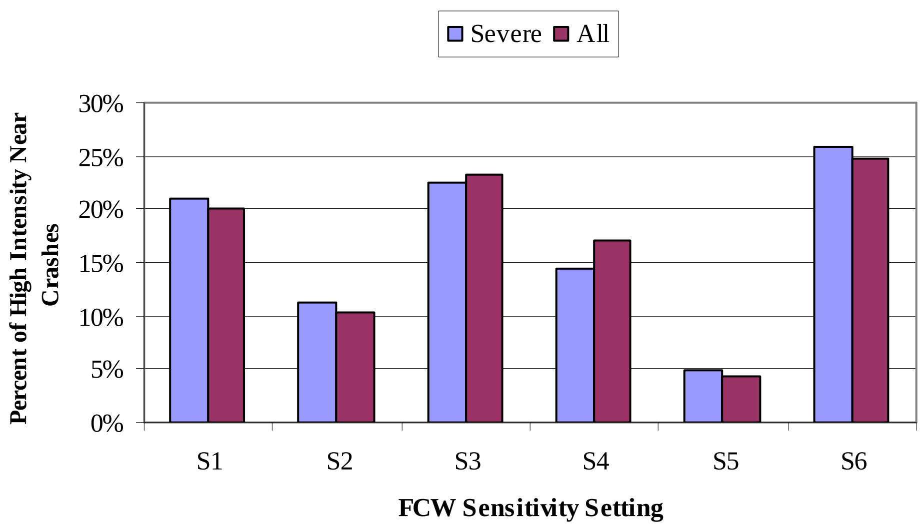


Figure 4-46. Distribution of High-Intensity Near-Crashes by FCW Sensitivity Setting

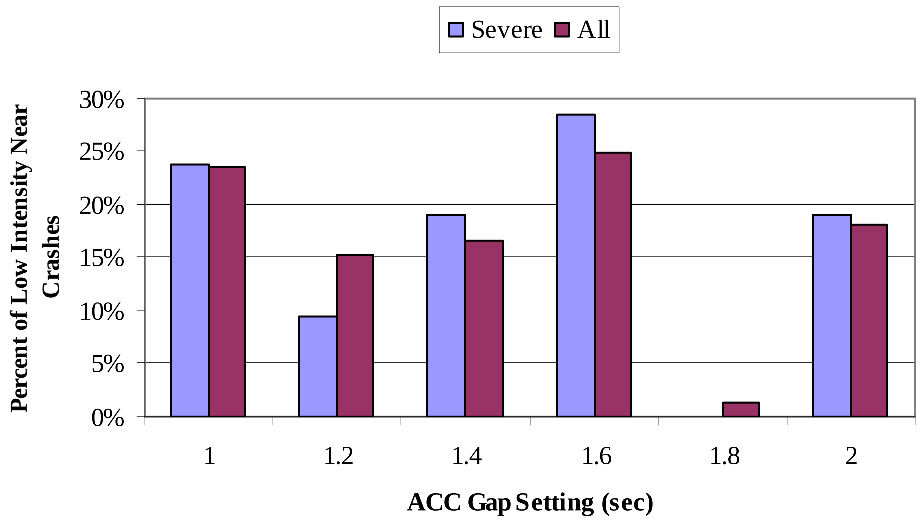


Figure 4-47. Distribution of Low-Intensity Near-Crashes by ACC Gap Setting

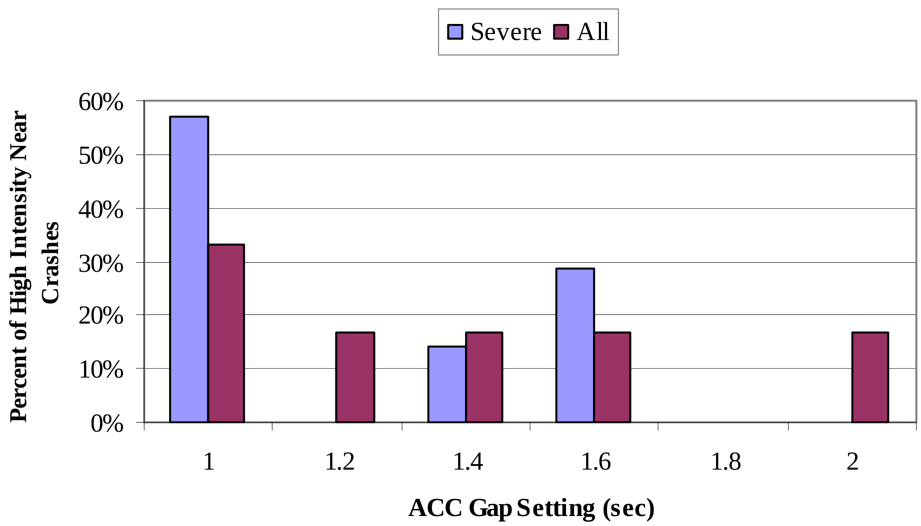


Figure 4-48. Distribution of High-Intensity Near-Crashes by ACC Gap Setting

4.3.2 Analysis of Video Episodes

This analysis identifies video episodes triggered by crash-imminent alerts in which drivers were inattentive or had to exert an intense response to avoid a rear-end collision. The intent of this analysis was to point out events that the ACAS was possibly helpful in preventing a rear-end collision or potentially heavy braking that might lead to someone else striking the ACAS vehicle from the rear. Based on observations of video episodes, the analysts subjectively identified 24 such events from the ACAS-Enabled test period (Periods 3 and 4). This is not to say that these were the only episodes where ACAS showed a positive safety impact. Many other episodes were also observed where ACAS played a beneficial role in providing timely alerts to drivers and thus assisted them in resolving potentially safety critical situations. These 24 episodes, however, provided dramatic evidence of the positive safety potential of ACAS. Table 4-37 provides a summary of these 24 episodes.

Table 4-37 is partitioned into two sets of events: the first set are events where the driver was clearly distracted with eyes not directed toward the road ahead at the time of the critical event (e.g., lead vehicle brakes), and the second set where the driver was not distracted based on the observation that the driver was looking at the road. The table lists the time headway at the start of the event prior to the ACAS warning. Next, the table shows the time to collision (range to lead vehicle/closing speed) at the time of ACAS warning, time to collision at the time of the driver's initial response to the ACAS warning, and the minimum time to collision during the event. The peak braking deceleration (m/s^2) during the event is also provided. Figure 4-49 illustrates the distribution of these peak decelerations. A brief description of the event is also noted.

For the 11 driver distracted events, it was clear that the driver was unaware of the critical events ahead as their eyes were not on the road. ACAS alerted the drivers of the lead vehicle braking (in one case the lead vehicle was stopped) and the diver responded to the alert by braking to avoid a crash. For the 13 not-distracted events, the driver appeared to be looking at the road ahead; however, there are at least two explanations for why the driver failed to respond to the event prior to being warned by ACAS. In several situations, the events were sudden and unexpected such as: sudden braking by lead vehicle, a lead vehicle conflict with a bike, a sudden new and stopped lead vehicle. In other situations, the driver may have been cognitively distracted and failed to notice unfolding events even though he/she was looking at the road. In 11 of the 13 cases, the lead vehicle braked and the driver responded by braking only after being warned by ACAS. In one case, the lead vehicle was stopped and in another case the driver's response to the ACAS warning was to brake and steer. For all 24 cases, the drivers' responses to ACAS warnings were relatively severe as measured by the peak braking rate (m/s^2) shown in Figure 4-49. The mean braking rate is about 4.9 m/s^2; this is quite high (about 0.5 g) and rarely encountered.

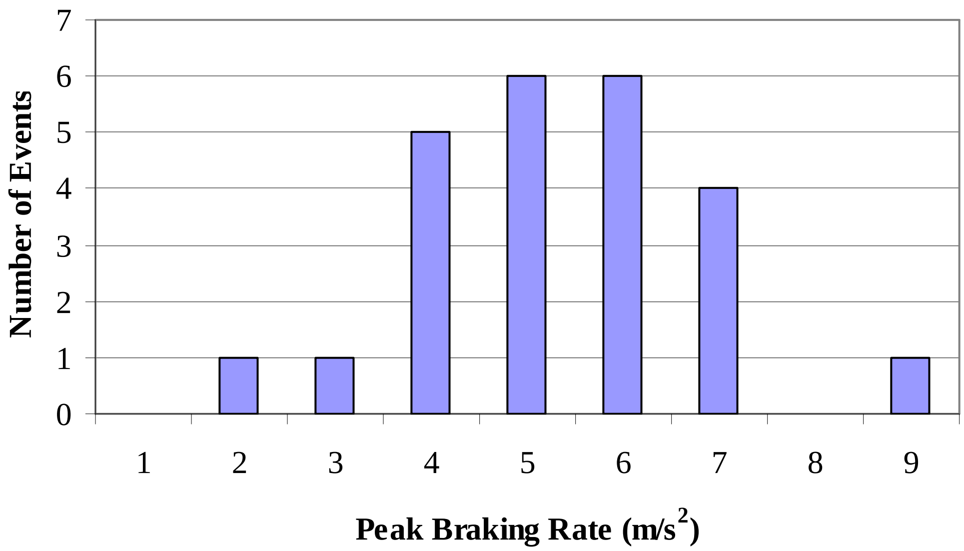


Figure 4-49. Distribution of Peak Braking Rates for ACAS Crash Avoidance Events

An examination of video episodes triggered by crash-imminent (silent) alerts during the ACAS-Disabled test period revealed 4 more cases where ACAS would have been very helpful as well. In 3 of these cases, subject # 31 was distracted (looking in rearview mirror, looking down inside the car, and retrieving something from his right side) when the silent alert was issued. The subject, however, managed to resolve the conflict by braking at peak deceleration levels of 5.1, 3.5, and 5.1 m/s^2. In the fourth case, subject # 48 braked after the alert at a peak deceleration level of 7.5 m/s^2 in response to a lead vehicle cutting in front as it entered the highway.

Summary Results of Severe Near-Crash Analysis:

ACAS has the potential to reduce the number of severe near-crashes per 1,000 km traveled by 10 percent and 20 percent respectively for low-and high-intensity levels based on aggregate FOT data from all subjects. FCW sensitivity settings did not affect the frequency rate of severe near-crashes. Similarly, ACC gap settings did not have an impact on the frequency rate of low-intensity severe near-crashes. However, 1-second gap setting was prevalent in high-intensity severe near-crashes. This result must be taken with caution since there were very few high-intensity severe near-crashes with ACC during the FOT.

Table 4-37. Summary Data, ACAS Crash Avoidance Events

Subject	Time Headway Start of Event	Time to Collision at ACAS Warning	Time to Collision at Driver Response	Time to Collision Minimum	Peak Brake m/s2	Scenario Description
Driver Distracted						
32	1.8	4.5	3.3	3.2	-3.4	Driver looking in rearview mirror. Lead vehicle brakes. Driver brakes after ACAS warning.
33	2.0	5.0	4.9	4.3	-2.4	Driver looking away to left. Lead vehicle brakes. Driver brakes after ACAS warning.
36	1.8	6.1	4.6	3.6	-6.0	Driver looking in side mirror. Lead vehicle brakes. Driver brakes after 3rd ACAS warning.
48	1.8	5.5	2.5	1.0	-4.5	Driver looking down. Lead vehicle brakes to stop. Driver brakes after ACAS warning.
49	2.1	4.1	3.2	2.1	-4.7	Driver looking in rearview mirror. Lead vehicle brakes. Driver brakes after ACAS warning.
53	1.3	6.1	2.5	2.2	-3.8	Driver retrieving something. Lead vehicle brakes. Driver brakes after ACAS warning.
65	1.1	6.7	5.6	2.8	-6.3	Driver looking back talking to rear seat passenger. Lead vehicle brakes. Driver brakes after ACAS
69	4.2	3.4	3.3	3.0	-4.0	Driver looking in rearview mirror. *Lead vehicle stopped*. Driver brakes after ACAS warning. Lead vehicle initially detected at 76.7 m, lost at 71.8 m, and re-detected at 63.3 m.
79	1.0	4.5	4.2	3.6	-5.8	Driver looking in rearview mirror to pass decelerating LV. Driver brakes after ACAS warning.
79	1.5	5.2	2.8	2.5	-4.6	Driver reading and then retrieving something from right side. Lead vehicle brakes. Driver brakes after ACAS warning.
84	2.0	4.6	2.3	1.9	-6.7	Driver looking in rearview mirror. Lead vehicle brakes. Driver brakes after ACAS warning.
Driver Not Distracted						
32	1.1	7.3	6.0	4.5	-3.5	Lead vehicle brakes hard suddenly on highway. Driver brakes after ACAS warning.
34	1.3	6.5	4.2	2.8	-5.6	Lead vehicle brakes hard. Driver brakes after ACAS warning.
35	2.4	3.1	3.0	2.4	-4.2	Lead vehicle brakes, host approaching fast. Driver brakes after ACAS warning.
37	1.4	19.0	6.0	3.8	-6.7	Lead vehicle brakes hard suddenly at onset of yellow signal. Driver brakes after ACAS warning.
38	4.4	3.6	2.8	1.4	-1.5	Lead vehicle brakes to turn right, then stops for bike. Driver brakes *and steers* after ACAS warning. Radar did not declare CIPV until 72 m away.
42	1.6	16.2	4.5	2.9	-5.5	Lead vehicle brakes. Driver brakes after ACAS warning.
42	1.7	4.7	4.3	3.9	-3.9	Lead vehicle brakes. Driver brakes after ACAS warning.
45	3.0	3.6	2.8	1.8	-5.5	Lead vehicle braking for cars stopped at intersection. Driver brakes after ACAS warning.
45	3.3	2.9	2.5	2.3	-3.9	First lead vehicle changed lanes to reveal another *lead vehicle stopped* at red light. Radar late in recognizing LVS. Driver brakes after ACAS warning.
52	1.7	5.4	3.3	2.8	-5.9	Lead vehicle brakes to turn left. Driver brakes after ACAS warning.
77	0.8	4.0	2.8	1.9	-8.3	Lead vehicle brakes. Driver seems attentive, but very tired. Driver brakes after ACAS warning.
84	1.3	8.1	4.7	2.9	-5.9	Lead vehicle brakes. Driver brakes after ACAS warning.
86	1.7	9.3	3.6	2.6	-4.5	Lead vehicle brakes for vehicle ahead slowly exiting road. Driver not aware of slow vehicle ahead of lead vehicle. Driver brakes after ACAS warning.

The observation of video episodes triggered by crash-imminent alerts identified 24 events where ACAS assisted the driver in potentially preventing a crash, near-crash, or heavy braking. For 11 events, the driver was clearly distracted and unaware of the events ahead. ACAS alerted the drivers of the lead vehicle braking (in one case the lead vehicle was stopped) and the driver responded to the alert by braking to avoid a crash. For 13 events, the driver appeared to be looking at the road ahead; however, the driver failed to respond to the event prior to being warned by ACAS. In 11 of these 13 cases, the lead vehicle braked and the driver responded by braking only after being warned by ACAS. In one event, the lead vehicle was stopped and in another case the driver's response to the ACAS warning was to brake and steer. For all 24 cases, the drivers' responses to ACAS warnings were relatively severe with a mean braking rate of about 4.9 m/s^2 (about 0.5 g).

4.4 ACAS DRIVER IMPACT ANALYSIS

This analysis examines driver performance as an additional means of identifying positive and unintended negative effects of ACAS use on safe driving behavior. This analysis consists of three parts:

1. Analysis of normal driving situations using numerical data.
2. Analysis of inattention (distraction or eyes-off-the-road) using video episodes.
3. Observation of specific video episodes suggesting positive and negative safety effects of ACAS.

4.4.1 Analysis of Driver Performance in Normal Driving Situations

This analysis investigates driver performance in normal driving situations with ACAS-Disabled and with ACAS-Enabled (Period 4), where the host vehicle is not closing in on a lead vehicle. The following measures of performance are selected for this analysis:

1. Time headway when ACAS vehicle is traveling at constant speed. Time headway is defined as the range between ACAS and lead vehicle (m) divided by the ACAS vehicle speed (m/s).
2. Lane position when ACAS vehicle is traveling at constant speed. Lane position is defined as distance (m) from lane center (positive is right of center).
3. Speed ratio of ACAS vehicle speed over posted speed limit when ACAS vehicle is traveling at constant speed.

This analysis was conducted for *all*, *male*, *female*, *younger*, *middle-age*, and *older* subjects. Driving performance was compared between ACAS-Disabled and ACAS-Enabled (Period 4) test periods under the following conditions:

- Aggregate of all driving conditions
- Road types: freeways and non-freeways
- Traffic levels: low, moderate, and heavy
- Driving modes: CCC and ACC, and Manual 1 and Manual 2 + FCW

T-tests were conducted to determine if there is any statistically significant change in the measures of performance between ACAS-Disabled and ACAS-Enabled test periods.

4.4.1.1 Driver Performance – Time Headway

Figure 4-50 through Figure 4-55 show the distribution of headways for ACAS-Disabled versus ACAS-Enabled test periods by subject group for various road types and traffic levels. Figure 4-56 and Figure 4-57 show the distribution of headways for various driving modes by subject group. For all cases shown in Figure 4-50 through Figure 4-55, the headways for ACAS-Enabled are slightly less than for ACAS-Disabled (one exception: *older* drivers, low traffic, headways are equal). As shown in Figure 4-50 for all conditions, the ACAS-Enabled headway is about 2.5 seconds for the *all* group versus 2.7 seconds for ACAS-Disabled. This lower headway with ACAS-Enabled is consistent for all conditions analyzed. This result, by itself, suggests a slight negative safety impact for ACAS. Other things being equal, a shorter headway means less time to respond to a conflict. However, there are several ameliorating factors that suggest that these results should not be a cause for concern:

- Although the results are statistically significant in most cases, the difference in headway is relatively small, about 0.3 second.
- The absolute level of headway for ACAS driving, about 2.5 seconds overall, is within a safe range for the normal driving conditions investigated. This headway is greater than maximum gap setting of 2 seconds available for ACAS.
- The lower headways for ACAS are likely due, in part, to the ability of ACC to accommodate driving in higher levels of traffic density. Whereas CCC can only be used effectively in low traffic and long headways, ACC can be used in heavier traffic and shorter headways. The availability of FCW may also improve the ability of drivers to drive safely in heavier traffic and shorter headways.

In the case of CCC versus ACC, the headways for ACC are less, about 2.2 seconds versus 2.7 seconds for *all* drivers. This result is consistent with the ICC evaluation, which found that ICC headways were slightly less than CCC (about 1.9 seconds versus 2.2 seconds) for freeway driving (Koziol et al., 1999). Since most cruise control driving is performed on freeways, these results are generally comparable. In the case of Manual 1 versus Manual 2 + FCW, the headways for Manual 2 + FCW are also less, about 2.5 seconds versus 2.7 seconds for *all* drivers. These results also show that the headways for ACC are less than Manual 1. This result is not consistent with the ICC evaluation, which found that ICC headways were slightly greater than Manual (about 1.9 seconds versus 1.7 seconds). This inconsistency in results is likely due to the fact that ICC results were for freeway driving only.

The shorter headways for ACC, by itself, suggest a slightly negative safety impact for ACAS. However, as discussed above, the absolute value of headways for ACAS is generally above 2 seconds and is in a safe range. In addition, the lower headways for ACAS and ACC may also be attributed, in part, to limitations of the method used to measure headways. The ACAS radar sensor is the basic means of detecting targets and their range ahead of the vehicle. Since the effective range of the radar is limited (about 120 m for reliable measurements), as vehicle speeds increase, the maximum time headways that can be measured decrease. For example, other things being equal, the maximum time headway detectable at 30 m/s (about 67 mph) will be about 4 seconds, whereas at 15 m/s the maximum detectable headway will be about 8 seconds. Indeed, as the speed ratio analysis in Section 4.4.1.3 below shows, the average speed ratio for ACC (about 1.31 for *all* subjects) is slightly more than for CCC (about 1.26) and much greater than for Manual 1 (about 0.86).

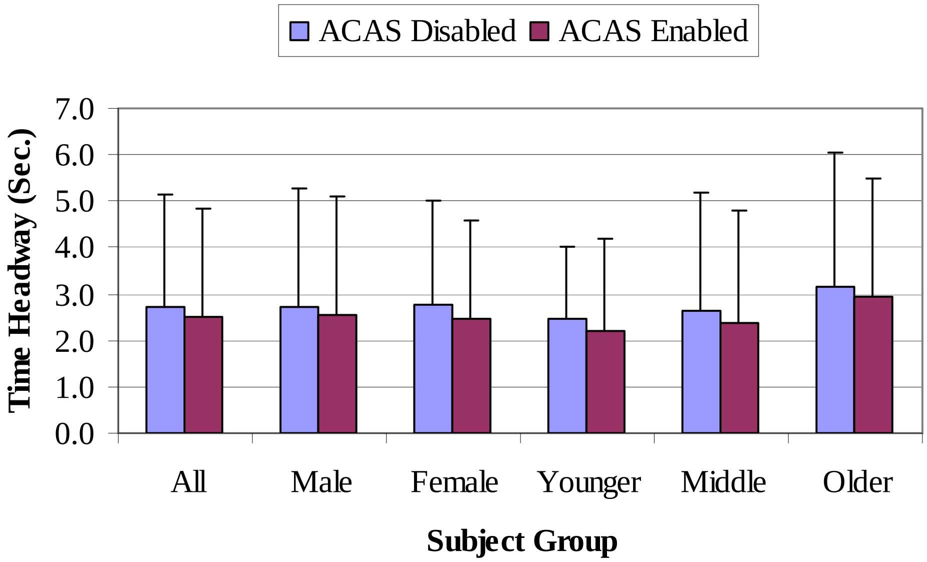


Figure 4-50. Time Headway for ACAS-Disabled versus ACAS-Enabled by Subject Group, All Conditions

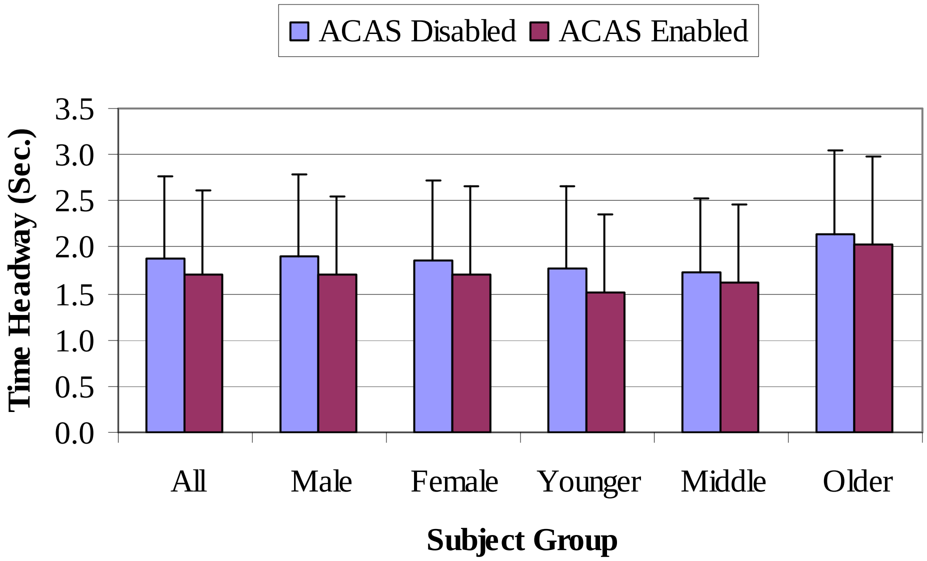


Figure 4-51. Time Headway for ACAS-Disabled versus ACAS-Enabled by Subject Group, Freeways

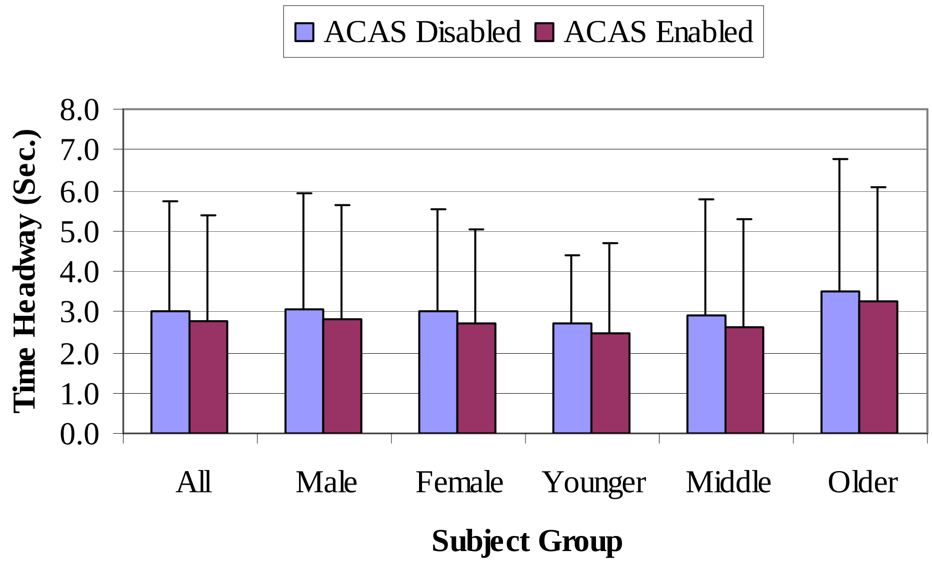


Figure 4-52. Time Headway for ACAS-Disabled versus ACAS-Enabled by Subject Group, Non-Freeways

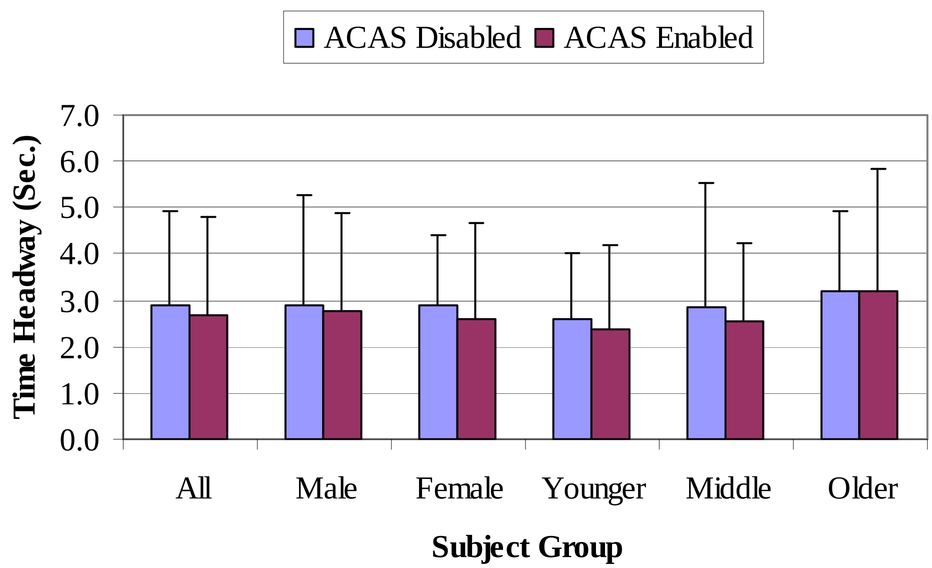


Figure 4-53. Time Headway for ACAS-Disabled versus ACAS-Enabled by Subject Group, Low Traffic

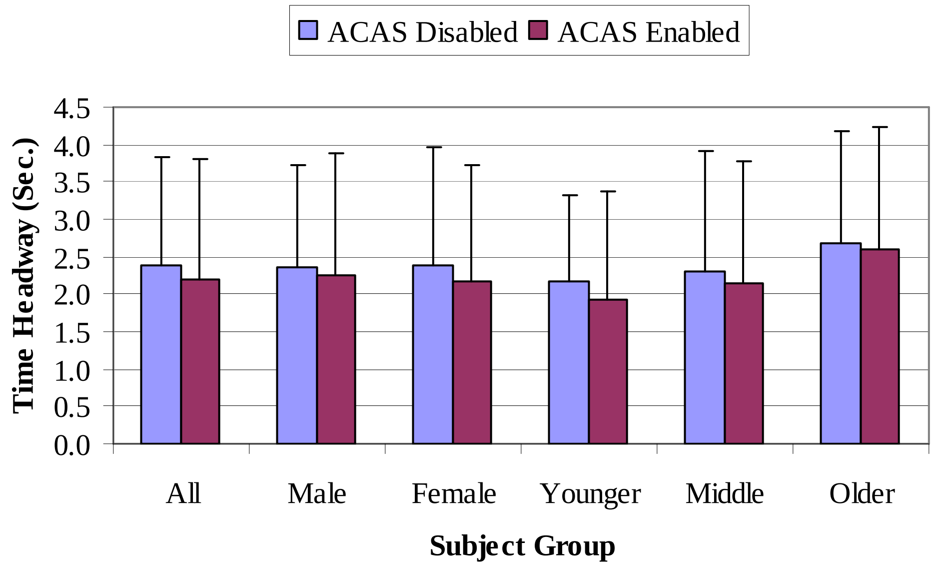


Figure 4-54. Time Headway for ACAS-Disabled versus ACAS-Enabled by Subject Group, Moderate Traffic

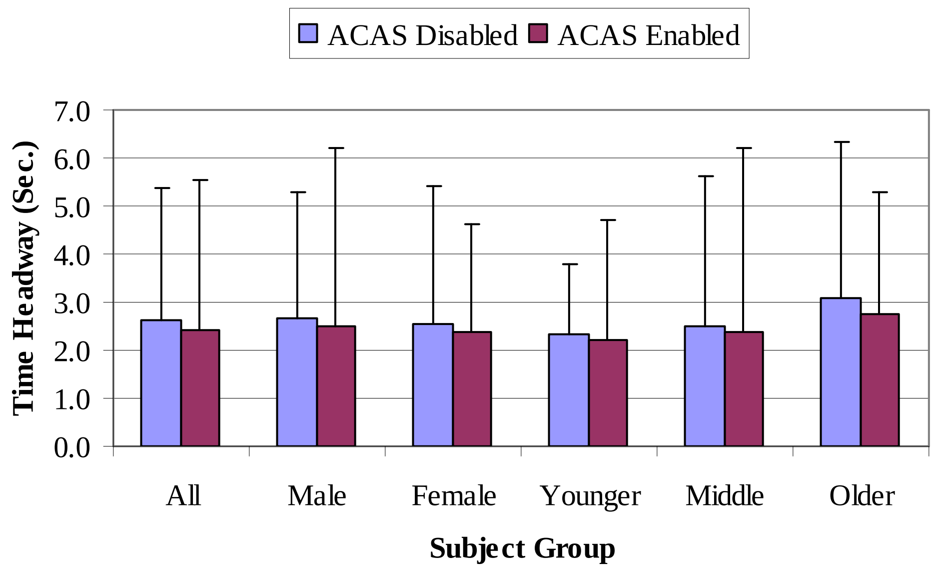


Figure 4-55. Time Headway for ACAS-Disabled versus ACAS-Enabled by Subject Group, Heavy Traffic

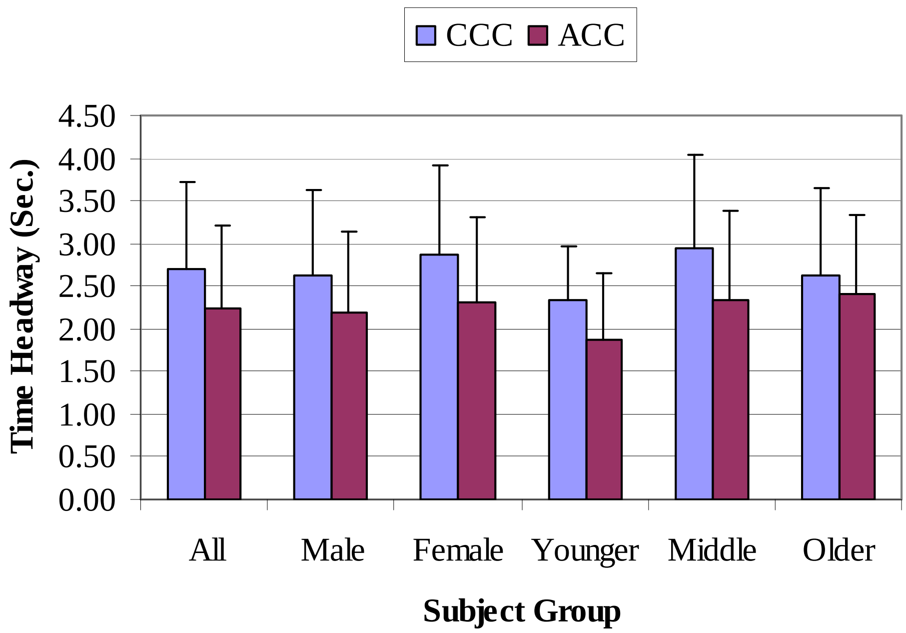


Figure 4-56. Time Headway for CCC versus ACC by Subject Group, All Conditions

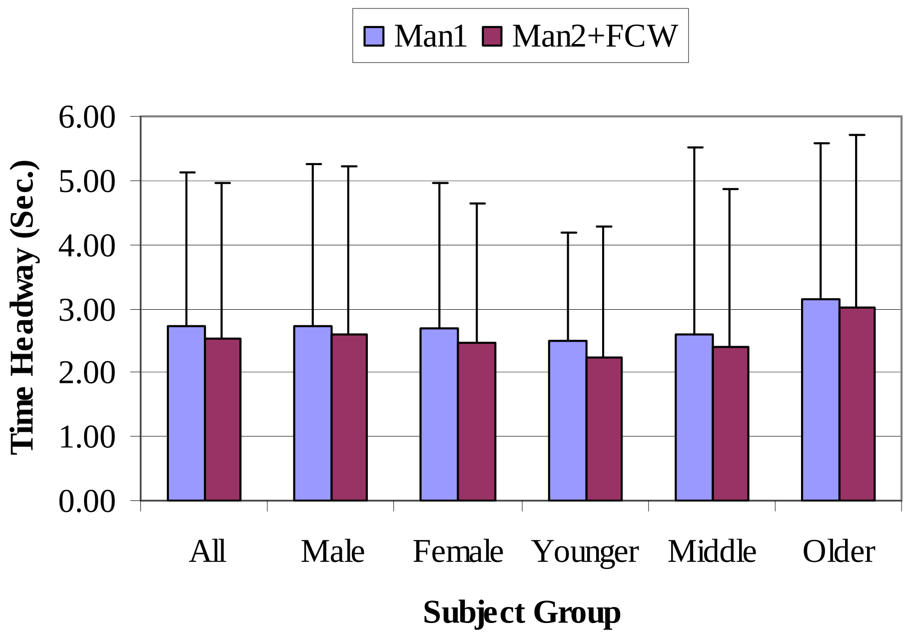


Figure 4-57. Time Headway for Manual 1 versus Manual 2 + FCW by Subject Group, All Conditions

4.4.1.2 Driver Performance – Lane Position

Figure 4-58 through Figure 4-63 show the distribution of lane position for ACAS-Disabled versus ACAS-Enabled (Period 4) test periods by subject group for various road type and traffic level conditions. The lane position value is the distance, in meters, from the lane center; a positive value is to the right of center. In general, as indicated in Figure 4-58 for all conditions, the lane position value for ACAS-Enabled is slightly greater than for ACAS-Disabled except for the *female* and *older* groups that are equal. The results, broken down by road type and traffic level, indicate a slightly greater lane position value for ACAS-Enabled. For the majority of situations, the lane position value for ACAS-Enabled is slightly greater than for ACAS-Disabled; however, there are some minor exceptions.

Although the differences in lane position between ACAS-Enabled and ACAS-Disabled are statistically significant in some cases, the absolute values are very similar. In fact, the maximum differences in mean lane position amount to less than 3 cm. Also, as indicated by the very large standard deviation error bars, there is considerable variation about the mean values for both ACAS-Enabled and ACAS-Disabled test periods. These results, based on the lane position performance measure, suggest no safety impact by ACAS.

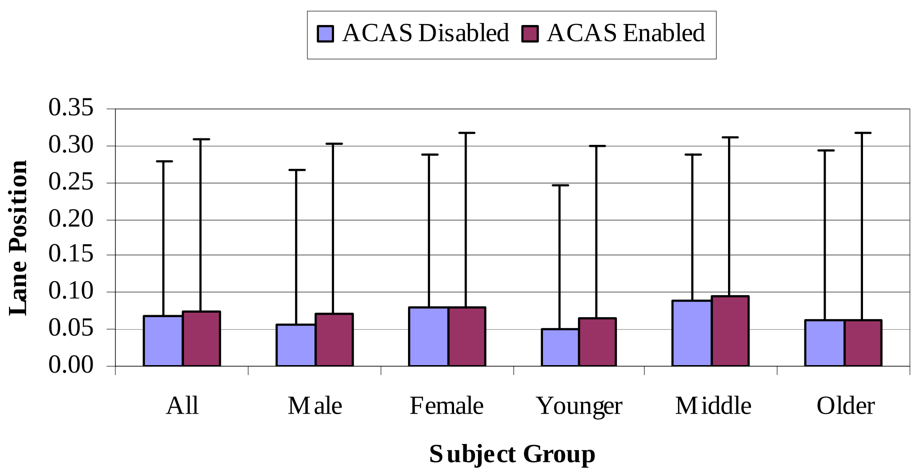


Figure 4-58. Lane Position (m) for ACAS-Disabled versus ACAS-Enabled by Subject Group, All Conditions

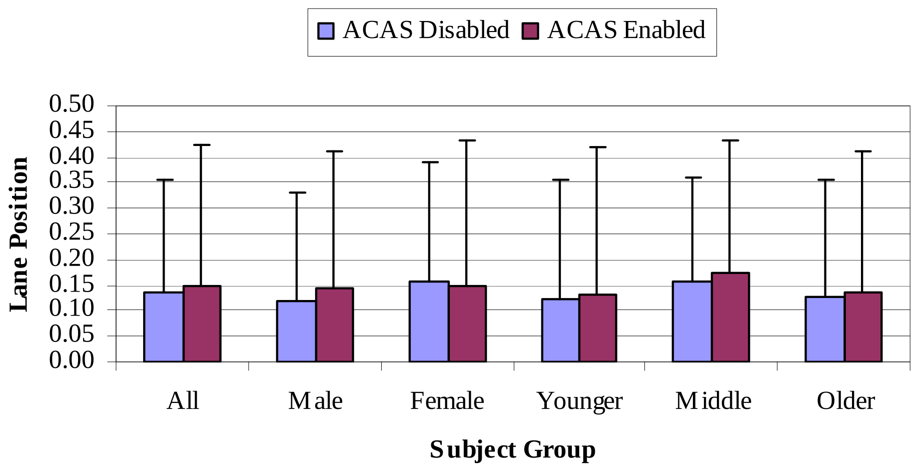


Figure 4-59. Lane Position (m) for ACAS-Disabled versus ACAS-Enabled by Subject Group, Freeways

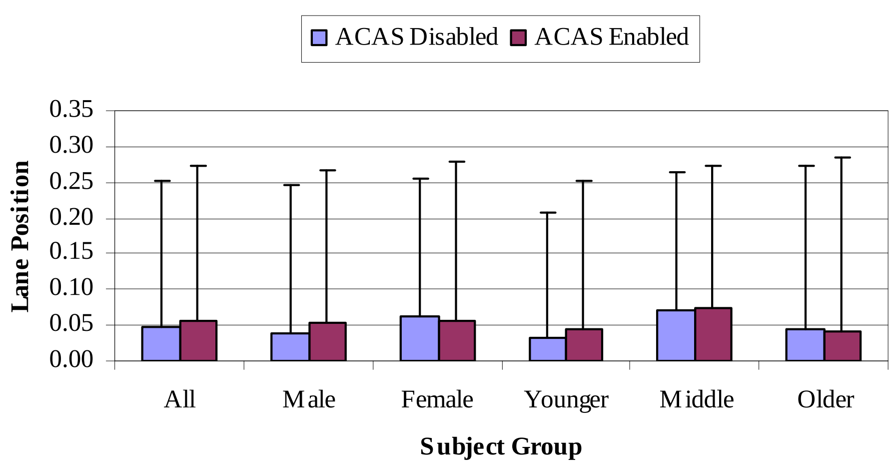


Figure 4-60. Lane Position (m) for ACAS-Disabled versus ACAS-Enabled by Subject Group, Non-Freeways

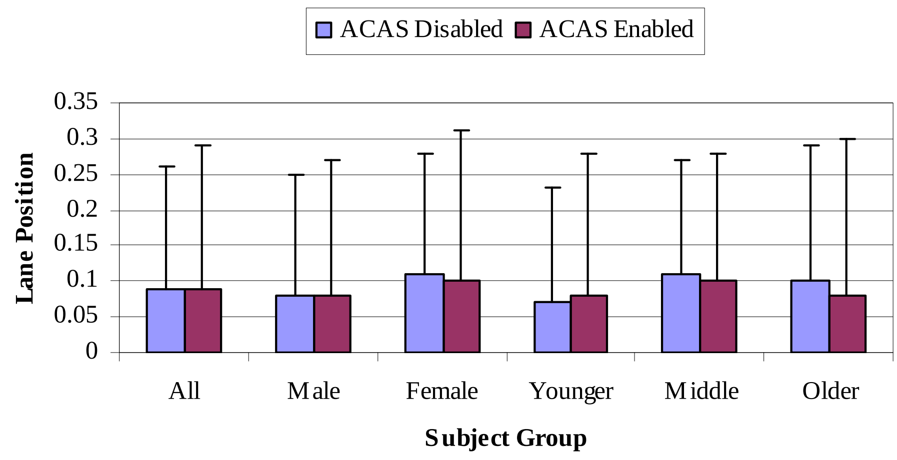


Figure 4-61. Lane Position (m) for ACAS-Disabled versus ACAS-Enabled by Subject Group, Low Traffic

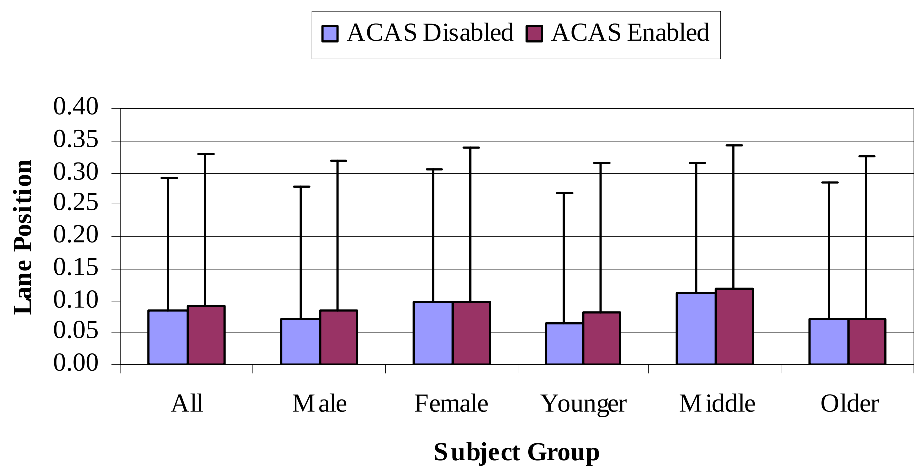


Figure 4-62. Lane Position (m) for ACAS-Disabled versus ACAS-Enabled by Subject Group, Moderate Traffic

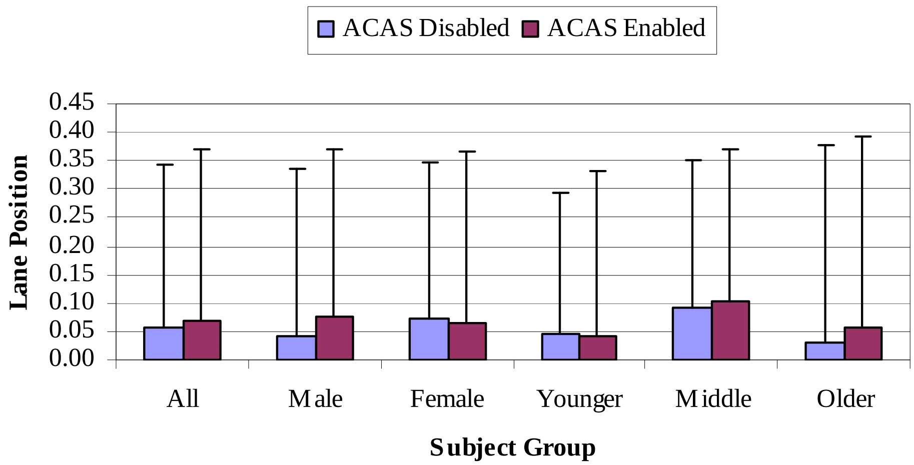


Figure 4-63. Lane Position (m) for ACAS-Disabled versus ACAS-Enabled by Subject Group, Heavy Traffic

4.4.1.3 Driver Performance – Speed Ratio

Figure 4-64 through Figure 4-69 show the distribution of speed ratios for ACAS-Disabled versus ACAS-Enabled (Period 4) test periods by subject group for various road types and traffic level conditions. Figure 4-70 and Figure 4-71 show the distribution of speed ratios for various driving modes by subject group. The speed ratio metric is the ratio of ACAS vehicle speed to the posted speed limit when the ACAS vehicle is traveling at constant speed. In general, the speed ratios for ACAS-Enabled are slightly less than for ACAS-Disabled for all road types and traffic levels. For example, as shown in Figure 4-64 for all conditions, the ACAS-Enabled speed ratio is about 0.90 for the *all* group versus 0.91 for ACAS-Disabled.

There are two exceptions to the general results of lower speed ratios for ACAS-Enabled identified above. For heavy traffic, the speed ratio for ACAS-Enabled (0.60 for *all* subjects) is slightly greater than for ACAS-Disabled (0.57); this result is statistically significant. This result may be attributed to ACAS providing drivers with an improved ability to drive in heavier traffic. Also, for low traffic, the speed ratios for both ACAS-Enabled (1.05 for *all* subjects) and ACAS-Disabled (1.12) are generally greater than 1.0. Although a speed ratio greater than 1.0 might suggest a negative safety impact for ACAS-Enabled, relative to ACAS-Disabled, the impact is slightly positive.

The speed ratio results shown in Figure 4-70 for CCC and ACC driving are notable in that the speed ratios for both systems are considerably greater than 1.0. For example, the speed ratios for the *all* group for CCC and ACC driving are 1.26 and 1.31, respectively. This result suggests a negative safety impact for both systems, but relative to CCC use, the slight increase in speed ratio for ACC does not appear to represent a meaningful additional impact. The relatively minor difference in speed ratios between CCC and ACC also appears negligible, especially in comparison to the large variations about the means observed in the data, which far exceed this difference.

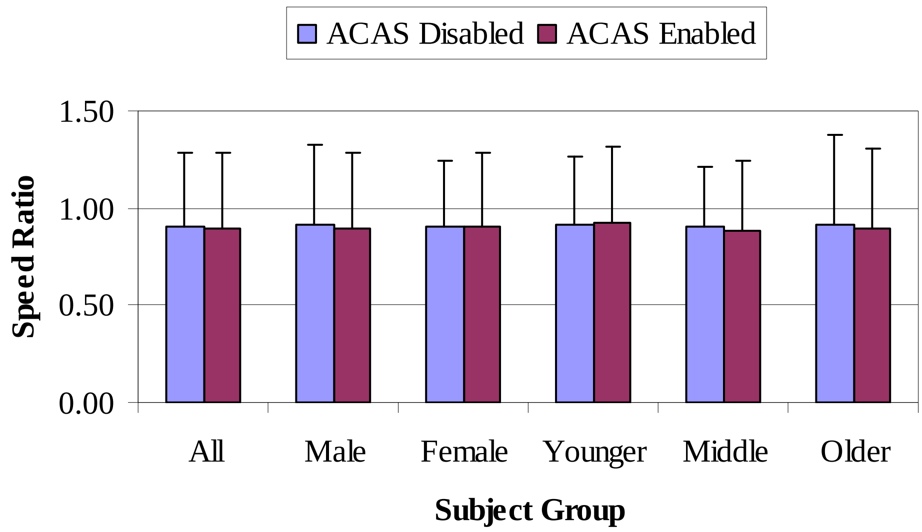


Figure 4-64. Speed Ratio for ACAS-Disabled versus ACAS-Enabled by Subject Group, All Conditions

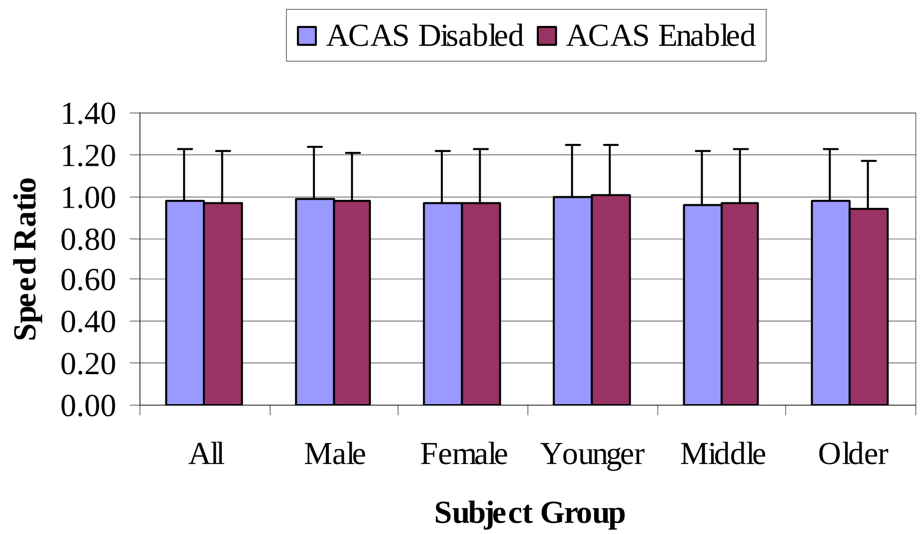


Figure 4-65. Speed Ratio for ACAS-Disabled versus ACAS-Enabled by Subject Group, Freeways

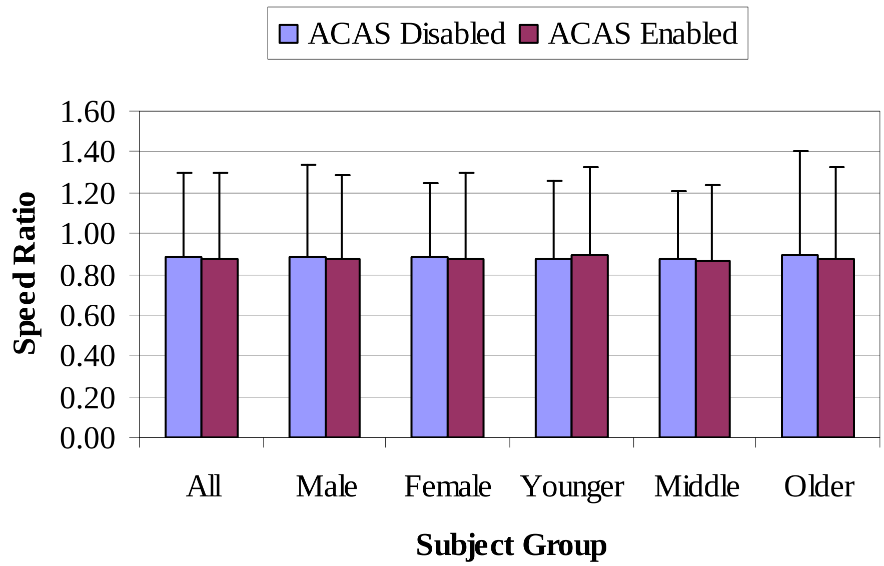


Figure 4-66. Speed Ratio for ACAS-Disabled versus ACAS-Enabled by Subject Group, Non-Freeways

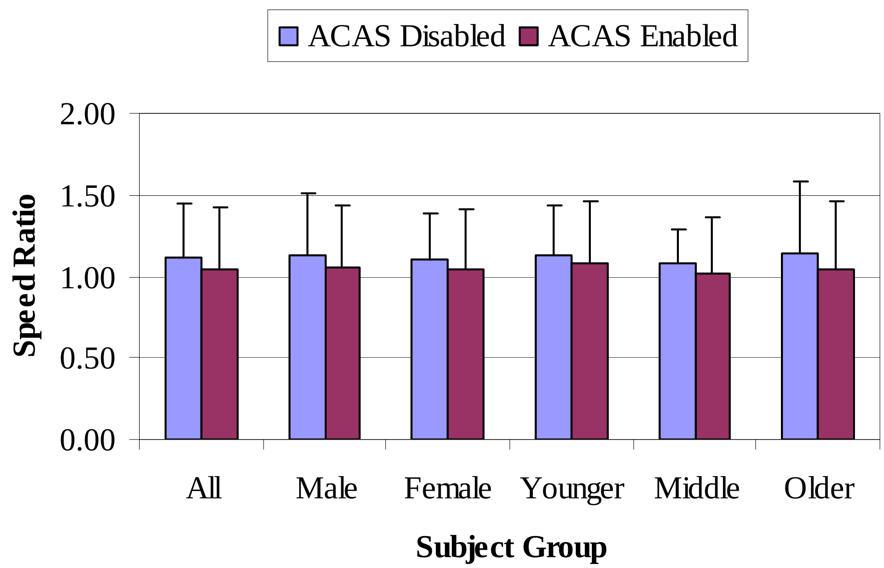


Figure 4-67. Speed Ratio for ACAS-Disabled versus ACAS-Enabled by Subject Group, Low Traffic

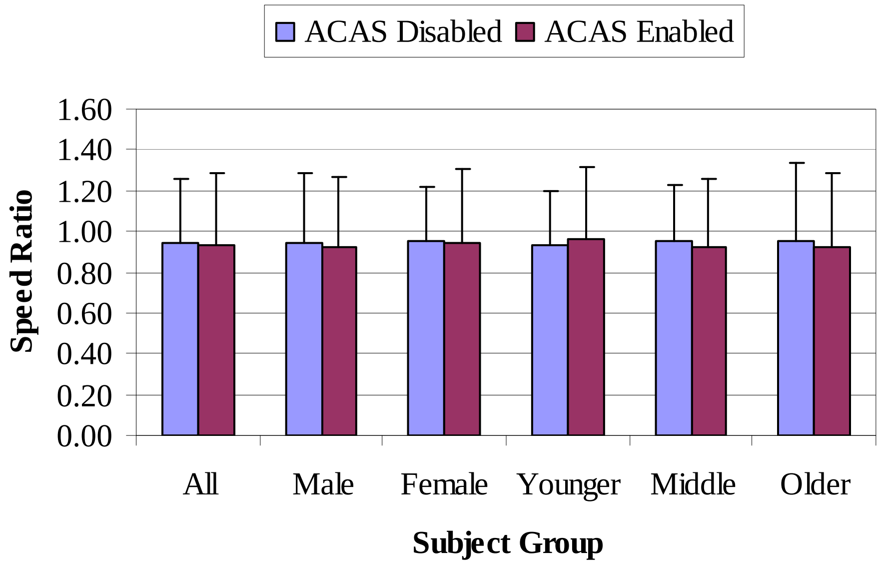


Figure 4-68. Speed Ratio for ACAS-Disabled versus ACAS-Enabled by Subject Group, Moderate Traffic

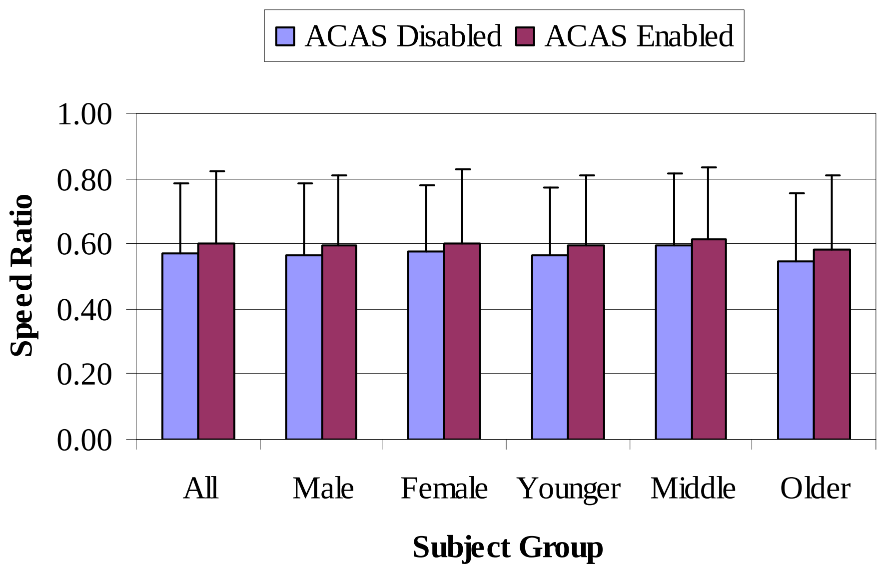


Figure 4-69. Speed Ratio for ACAS-Disabled versus ACAS-Enabled by Subject Group, Heavy Traffic

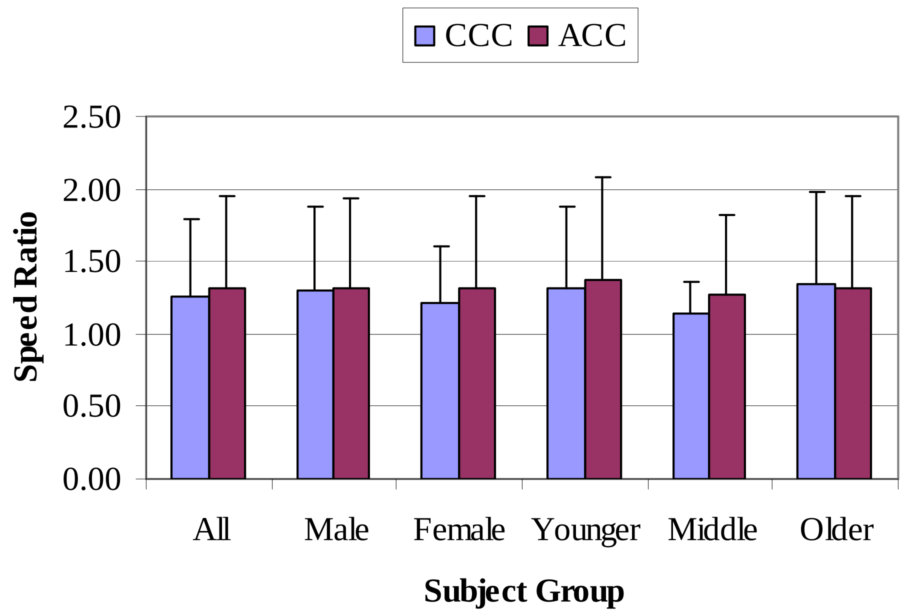


Figure 4-70. Speed Ratio for CCC versus ACC by Subject Group, All Conditions

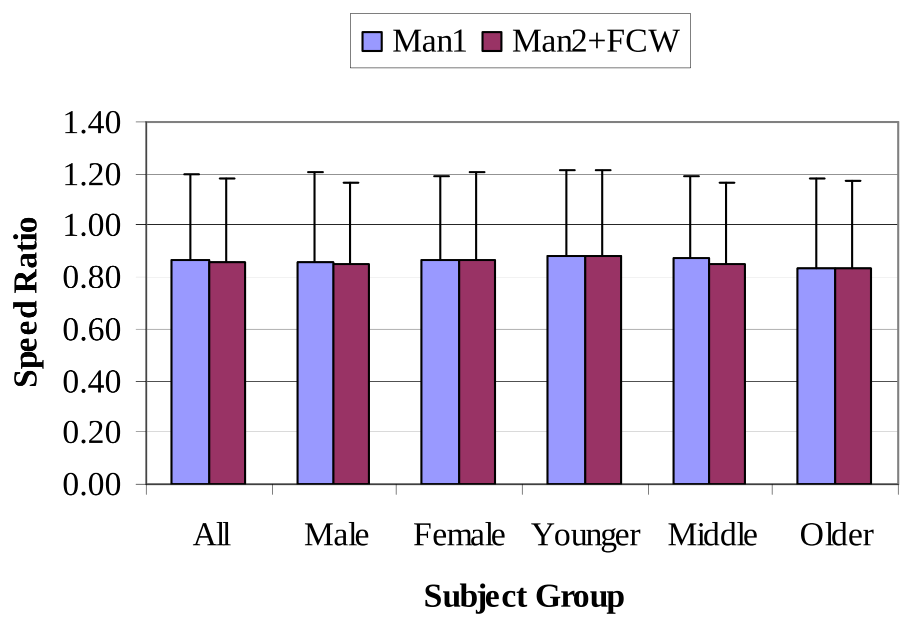


Figure 4-71. Speed Ratio for Manual 1 versus Manual 2 + FCW by Subject Group, All Conditions

4.4.2 Analysis of Driver Inattention

This analysis examines whether or not ACAS use has any effect on driver inattention based on observations of driver behavior from episode videos triggered by the crash-imminent alerts. These observations are considered generally representative of overall normal driving performance since the alerts occur randomly, triggered mostly by out-of-path targets or non-hazardous in-path targets such as lead vehicle turning ahead. This analysis was conducted at the aggregate level for *all* subjects. Comparison of inattention rates was made between ACAS-Disabled and ACAS-Enabled test periods by taking inattention episodes as a ratio of all episodes in each driving mode. Inattention is measured by distraction and eyes-off-the-road (> 1.5 seconds). The following is a list of the distraction categories identified:

- Dialing phone
- Singing/whistling
- Adjusting controls
- Yawning
- Talking to passenger
- Searching interior
- Scanning rear-view mirror
- Reaching for items
- Talking/listening to phone
- Grooming
- Scratching face
- Drinking/eating/smoking
- Reading
- Scanning back adjacent lanes
- Looking to the side/outside car
- Other

4.4.2.1 Driver Inattention – Distraction

Figure 4-72 shows the Distracted Episode Ratio results for ACAS-Disabled versus ACAS-Enabled test periods. The ratios were computed by taking the average of the individual driver ratios. The results indicate that the distraction ratios for ACAS-Disabled (0.33) and ACAS-Enabled (0.34) are essentially equal. Overall, there were a total of 253 episodes for ACAS-Disabled of which 100 had driver distractions and 726 episodes for ACAS-Enabled of which 268 had driver distractions. If the distraction ratios are computed on the basis of these overall population data, the ratios are 0.40 and 0.37 for ACAS-Disabled and ACAS-Enabled, respectively. Both results are similar and indicate a negligible difference between ACAS-Disabled and ACAS-Enabled.

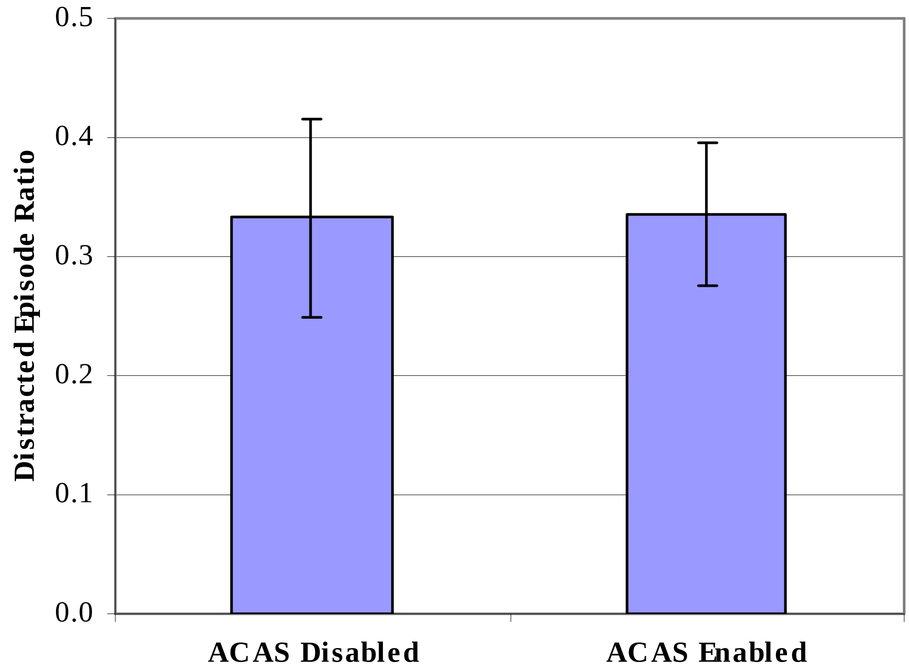


Figure 4-72. Distracted Episode Ratio for ACAS-Disabled versus ACAS-Enabled

4.4.2.2 Driver Inattention – Eyes-Off-the-Road

Figure 4-73 shows the Eyes-Off-the-Road Episode Ratio results for ACAS-Disabled versus ACAS-Enabled test periods. Again, the ratios were computed by taking the average of the individual driver ratios. The results indicate that the eyes-off-road ratio for ACAS-Disabled (0.028) is slightly higher than for ACAS-Enabled (0.024). Overall, there were a total of 253 episodes for ACAS-Disabled of which 11 had driver eyes-off-road distractions and 726 episodes for ACAS-Enabled of which 19 had driver eyes-off-road distractions. If the distraction ratios are computed on the basis of these overall population data, the ratios are 0.043 and 0.026 for ACAS-Disabled and ACAS-Enabled, respectively. Since the number of eyes-off-road distractions is relatively small, less than one per driver, the results based on overall population data might be considered more statistically reliable. In either case, the results suggest some positive safety impact for ACAS. This positive result may be attributed to increased driver focus on the roadway ahead in response to the ACAS visual display and its various warnings and alerts.

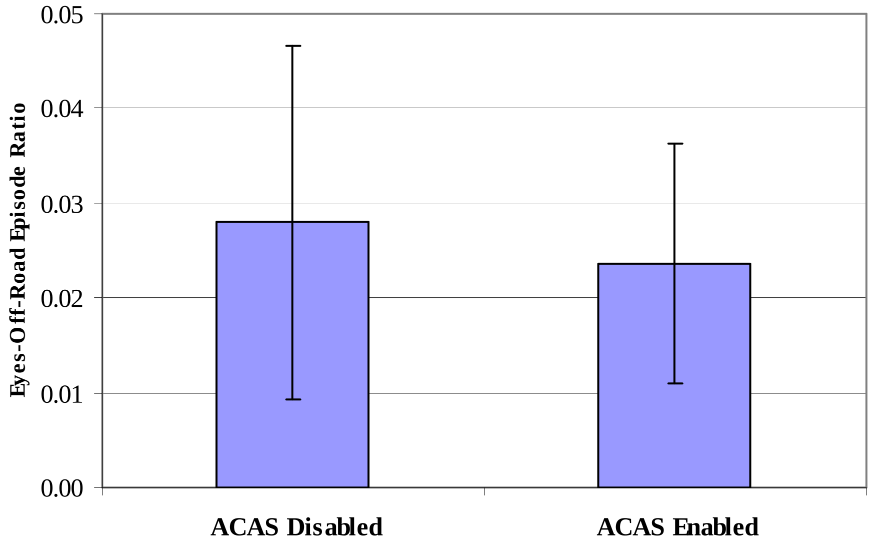


Figure 4-73. Eyes-Off-the-Road Episode Ratio for ACAS-Disabled versus ACAS-Enabled

4.4.3 Observation of Video Episodes

Observation of the video episodes also identified other events that suggested potential positive and negative safety impacts of ACAS. Since these are isolated events and anecdotal, they should not be generalized; however, they merit documentation for future consideration.

Potential positive safety impacts of ACAS:

- ACAS out-of-path target alerts may have some positive safety impacts by focusing driver attention to the road. An ACAS FOT video was observed that showed a driver receiving an (silent) out-of-path target alert triggered by an electric pole as the vehicle was departing the road edge.
- Crash imminent alerts caused by a lead vehicle turning ahead were the source of nuisance to many drivers, given that the lead vehicle turned in time as expected. However, these alerts could be helpful if the turning vehicle had to slow down due to obstacles at the intersection. An ACAS FOT video was observed that showed a lead vehicle turning that suddenly stopped to allow a bicyclist to cross the side road of the intersection. The ACAS warning in this case alerted the driver of the host (following) vehicle to the situation ahead. The driver of the host vehicle was looking ahead as seen in the video, but it could not be determined whether or not the driver saw the bicyclist before the alert.

Potential negative safety impacts of ACAS:

- Relatively slow acceleration of ACC in free-flow traffic may not be expected by a following driver. A rear-looking video was observed during the system characterization test, conducted by the independent evaluator, which showed a following vehicle abruptly changing lanes to avoid the ACAS vehicle slowly accelerating while in ACC.

- Occasional tracking of a decelerating lead vehicle exiting a freeway, already on exit ramp, may cause the ACAS vehicle while in ACC to slow and then accelerate in a manner unexpected by a following driver. This observation was noted from public road drives conducted by the independent evaluator.
- It was observed from the ACAS FOT data that the ACAS radar occasionally loses track of a lead vehicle decelerating ahead (intermittent loss of closest in-path moving target flag). When this occurs, it might cause a delayed crash-imminent alert.

Members of the independent evaluation team observed another potential negative safety impact by ACC as they test-drove the ACAS vehicle in rainy conditions. While in ACC operation, it was observed that disengagement of ACC due to heavy precipitation was inconsistent. In some weather conditions that normally would cause automatic disengagement of ACC, the ACC continued to operate even though the radar kept losing track of the lead vehicle.

Summary Results of Driver Impact Analysis:

No unintended negative consequences were observed by examining travel speed, time headway, lane position, distraction, and eyes-off-road. These results were based on a short-term exposure with ACAS. The analysis of driver adaptation and risk compensation would require longer exposure periods than afforded by this FOT.

5. DRIVER ACCEPTANCE

5.1 INTRODUCTION

The primary benefit of ACAS use is expected to be a reduction in rear-end collisions. However, realizing this benefit depends on the degree to which drivers accept and use ACAS. Driver acceptance is the precondition that will permit new automotive technologies to achieve their forecasted benefit levels. Driver acceptance of ACAS is also expected to generate benefits such as allowing for more comfortable, less stressful driving and more frequent and longer travels. Successfully adopting new technologies and attaining their benefits depends on drivers understanding and operating these technologies appropriately. This chapter presents the independent evaluation's analyses of driver acceptance of ACAS, one of the three goals that need to be addressed to understand safety benefits. Because the effectiveness of new technologies is not assured, there is a need to determine whether drivers will accept and use them as intended. Driver acceptance measurement also provides a means to estimate drivers' interest in purchasing and using ACAS as a basis for estimating the safety benefits associated with its use.

Recognizing the contribution of driver acceptance to the eventual success of the ACAS technology, the independent evaluation specifies it as an evaluation goal. Driver acceptance encompasses the many issues associated with user acceptance of a new technology. Drivers are classified as accepting ACAS technology if they express interest in using or acquiring ACAS in a personal vehicle, there is compatibility between their expectations and ACAS performance, they find ACAS easy and intuitive to use, and if they perceive that ACAS offers them ways to enhance their driving performance. From these criteria, the independent evaluation developed a Driver Acceptance Framework, a heuristic that captures the many elements of driver acceptance and guides data collection and analysis. The framework is enumerated separately for FCW and ACC due to their different capabilities.

This section defines the driver acceptance goals and objectives. The driver acceptance framework that specifies objectives and sub-objectives and frameworks, essentially similar, were developed to match FCW and ACC capabilities. This section describes the data and methodologies used to analyze the driver acceptance data. The results of the driver acceptance data analysis are reported using the framework as its organizing principle. This section concludes with a summary of the analyses as well as key driver acceptance conclusions.

5.2 DRIVER ACCEPTANCE GOALS AND OBJECTIVES

The NHTSA Strategic Plan 1997-2002 (1997) stated that driver acceptance should be understood in terms of the following objectives: ease of use, ease of learning, adaptation, and perception. Building on NHTSA's definition of driver acceptance, the ACAS Independent Evaluation formed a framework to express the breadth and complexity of driver acceptance. On a general level, the framework identifies the range of aspects of driver acceptance. Collectively, these aspects of driver acceptance should answer whether ACAS satisfies drivers' needs and requirements.

This framework modifies the original driver acceptance framework presented in Najm, Stearns, and Boyle (2001) and was revised as a result of meetings with, and input from, the U.S. DOT's IVI Human Factors Team. The framework identifies the five objectives used to describe the driver acceptance components (see Figure 5-1). Each objective embodies several sub-objectives, which together form a composite and comprehensive picture of drivers' FOT experience using ACAS.

Moving from left to right in Figure 5-1, two strands of research provide conceptual support for the first two objectives. The Technology Acceptance Model (TAM), developed by Davis (1989, 1985) has been widely used to understand user acceptance of computer technology but can be applied to driver acceptance. The TAM identified "perceived ease of use" and "perceived usefulness" as the important influences on technology acceptance. The Driver Acceptance Scale, a scaling technique developed and tested in Europe to assess acceptance of transportation innovations (van der Laan, Heino, and de Waard, 1997) gives independent and convergent support for the TAM concepts.

Using the TAM and the Driver Acceptance Scale as precursors, the first two objectives in the ACAS Driver Acceptance Framework are designated "ease of use" and "perceived value." Ease of use focuses on driver encounters with ACAS expressed as the usability of its interface, tolerance of alarm issuance algorithms and the incidence of valid versus false alarms, individual variability in use patterns, and how understandable and intuitive drivers find the implementation.

The second objective, perceived value, refers to whether drivers think that using ACAS improved their safety and comfort, and measures whether drivers found ACAS compatible with their expectations, or mental model, of ACAS operation. Because drivers need to learn as well as retain ACAS operational requirements, there needs to be an assessment of how easy it is to learn to use. The third objective, ease of learning, addresses how long it took drivers to learn to use ACAS comfortably and their assessment of the utility of the instructional process. Research has shown that simplified learning processes result in quicker acceptance of new technologies (Kantowitz et al., 1996).

The fourth objective, advocacy, examines whether sustained exposure to, and use of, ACAS caused drivers to become interested in acquiring it. Advocacy is measured in several ways including willingness to accept ACAS in a rental vehicle, interest in purchasing ACAS, level of trust felt for the ACAS capability, amount of money they would spend to acquire ACAS, and interest in endorsing ACAS. As part of the advocacy objective, analyses use the FOT data to estimate drivers' interest in purchasing ACAS.

Van der Laan and colleagues' (1997) research study aimed to develop a consistent procedure for assessing driver acceptance using subjective scales. After collecting scaled responses to advanced telematics using data from both simulation and on the road studies, factor analyses showed that the scaled responses formed two clusters described as usefulness and satisfaction; scale scores on these two factors provide a summary measure of driver acceptance. Including the van der Laan scale scores as part of the advocacy objective provides face validity for the other measures of advocacy.

The fifth objective, driving performance, assesses whether ACAS use had an effect on driving behavior, trip making, and vehicle use. Driving performance also incorporates behavioral adaptation, i.e., "those behaviors, which may occur following the introduction of changes… which are not consistent with the initial purpose of the change" (OECD, Organization for Economic Cooperation and Development, 1990).

The temporal aspect of driver acceptance is not well understood. Because it takes time to see effects on behavior, there is a dotted line in the framework linking to driving performance to suggest that this objective may not be observable on the same time scale as the other four. Weinberger (2001) traced driver acceptance week by week and reported that it is important to consider how a driver habituates to a vehicle and that the process may require a number of weeks.

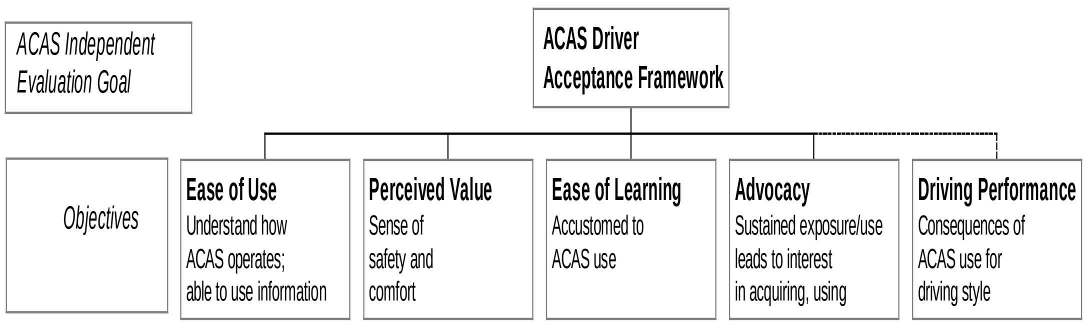


Figure 5-1. Driver Acceptance Framework Objectives

While the ACAS objectives apply to both the FCW and ACC systems, the sub-objectives vary slightly due to their operational characteristics. The independent evaluation identified measures of performance for each sub-objective. Because the measures of performance map to operational characteristics, the Driver Acceptance Framework is elaborated for each ACAS capability, FCW and ACC.

Figure 5-2 shows the Driver Acceptance framework for FCW.[1] A similar framework for the components of Driver Acceptance to assess the ACC system is presented later in this section.

[1] The sub-objectives in the framework are ordered alphabetically for easy reference.

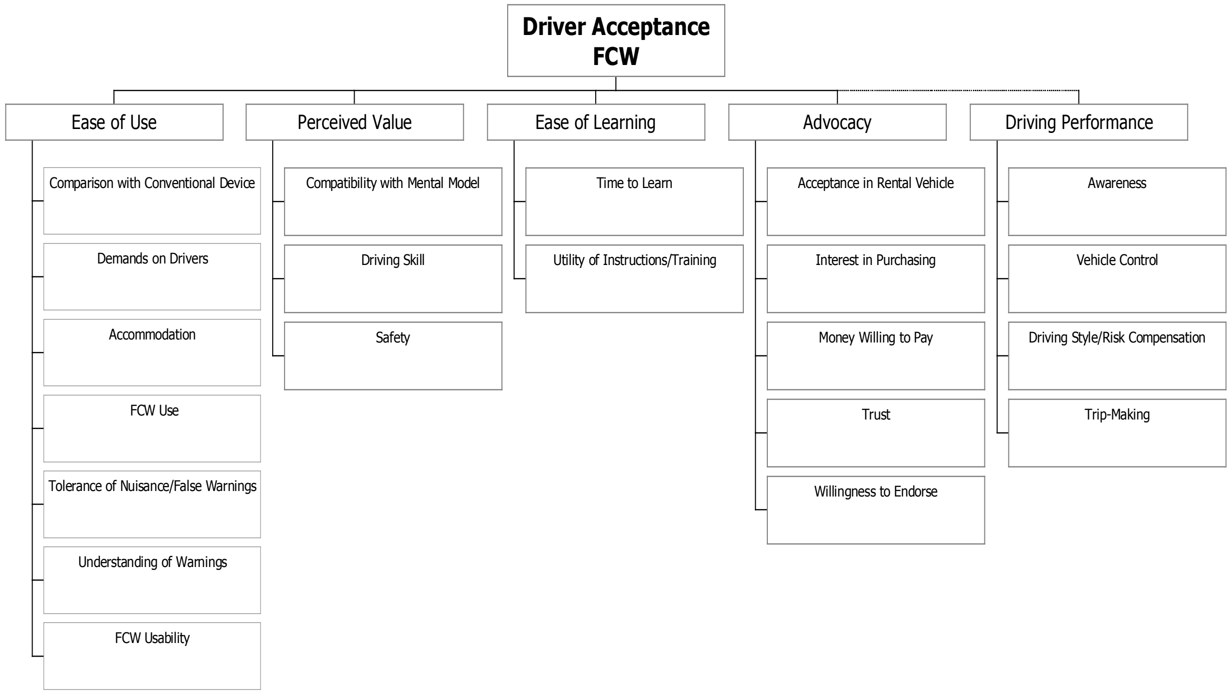


Figure 5-2. Driver Acceptance Framework Objectives and Sub-Objectives for FCW

The ease of use objective and its seven sub-objectives examine whether drivers found FCW easy to use in a variety of driving conditions. The first sub-objective, comparison with conventional device, asks drivers to compare their use of FCW with other automotive safety features. The second sub-objective, demands on drivers, measures whether drivers felt that they expended additional effort to use FCW. The third sub-objective, driver accommodation, explores whether and how, drivers altered their driving to accommodate FCW. The fourth sub-objective, use patterns, examines how subjects use FCW. The fifth sub-objective, tolerance of nuisance/false warnings, examines how drivers accept nuisance and false FCW warnings. Erroneous alarms may cause drivers to lose confidence in system reliability. False alarms, which are false positives, may cause drivers to brake suddenly, become distracted, or ignore other information. The driver may also consider some alarms "too early" (nuisance alarms) and this could affect the driver's acceptance of the system. Conversely, if there is no alert in situations that require an alert, drivers may take longer to react and have less time for a successful avoidance maneuver. The sixth sub-objective, understanding of warnings, examines how well drivers understood the FCW's visual and auditory warnings.[2] The seventh sub-objective, usability, assesses whether drivers evaluate FCW as comfortable and easy to use. There is a need to document whether drivers find the FCW controls easy to use while driving in differing conditions and whether they like the content and location of displays (Becker et al., 1995).

[2]FCW shows an imminent crash-warning icon on the HUD, accompanied by an auditory alert, to let drivers know when they are too close to the lead vehicle and should brake. The ACC light on steering wheel lets the driver know that ACC is engaged. The HUD will display a "Driver Control required" message to warn drivers that ACC is no longer engaged and they have to take control.

The HUD is a novel element in the driver's forward visual scene and there are concerns related to the use of automotive HUDs. Its effectiveness depends on the clarity of the visual field with the addition of the HUD. Drivers may experience problems distinguishing colors, or interpreting colors properly under different lighting conditions. Clutter should be avoided in a HUD because the driving scene itself is busy and provides clutter. Drivers' reaction to the HUD and its usability are also analyzed as part of the ease of use objective.[3, 4]

The results of research on the ability of drivers' eyes to accommodate HUD content and to the forward scene are mixed. Studies have suggested that the lower the position of the HUD, the more there are problems of "eccentricity," or misalignment between display position and elements in the forward field of view (Cole, 1984). Other studies indicate that reaction time to external stimuli is significantly faster with an HUD than with a conventional instrument panel (Okabayashi, Sakata, Furukawa, and Hatada, 1989, Sojourner and Antin, 1990).

Drivers use the HUD to interface with ACAS. It is important to consider whether drivers understand the HUD information and find its quality, location, and clarity adequate. As they use foveal vision to see the HUD as well as the forward scene (Dingus, Jahns, Horowitz, and Knipling, 1998) there is a need to assess how well drivers feel they can use the HUD while driving. It is also necessary to look into whether the HUD display on the lower part of the windshield obscured drivers' view of the forward scene.

The second objective, perceived value, explores whether drivers perceived that FCW use increased their safety and/or driving skills. The post-drive survey included a comprehensive question to assess drivers' overall satisfaction with FCW. The compatibility with the mental model sub-objective addresses whether FCW worked in ways that drivers expected. The driving skill enhancement sub-objective measures drivers' opinions of their driving using FCW. Because FCW can assume tasks such as monitoring risk in the forward scene, it is necessary to find out if drivers reallocated their attention and spent more time doing other things in the vehicle.

The third objective, ease of learning, addresses whether drivers learn to use FCW in a timely and effective manner. Because ACAS combines FCW and ACC functions, drivers may require time to become competent using FCW and to learn FCW's capabilities as well as its limitations. Optimally, FCW should be intuitive and understood easily by the driver. If a technology is intuitive, users will retain information about its operations and recall information readily because its function is intuitive. The utility of instructions/training sub-objective asks drivers if they thought their instructions and training prepared them to understand and use FCW.

[3] The ACAS driver-vehicle interface uses an HUD as well as auditory alerts. The HUD is a new element in the driver's forward visual scene. The HUD is always on when the vehicle is running and has brightness and windshield position adjustments. The HUD uses icons to display the FCW as well as ACC settings and displays an iconic representation of the headway distance to a lead vehicle, if there is one, as well as color and size changes in icons to warn of an impending rear-end collision.

[4] The auditory quality of the alerts (i.e., relative prominence of alerts given different levels of ambient noise) is a system capability issue and is discussed in the system capability chapter.

Objective 4, advocacy, looks into whether sustained exposure to, and use of, FCW caused drivers to become interested in acquiring and/or endorsing FCW. A European scale of driver acceptance (van der Laan et al., 1997) provides a global measure of acceptance of new technologies in transport telematics. The Driver Acceptance Scale consists of nine 5-point rating scale items, which form two scales denoting "usefulness" and "satisfaction." Proprietary research by motor vehicle manufacturers has used these scales to predict purchase intent for new vehicle technologies (Stearns, 2004) making this an appropriate measure to include as part of the advocacy objective.

The acceptance in a rental vehicle sub-objective measures whether drivers would be willing to rent a vehicle with FCW. The interest in purchasing sub-objective asks whether FOT drivers would want to obtain the FCW function as part of their next car purchase. Asking whether drivers would purchase FCW features as new car options is a way to measure drivers' commitment to ACAS. It is also useful to ask if drivers would pay to obtain ACAS in a new vehicle (Becker et al., 1995). The third sub-objective, level of trust, inquires whether drivers trust the FCW operation enough to see significant people in their lives use it. The fourth sub-objective, amount of money willing to pay, asks what drivers would pay to purchase FCW. Even if FCW is beneficial, drivers may, or may not, be willing to pay for it. The fifth sub-objective, willingness to endorse, asks if drivers would recommend FCW to others.

The fifth objective, driver performance, examines whether FCW use leads to lasting changes in driving behavior. The awareness sub-objective looks at whether FCW use affected drivers' awareness of unsafe conditions. The second sub-objective, control inputs, examines whether changes in the frequency of operating in-vehicle controls from P3 to P4. The driving style/risk compensation sub-objective explores whether the introduction of FCW is followed by new behaviors that do not correspond with the initial intent of FCW. The use of safety enhancing features might lead to compensatory changes in driving style and patterns (Smiley, 2000). FCW's driving support may cause drivers to adjust their driving behavior to compensate for its effects. The fourth sub-objective, trip patterns, examines whether drivers changed their trip making from P3 to P4.

Figure 5-3 shows the driver acceptance framework for ACC. It is similar to the framework for FCW (Figure 5-2) but several sub-objectives differ, reflecting ACC's operational characteristics.

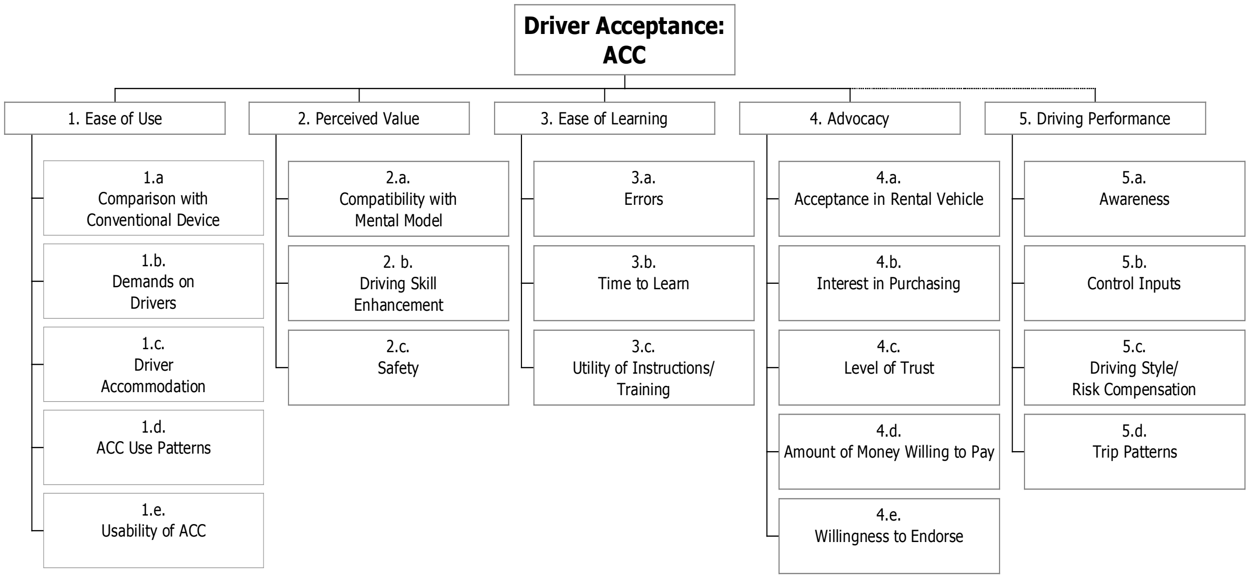


Figure 5-3. Driver Acceptance Framework Objectives and Sub-Objectives for ACC

5.2.1 Driver Acceptance Framework for ACC

ACAS integrates ACC and FCW functions. ACC maintains a constant headway selected by the driver when the lead vehicle is traveling slower than the selected cruise speed. The driver must first turn on the ACC function. The driver can then engage the ACC when the vehicle speed exceeds 40 km/h (25 mph). ACC becomes inactive when the vehicle speed falls below 32 km/h (20 mph). The ACC's maximum automatic braking capability is limited to 0.3g level. FCW provides advisory displays and alerts the driver to avoid, or reduce, the severity of collisions with a moving or stationary lead vehicle. FCW's crash-imminent warning algorithm is calibrated to account for ACC's braking capability. A color HUD provides visual information about the following distance to help drivers maintain a safe distance behind lead vehicles. The HUD shows a green vehicle icon when ACC is tracking a vehicle ahead as well as the ACC gap setting, set speed, and actual travel speed.

While the ACAS objectives apply to both the FCW and the ACC systems, FCW and ACC have slightly different sub-objectives due to their different operational capabilities. Objective 1, ease of use, has five sub-objectives. The five sub-objectives are comparison with conventional device, demands on drivers, driver accommodation, use patterns, and usability. The ACC driver-vehicle interface uses the HUD and HUD usability is examined as part of the FCW Driver Acceptance Framework.

5.3 METHODOLOGY

5.3.1 Subjective Data

Two FOT driver surveys were used for these analyses. Each survey contained a variety of formats, including Likert-type scales, multiple-choice, and open-ended items. These addressed the major themes of system ease of use, ease of learning, advocacy, perceived value, the HUD, and driver performance.

The post-drive survey was administered upon the return of each research vehicle and was reviewed by an UMTRI researcher for completeness and to ask participants for clarification if ambiguity existed. Additionally, there was a subsequent live discussion session with each driver regarding survey responses, during which seven additional questions were asked and video replay of forward- and face-camera clips for FCW imminent alerts was provided for the purposes of obtaining driver-feedback on the usefulness of the alerts. Up to 12 alerts from each driver's total were shown, as available. Volpe Center researchers documented the audio portion of live debriefing sessions via telecom.

A take-home survey was completed on the driver's own time, after completing the FOT, and a $50 bonus was paid once it was returned. Additionally, 25 drivers attended one of four focus groups that were held to obtain supplementary subjective inputs from participants who had completed the FOT driving, subsequent surveys, and debriefing sessions. Further detail on the surveys, debriefing, and focus group sessions may be found in (University of Michigan Transportation Research Institute and General Motors, 2005).

5.3.2 Objective Data

Various DAS data were provided from Volpe Center-created SAS tables and imported into the main SPSS database. Obtained data were aggregated at the participant level and provided for both ACAS-enabled and disabled periods. Variables included those that characterized travel behavior, alerts, and data parsing ACC and FCW driving, where feasible.

5.3.3 Data Integration

Photocopies of raw survey data were obtained from UMTRI, screened, coded, and entered into a statistical database program (SPSS 11.0 for Windows) for quantitative analysis. Additionally, various biographic data as obtained by UMTRI during participant screening (e.g., age, sex, occupation, and zip code) were periodically provided in an electronic format and uploaded into the main database. Similarly, the number of Michigan Department of State-recorded motor vehicle accidents and driving convictions, if applicable, for the period of 1995-2003 were obtained for each participant. Participant zip code was subsequently used in conjunction with United States Census Bureau (United States Census Bureau, 2000) data to determine median household income levels for that area.

5.3.4 Data Analysis

Statistical analysis initially involved generating frequency response distributions and descriptive statistics for each variable, as appropriate. Data was screened and any statistical outlier values were identified. As response scales within the survey data were fixed in most every case, outlier values were not a factor in the same way for those variables. Where appropriate, subsequent analyses were conducted excluding those participants whose driving behaviors deemed them statistical outliers. Variables with extreme outliers were determined using box plots, where values exceeding three box lengths (box represents the interquartile range, containing 50 percent of data values) qualified as "extremes."

Further analysis was segmented by way of the major themes that were part of the Driver Acceptance Evaluation Plan and subsequent Analysis Plan. The themes encompassed the areas of system ease of use, ease of learning, advocacy, perceived value, the HUD, and driver performance. Prior research experience using the same/similar survey items, as well as similar FOT designs, led to the formation of these themes and the a priori decisions regarding which items addressed which themes.

As a means of confirming the inter-relatedness of relevant survey items within themes, the Spearman's rho test was used. Spearman's rho is a non-parametric form of correlation where linearity is not assumed and the variables must exist, at minimum, on an ordinal scale. Such a test is useful in the case of Likert-type survey items, which assume an underlying continuum, though conservatively are measured on an ordinal level.

Subsequent analyses were performed to investigate the possibility of between-group differences within each of the major areas of interest for driver acceptance. The grouping variables that were initially targeted included the following:

- Gender (male, female)
- Age group (younger, middle-age, older)
- Reported motor vehicle accidents (zero, one or more)
- Reported driving convictions (zero, one or more)
- Self-reported approximate annual mileage (median split at 17,000 miles/year)
- Median household income by zip code, U.S. Census (2000; lower third, middle third, upper third)

Multivariate analysis of variance (MANOVA), being fairly robust to violations in non-normality and unequal cell sizes, was used to determine if statistical differences existed between groups as indicated above. As a non-parametric option, the Kruskal-Wallis (K-W) test was also considered for use. The K-W test is desirable in some situations, in that normality is not an assumption of the procedure. However, having dependent variables with continuous distributions of the same (albeit, non-normal) form is an assumption of the K-W test, and this was not typical for the current data set. For this reason, MANOVA was chosen for use. However, it should be noted that in cases where both MANOVA and the K-W test were run, statistical findings did not differ.

Initial MANOVAs employed each of the groups as independent variables (IVs) in conjunction with a predefined set of dependent variables that were taken from the Driver Acceptance Analysis Plan and mapped onto the various areas of interest for this focus. In particular, initial efforts were concentrated on the area of system advocacy. Here, significant findings for differences between participant groups in every case, with the exception of age group, were non-existent or, if present, most likely spurious. For this reason, unless deemed necessary as a function of obtained results, it was decided a priori that the focus of the between-group MANOVAs conducted for driver acceptance should be restricted to age group, with the possibility that gender and age group may interact and therefore warrant joint investigation. In cases where IV's existed with more than two levels, Tukey's HSD test was employed as a post-hoc range test.

5.3.5 Data Collection

Data was collected using the FOT's naturalistic context, operating on roadways and traffic conditions, as well as from surveys, focus groups, and post survey debriefing sessions. The FOT vehicles were instrumented to collect operational data. Upon completion of their FOT participation, drivers were asked about their driving behavior and their perception and use of ACAS. UMTRI also invited a subset of the FOT drivers to participate in four focus groups, which the independent evaluators observed.

Upon completion of their FOT experience, each driver was required to complete a post-drive survey that included questions regarding their experiences with ACC and FCW. Some questions were open-ended (allowing drivers to provide written comments), others were anchored, Likert-type, scale questions ranging from 1 to 7. The format of the post-drive survey was divided into sections that address the following driving states and system attributes: manual driving, ACC, FCW, combined ACC and FCW, and the DVI (including the HUD, comment button, etc.). Drivers were also given a secondary post-drive survey to complete on their own time and returned to UMTRI in a self-addressed envelope with pre-paid postage. When the driver completed the post-drive survey, an UMTRI researcher reviewed survey responses and showed the driver video replays of situations when he/she received a FCW imminent alert.

After taking part in the FOT, drivers were invited to take part in a focus group, held at UMTRI, to discuss participant's experience with the ACAS systems. Each focus group was presented a predetermined series of questions for discussion among the attendees, with a researcher from UMTRI facilitating the discussion. Focus groups were held at intervals throughout the FOT in an attempt to minimize the time between participating in the field test and taking part in a focus group. Drivers were paid an additional fee for their participation in a focus group.

5.3.6 Sampling and Recruiting FOT Drivers

Identification of subjects began with a random sample of names and addresses, provided to UMTRI by the Michigan Department of State (Michigan's driving license bureau), of licensed drivers living in nine adjacent counties in Southeastern Michigan representing major metropolitan, as well as rural areas, of the State (within a 1 to 1.5 hour drive of UMTRI). UMTRI mailed postcards to potential subjects announcing the FOT and asking them if they would be interested in participating. When subjects called a toll-free number at UMTRI, an UMTRI researcher telescreened the potential subjects and asked potential subjects questions regarding their annual VMT and health status. At the end of the telescreening call, the subjects were told either that their health and driving habits do not qualify them for the study or they are offered a space in the study.

Based on their experience recruiting subjects for the ACAS Pilot Test 3, UMTRI estimated that they sent 100 postcards to get 10 calls and, from the 10 calls, selected one subject who met the FOT's selection criteria of mileage driven per year, age, and absence of specified health conditions.

UMTRI intended to define the mileage criteria they used for subject selection in relation to the 2001 National Household Travel Survey (formerly known as NPTS) (http://www.bts.gov/nhts) mean annual mileage for each age and sex category. UMTRI found that the standard errors for subgroups were huge and not useful as cut-off points. It ruled in as potential subjects respondents who drive either more than or up to 25 percent below the mean annual mileage for their age group and gender.

If selected from the telescreening, UMTRI mailed the subject an information package. The package contained the information letter, an informed consent form (to be read ahead and signed at UMTRI in front of UMTRI staff), the subject selection information questionnaire, the driving habits questionnaire, and a map showing UMTRI's location.

Upon arrival, an UMTRI researcher met with the subjects and first asked to see their driver's license. The researcher told subjects they were the only people authorized to drive the FOT vehicle, that they should not drive the FOT vehicle out of the United States, and checked to see if they met all of the health requirements listed on the informed consent form and then asked them to sign the informed consent (see Appendix E). Both the information letter and informed consent were mailed to the prospective drivers prior to coming to UMTRI in order to have adequate time to read and understand the conditions of participation.[5]

Each subject watched a 15-minute video on the ACAS system and how to operate it. Subjects were told that there was both a CD and a video, the same as the video they watched, as well as the text, or script of the video, in the FOT vehicle's glove compartment for reference at a later time. Subjects were told to wear their seatbelts. Subjects with young children were shown the owner's manual, which had pages marked showing how to attach the child seat properly.

The UMTRI researcher showed each subject the FOT vehicle and its ACAS features. The subject was shown the yellow comment button on the dashboard. Subjects walked around the vehicle, were asked to sit in the vehicle to be oriented to its features, and drove a twenty minute accompanied test drive using a pre-determined route, prior to receiving the FOT vehicle. At the conclusion of the test drive, the subject's seated height and her distance to the eye box were measured. The experimenter asked the subject if the seat position and mirror settings were comfortable and set the driver's seat to stay in the same position.

During the test drive, the UMTRI researcher prodded the driver to experiment with the range of gap and sensitivity settings and to become familiar with the "bars" and the "waves." First, the subject was asked to increase and decrease the number of waves (FCW) and then, when on a highway, to increase and decrease the bars (ACC) to find their "personal comfort level." At the end of the test drive, the subject was instructed to reset both the ACC and FCW at 4, which are the settings the ACAS system will start at when the system is enabled 6 days later. The FOT subjects were told to limit their ACC use to highways and freeways and not to engage ACC if the visibility is low.

[5] Information on subject selection is drawn from UMTRI Plan, Revision 1, May 2002.

The FOT drivers were told to drive the vehicle without the ACAS features for the first 6 days and, on their second ignition of the FOT vehicle on day 7, that the ACAS features will be turned on remotely. They were told the date of this change and this information was also placed on a piece of paper in the car's glove box.

When subjects completed their FOT participation, they returned the FOT vehicle to UMTRI on a predetermined day. After they handed the FOT vehicle over to the UMTRI staff, subjects were asked to complete the post-drive survey. Upon completion of the survey, each subject met with an UMTRI FOT staff member in a conference room to review and discuss a selection of their responses to the survey items and also to see video replays of specific incidents they experienced while they drove the FOT vehicle. The video clips were downloaded from the FOT vehicle's recording equipment while the subject was answering the post-drive survey. Upon completion of the debriefing, each subject was paid $250 for participation in the FOT and was asked to complete a take-home survey in return for $50 upon its completion.

5.4 FOT DRIVER CHARACTERISTICS

5.4.1 FOT Participant Recruitment and Selection

UMTRI and GM designed the process for selecting FOT participants to identify individuals who reported driving more than the median number of miles for their age and sex, as documented by the 2001 National Household Travel Survey, and would, thereby, be more likely to make frequent use of the ACAS features. The NHTS is a U.S. Department of Transportation effort sponsored by the Bureau of Transportation Statistics and the Federal Highway Administration to collect data on both long-distance and local travel by the American public.[6]

UMTRI recruited potential participants in adjacent counties via the postal mail. Interested parties were screened for exclusion on the basis of meeting various criteria, such as mileage driven per year, age, driving record, and absence of specified health conditions (see Appendix E).

5.4.2 FOT Participants

Participants in the FOT totaled 96. Three different algorithms were deployed for the ACAS, referred to as A, B, and C. This resulted in three distinct groups of participants for the study. Algorithms A and B each consisted of 15 participants, while Algorithm C was comprised of 66 participants. For the purposes of the current description, only Algorithm C participants were considered, as changes in the system were too substantial to permit cross-group comparisons.

Descriptive characteristics of the Algorithm C participants are found in Table 5-1. Of the 66 total C participants, there was an equal split (n = 33) of males and females. Additionally, three age groups were recruited. The younger group consisted of participants ranging in age from 20 – 30, the middle-age group consisted of participants ranging from 40 – 50 years, and the older

[6] http://www.bts.gov/programs/national_household_travel_survey/ accessed 11/03/2004.

group consisted of 60 – 70 year-old participants. Age groups were balanced for number of participants (n = 22 per group) and males and females (n = 11 per group).

Participants drove the FOT vehicles for a total of 26 days. The first six days were a baseline period; DAS data were collected; however, ACAS was disabled. On day seven, the ACAS system was enabled and began providing feedback to the drivers for the remainder of the FOT.

Table 5-1. Algorithm C Participant Demographic Characteristics

Mean Age (years)		46
	Younger	27
	Middle	45
	Older	66
Mean number of MI Dept. of State-Recorded Motor Vehicle Accidents (1995-2003)		0.39
	Zero	71%
	One or more	29%
Mean number of MI Dept. of State-Recorded Driving Convictions (1995-2003)		0.89
	Zero	56%
	One or more	44%
Mean annual mileage (self-reported estimate)		19,527
	≤17,000 miles/yr (median split)	12,676
	≥17,000 miles/yr	26,379
Employment Status		
	Employed	73%
	Home/retired	27%
Education Level Completed		
	High School	27%
	College	55%
	Post-college	18%
Conventional Cruise Control Use		
	Never	3%
	Seldom	11%
	Occasional	39%
	Frequent	47%
Median Household Income by Zip Code (1999; Census 2000 data)		$50,149
	Lower third	$33,809
	Middle third	$50,149
	Upper third	$74,949
Mean Number of Years Driving		29
	Younger	11
	Middle	29
	Older	48

5.4.3 Travel Behavior

As presented in Table 5-2, FOT travel behavior characteristics indicate that across all driving, the mean number of hours driven per day was 1.5 hours, covering, on average, a distance of 19.9 km per trip. Over the course of the FOT, in valid trips, a mean of 2,392 km were driven. On average, 1,843 (77%) of this total was ACAS-enabled driving. Having the system enabled did not increase or decrease driving behavior for the remainder of the FOT (i.e., enabled km driven were proportionally equivalent to the disabled period). As it pertains to ACC, 36 percent (665 km) of driving with ACAS enabled occurred with ACC engaged. More detailed summary statistics regarding participant travel behavior are provided for reference in Appendix F.

Table 5-2. FOT Travel Behavior Summary for Algorithm C Participants

	Mean	*SD*
Hours driven/day (entire FOT)	1.5	0.6
Km driven/valid trip (entire FOT)	19.9	9.5
FOT total distance traveled (valid trips)	2,392	1222
ACAS-enabled km traveled (valid trips)	1,843	1,069
ACAS-enabled km of ACC engagement (valid trips)	665	746

The proportion of ACAS-enabled travel using ACC by driver is depicted in Figure 5-4. On average, ACC was used for 35 percent of all ACAS-enabled driving, though there was much variability in its use. One driver never engaged the ACC system, while another used it 85 percent of the time.

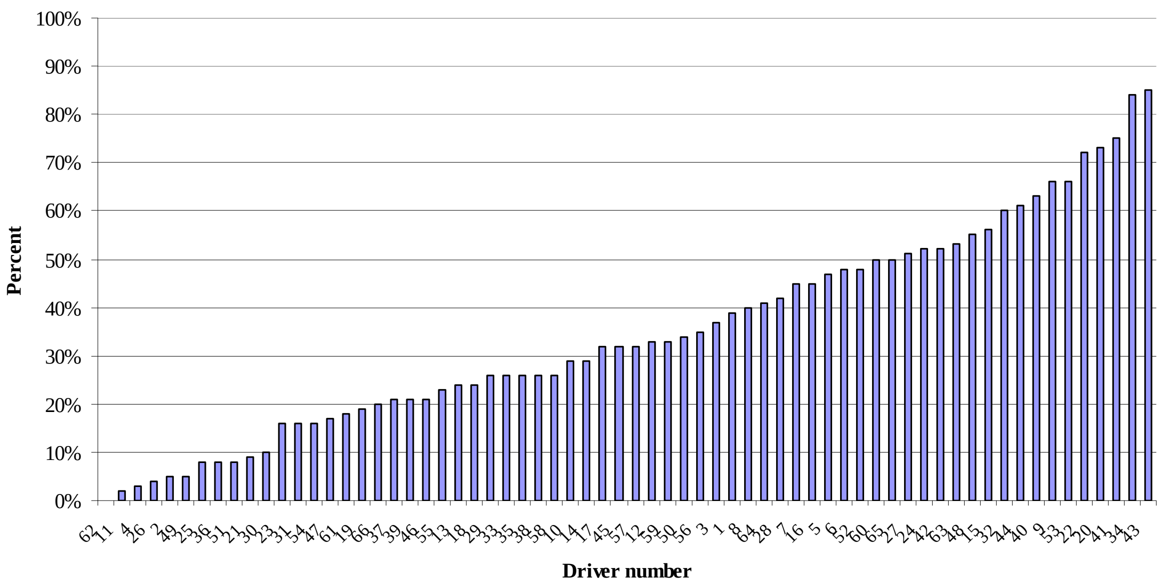


Figure 5-4. Proportion of ACAS-enabled Travel Using ACC by Driver

Table 5-3 provides a comparison of participant demographic characteristics (as drawn from Table 5-1) on the FOT travel behavior variables that are found in Table 5-2. As depicted in Figure 5-5, two participants, both older women, were deemed statistical outliers (2.5 times the standard deviation plus the mean) and eliminated from these analyses due to excessive distances driven in ACC mode, while ACAS was enabled.

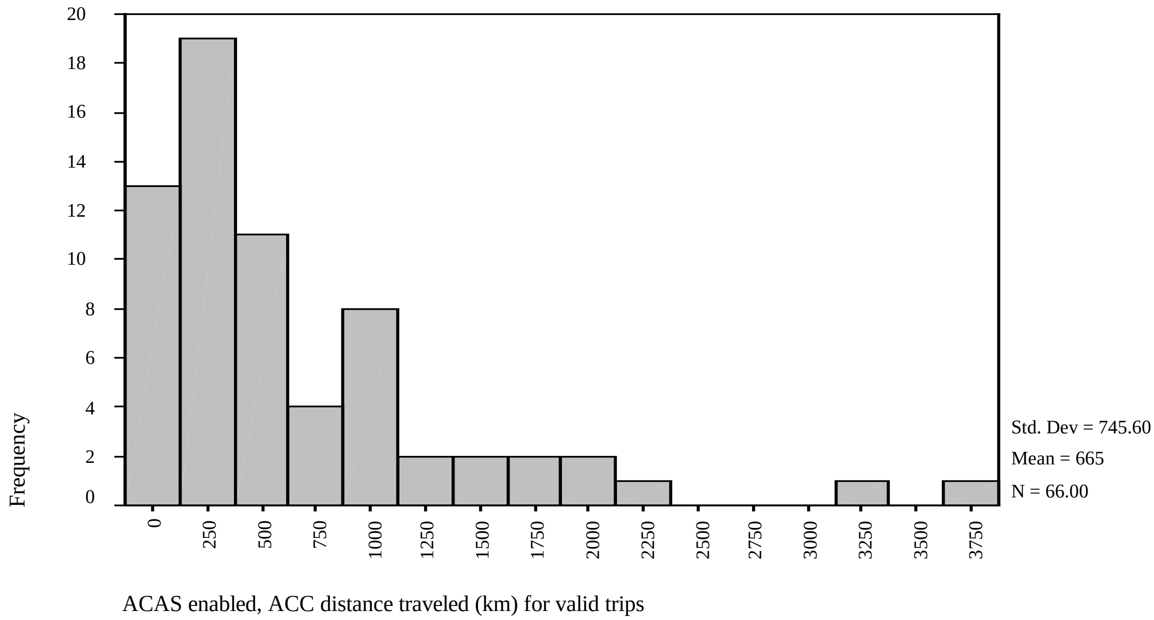


Figure 5-5. Frequency Distribution of ACAS-enabled, ACC Use Showing Statistical Outliers

MANOVA was used in conjunction with post hoc testing, where appropriate, to determine where significant between-group differences existed. Results were nonsignificant (NS), except where means are provided in the table.

With regard to gender, a significant difference emerged for ACAS-enabled, ACC-engaged driving. Once the female outlier participants were removed from the sample, males were found to have driven significantly more under those conditions ($F(1, 62) = 4.96$, $p = .03$). Age groups also differed from each other on this variable. The older group drove more using ACC than those in the middle-age group ($F(2, 61) = 3.11$, $p = .05$). Finally, as one would expect, participants who reported driving less than 17,000 miles per year also traveled fewer total km and fewer km per valid trip over the duration of the FOT ($F(1, 62) = 10.78$, $p = .00$, and $F(1, 62) = 4.54$, $p = .04$, respectively), as well as fewer total km and km with ACC engaged during valid trips for ACAS-enabled driving ($F(1, 62) = 9.27$, $p = .00$, and $F(1, 62) = 4.48$, $p = .04$, respectively).

Table 5-3. MANOVA Results for FOT Travel Behavior Variables by Demographic Characteristics – Significant Between Group Differences in Means Only ($p < .05$)

		Total km traveled (entire FOT)	Km per valid trip (entire FOT)	Total km traveled (ACAS enabled, valid trips only)	Km traveled with ACC engaged (ACAS enabled, valid trips only)
Gender	*Male*	NS	NS	NS	721.5
	Female				422.0
Age Group	*Younger*				*535.8 (NS)*
	Middle	NS	NS	NS	403.9
	Older				810.9
Motor Vehicle Accidents (1995-2003)	*Zero*	NS	NS	NS	NS
	One or more				
Annual mileage (self-reported estimate)	*≤17,000 mi*	1874.1	17.0	1414.0	433.7
	≥17,000 mi	2722.1	21.7	2089.7	719.2

5.4.4 Representativeness of the ACAS FOT Sample

It is illustrative to compare the travel behavior of the ACAS FOT participants with the results of the 2001 NHTS. Using the online data analysis tool available at http://nhts.ornl.gov/2001/index.shtml, it was determined that data selected from the NHTS matched the age and gender categories of the FOT participants. In cases where the NHTS provided two age categories that spanned one age group in the FOT, the two were necessarily combined for comparison. NHTS age categories were by averaging mean for the two age categories for comparison.

As shown in Figure 5-6, FOT distance traveled was extrapolated to predict mileage over a year and then graphed in comparison to the NHTS data. For all comparable groups, with the exception of the middle-age group of males, there is evidence to suggest that UMTRI was successful in identifying participants who drove more than the national average for their age and gender. Most notable is the divergence depicted for the older, female, and older female groups.

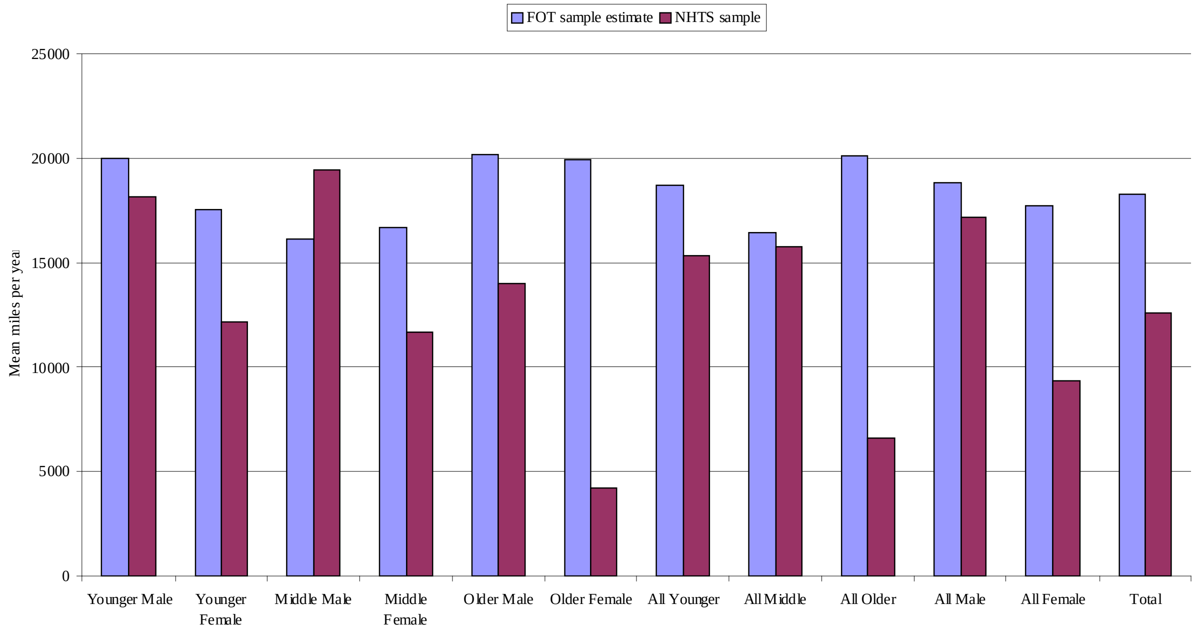


Figure 5-6. Comparison of FOT Sample Estimates and NHTS (2001) Mean Reported Miles Driven per Year

Similarly, Figure 5-7 shows that comparable groups of FOT participants made more daily trips on average than their NHTS counterparts.

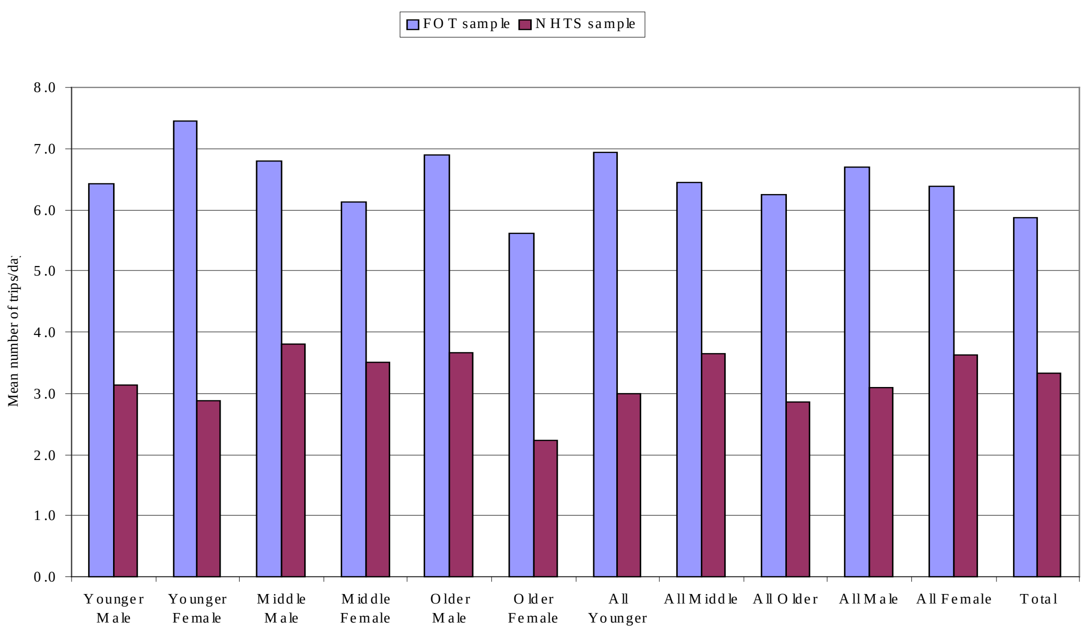


Figure 5-7. Comparison of FOT Sample and NHTS (2001) Mean Number of Trips per Day

Figure 5-8 shows a breakdown of driving-minutes per day by comparable FOT and NHTS groups. Visual comparison indicates that FOT participants spent more time driving their vehicles. On average, for those who drove on their travel day, the NHTS sample reported 82 minutes per day, versus a mean of 93 minutes per day for the FOT sample, or 22 percent more time.

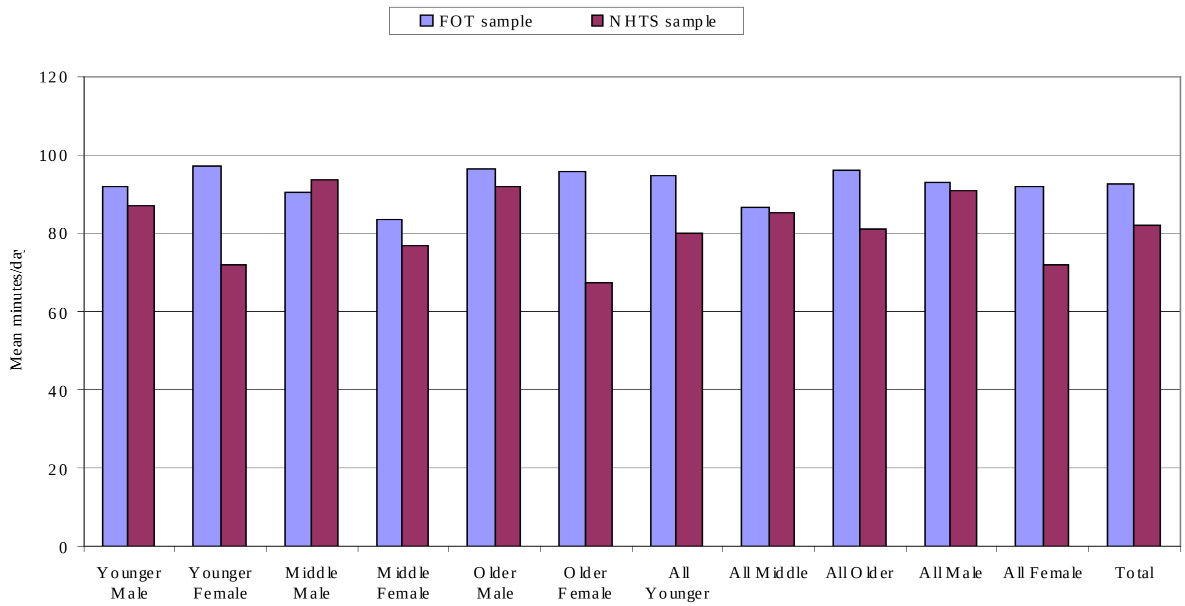


Figure 5-8. Comparison of FOT Sample and NHTS (2001) Mean Number of Minutes Driven per Day

5.4.5 Imminent Alerts

Similar to section 5.2.3 on FOT travel behavior, the FOT participant categories, as found in Table 5-2, were analyzed for potential differences in FCW-generated imminent alerts. For purposes of consistency, the same two outlier-participants were removed from current analyses as in the FOT travel behavior analyses. MANOVA was used to determine if groups differed statistically on variables that measured the mean number of ACAS-enabled alerts per 100 km and the mean number of ACAS-enabled alerts received with ACC engaged. By design, the ACC system moderated the number of alerts that FCW generated by controlling vehicle speed under certain conditions, thereby reducing the mean number of alerts per driver. However, it is important to note that this variable was not normalized by km driven and is therefore affected by the fact that participants traveled varying distances over the course of the FOT.

Results indicated that males received significantly more alerts with ACC engaged than females ($F(1, 62) = 4.40$, $p = .04$); however, the difference between the groups on the number of alerts per 100 km was nonsignificant. Drivers in the group that experienced one or more accidents and those with one or more driving convictions also received significantly more FCW alerts with ACC engaged, though it is important to note that the breakdown of this variable (zero versus one or more) did not permit equal cell sizes for statistical comparison ($F(1, 62) = 4.63$, $p = .04$, and $F(1, 62) = 6.99$, $p = .01$, respectively). Finally, a significant difference was found, whereby participants who had experienced one or more motor vehicle accidents received, on average, significantly more alerts per 100 km than those participants who were not involved in any accidents over the specified time period ($F(1, 62) = 5.90$, $p = .02$).

Table 5-4. MANOVA Results for FOT Alert Variables – Significant Between-Group Differences in Means Only ($p < .05$)

		Alerts per 100 km (ACAS enabled)	Alerts with ACC engaged (ACAS enabled)
Gender	*Male*	NS	1.39
	Female		.58
Motor Vehicle Accidents	*Zero*	1.6	.74
(1995-2003)	*One or more*	2.5	1.7
Motor Vehicle Convictions	*Zero*	NS	.56
(1995-2003)	*One or more*		1.6

5.5 ASSESSING DRIVER ACCEPTANCE

5.5.1 Advocacy – FCW

The advocacy objective examined the degree to which drivers were interested in the purchase and use of FCW. Advocacy was gauged using several subjective measures as found in the FOT surveys. For example, drivers were asked how likely they would be to rent or purchase a vehicle equipped with FCW, as well as what price they would pay for such a system. Additionally, the degree to which drivers would endorse and were comfortable with the use of FCW by others was assessed. Drivers also responded to a Driver Acceptance Scale (van der Laan et al., 1997; see Appendix G) that was designed for the purposes of assessing attitudes toward new vehicle technologies. This scale generates composite scores for two subscales, termed “usefulness” and “satisfaction.” Survey item responses were analyzed in conjunction with the scale results; the latter has been used as a proxy for driver acceptance.

This section presents the results of the FCW advocacy measures. It includes both descriptive and quantitative discussion of the advocacy survey items in tandem with Driver Acceptance Scale results, as well as a section that explores the consistency of drivers’ responses to certain advocacy measures. Relevant driver anecdotes are also provided based on debriefing and focus group sessions. Finally, FCW advocacy as forecasted vis-à-vis purchase intent is discussed and conclusions are offered.

5.5.1.1 FCW Statistical Findings

Correlations were calculated among the advocacy measures and the Driver Acceptance Scale scores.[7] All were significantly intercorrelated and relationships were in the expected direction (the full correlation matrix is located in Appendix H). The second survey item, "…consider purchasing FCW…," was most highly correlated with the "usefulness" and "satisfaction" subscales, at .87 and .88 respectively, while the subscales themselves were correlated at .89.

Table 5-5 presents descriptive statistics for responses to each of the survey measures as broken down by sub-objective. As responses were not always normally distributed, measures of central tendency in addition to the mean and standard deviation are provided for each measure.

Table 5-5. Advocacy Sub-Objective Survey Measure Descriptive Statistics

Sub-objective	Survey Item	Mean	Standard Deviation	Median	Mode
Acceptance in Rental Vehicle					
	Would you be willing to rent a vehicle equipped with FCW? *1 (very unwilling) - 7*	5.4	1.8	6.0	7.0
Interest in Purchasing					
	How likely would you be to consider purchasing FCW if you were purchasing a new vehicle today? *1 (definitely not) - 5*	3.1	1.3	3.0	4.0
Level of Trust					
	How comfortable would you feel if your child, spouse, parents – or other loved ones – drove a vehicle equipped with FCW? *1 (very uncomfortable) - 7*	5.6	1.7	6.0	7.0
Amount Willing to Pay					
	At $1,000, how likely would you be to consider purchasing FCW if you were purchasing a new vehicle today? *1 (definitely not) - 5*	2.5	1.6	2.0	1.0
Willingness to Endorse					
	Would you recommend to your child, spouse, parents – or other loved ones – to use FCW? *(% yes)*	65%	.	.	.
Driver Acceptance Scale					
	Usefulness subscale *(-2,…,+2)*	0.9	1.0	1.0	2.0
	Satisfaction subscale *(-2,…,+2)*	0.5	1.3	0.5	2.0

[7] Correlations were performed using Spearman's rho for nonparametric data. Many of the significant correlations reported are of a relatively low magnitude.

Table 5-6 shows the statistical relationship between driver age and driver advocacy of FCW, as broken down by sub-objective, with any significant group differences noted briefly in the rightmost "results" column and nonsignificant results denoted using "NS." Analysis of Variance (ANOVA) was performed for Likert-type survey measures and Chi square analyses were used for dichotomous measures. Results showed that older drivers expressed a greater willingness to rent an FCW-equipped vehicle, consider purchasing a vehicle with FCW, and comfort with having loved ones drive an FCW-equipped vehicle.[8] Older drivers also reported significantly higher scores on the "satisfaction" scale than middle-age and younger drivers. Drivers' gender was not significantly related to any of the advocacy sub-objective measures. Significant findings are depicted graphically and discussed in more detail below.

[8] Parametric ANOVA results are reported here and throughout this report. A nonparametric version of this analysis, the Kruskal-Wallis test, was also run for the Advocacy objective and produced the same results. Further justification for the use of ANOVA in subsequent analyses is provided in the section on data analysis (5.3.4).

Table 5-6. Statistical Comparison of FCW Advocacy Sub-Objective Measures by Driver Age Group

Sub-objective	Survey Item	Age Group	Mean	ANOVA, χ2 Results
Acceptance in Rental Vehicle				
	Would you be willing to rent a vehicle equipped with FCW?	Younger	4.5	O more willing to rent than Y
	1 (very unwilling) - 7	Middle	5.3	
		Older	6.2	
Interest in Purchasing				
	How likely would you be to consider purchasing FCW if you were purchasing a new vehicle today?	Younger	2.6	O more likely to consider purchasing than Y
	1 (definitely not) - 5	Middle	3.0	
		Older	3.6	
Level of Trust				
	How comfortable would you feel if your child, spouse, parents – or other loved ones – drove a vehicle equipped with FCW?	Younger	4.7	O more comfortable than Y
		Middle	5.6	
	1 (very uncomfortable) - 7	Older	6.3	
Amount Willing to Pay				
	At $1,000, how likely would you be to consider purchasing FCW if you were purchasing a new vehicle today?	Younger	2.4	NS
		Middle	2.4	
	1 (definitely not) - 5	Older	2.8	
Willingness to Endorse				
	Would you recommend to your child, spouse, parents – or other loved ones – to use FCW?	Younger	59%	NS
	(% yes)	Middle	64%	NS
		Older	73%	O more likely to recommend (χ2)
Driver Acceptance Scale				
	Usefulness subscale	Younger	0.7	NS
	(-2,…,+2)	Middle	0.8	
		Older	1.2	
	Satisfaction subscale	Younger	0.05	O more satisfied than M & Y
	(-2,…,+2)	Middle	0.3	
		Older	1.2	

Figure 5-9 depicts a response distribution showing the degree to which the older driver group reported being more willing to rent an FCW-equipped vehicle than the younger group ($F(2, 55) = 4.34$, $p = .02$). In fact, 82% of the older group responded with the highest two scores, 6 or 7, compared to one third of the younger drivers.

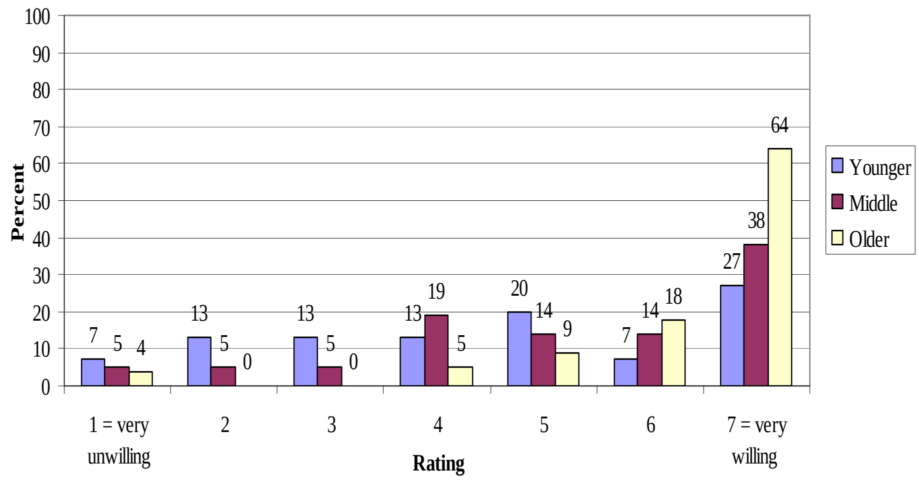


Figure 5-9. Willing to Rent a Vehicle with FCW by Age Group

Figure 5-10 depicts the mean scores for each age group and Figure 5-11 shows the distribution of responses for this measure, where it is evidenced, particularly for the middle-age group, that attitudes regarding FCW purchase were mixed.

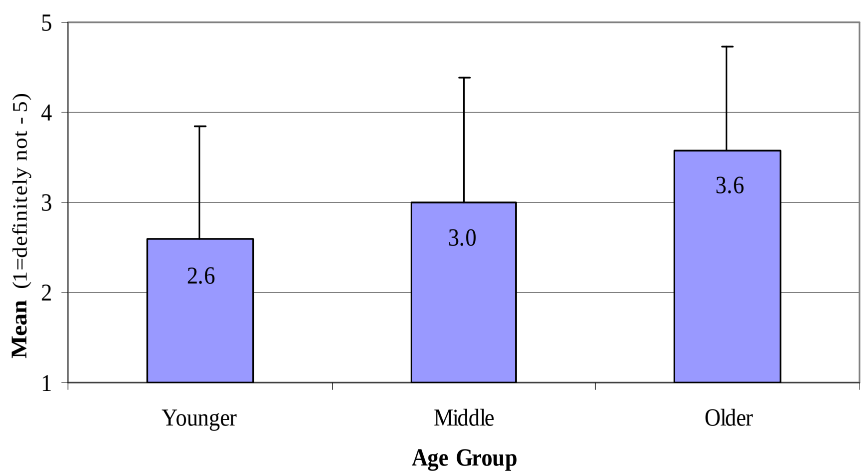


Figure 5-10. Likelihood of Considering FCW Purchase in a New Vehicle by Age Group

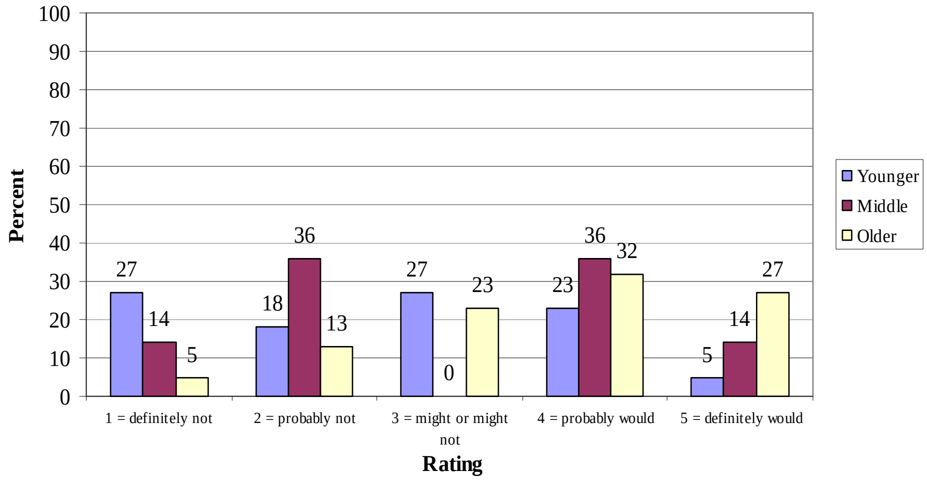


Figure 5-11. Response Distribution for Likelihood of Considering FCW Purchase in a New Vehicle by Age Group

Older drivers reported being more comfortable than the younger age group with the possibility of their loved ones driving an FCW-equipped vehicle ($F(2, 55) = 4.70$, $p = .01$). Figure 5-12 depicts the response distribution for this measure, where 82 percent of the older drivers indicated that they would feel quite comfortable (a score of 6 or 7) if their loved ones drove a vehicle with FCW, while the younger group's responses were more neutral and mixed.

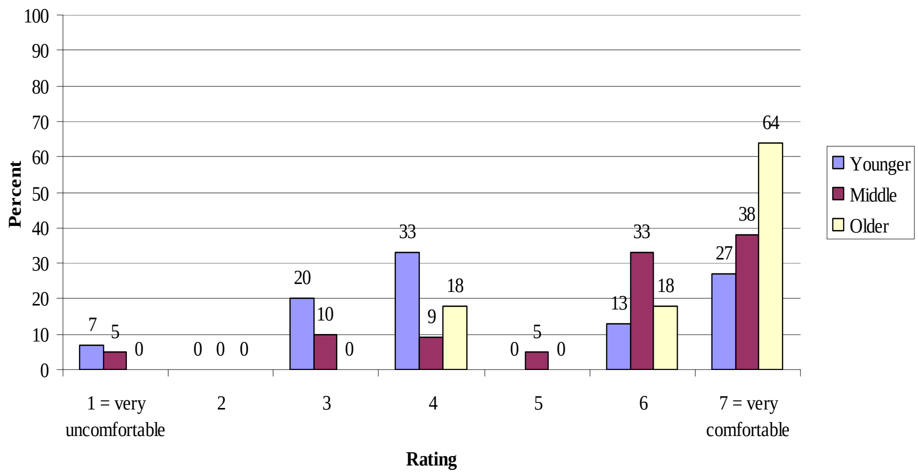


Figure 5-12. Comfort Level if Loved Ones Drove an FCW-equipped Vehicle by Age Group

When drivers were asked, "At what price level might you begin to feel FCW is too expensive to consider purchasing?" the mean amount was $899.[9] However, 8 percent of the sample did not

---

[9] The standard deviation was $145. The median and mode were both $500 with a minimum of $0 and a maximum of $6,000.

answer this question and responses that were obtained were variable. Some drivers claimed that they could not estimate the cost of a feature on a new car because they purchased used cars or did not know what such "options" sold for separately.

Almost two thirds of the drivers, 65 percent, said they would recommend FCW use to others. Figure 5-13 illustrates responses of the three age groups for recommending FCW use. In the case of the younger and middle-age groups, responses were not statistically differentiated. However in the case of the older drivers, 73 percent the difference between "would" and "would not" recommend was significant (χ^2 (1, N = 22) = 4.55, p = .03).

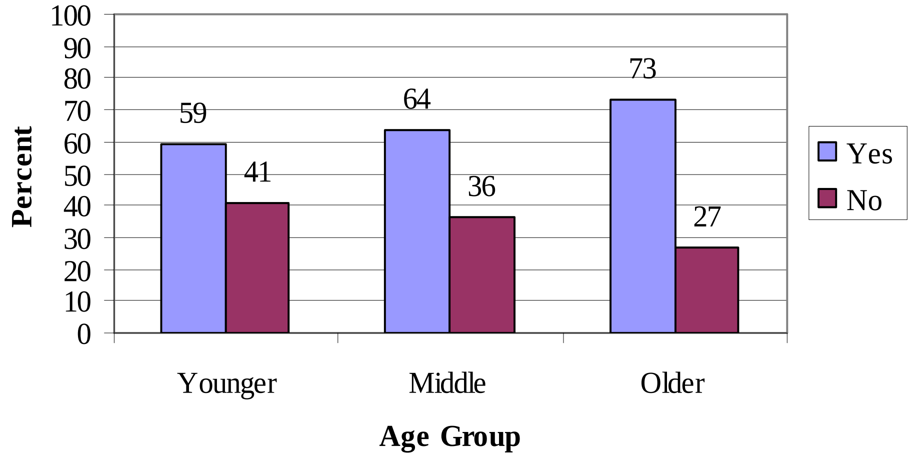


Figure 5-13. Recommend FCW Use to Loved Ones by Age Group

5.5.1.2 Investigating Travel Behavior and FCW Advocacy Measures

Follow-on analyses were conducted to see if objective travel behavior measures were correlated with the advocacy measures. The objective measures encompassed ACAS-enabled driving and included FCW distance traveled (km) in valid trips, number of FCW alerts and mean number of FCW alerts per 100 Km. No meaningful statistical relationships were obtained among the survey and objective travel behavior measures.

5.5.1.3 Driver Acceptance Scale

In addition to individual survey items used to assess FCW system advocacy, the Driver Acceptance Scale and resulting usefulness and satisfaction subscales provides a conceptually clear means of classifying attitudes toward such a system. Figure 5-14 shows the quadrants created by crossing the positive and negative ranges for the "usefulness" and "satisfaction" Driver Acceptance scale scores and illustrates the distribution of responses to this composite measure. The cluster of drivers in the upper right quadrant rated FCW positively for both satisfaction and usefulness (n = 41).[10] The cluster in the lower left corner displays drivers who

[10] Driver count per quadrant does not include individuals who rated the system neutral (subscale score = 0) for either usefulness and/or satisfaction (n = 6).

rated FCW negatively on both the satisfaction and usefulness subscales (n = 12).[11] The upper left cluster of drivers manifested positive usefulness, with negative satisfaction ratings, suggesting that a small number of individuals recognized the usefulness of the FCW system, but were not satisfied with it (n = 7). There were no drivers who rated the system positively for satisfaction and negatively for usefulness.

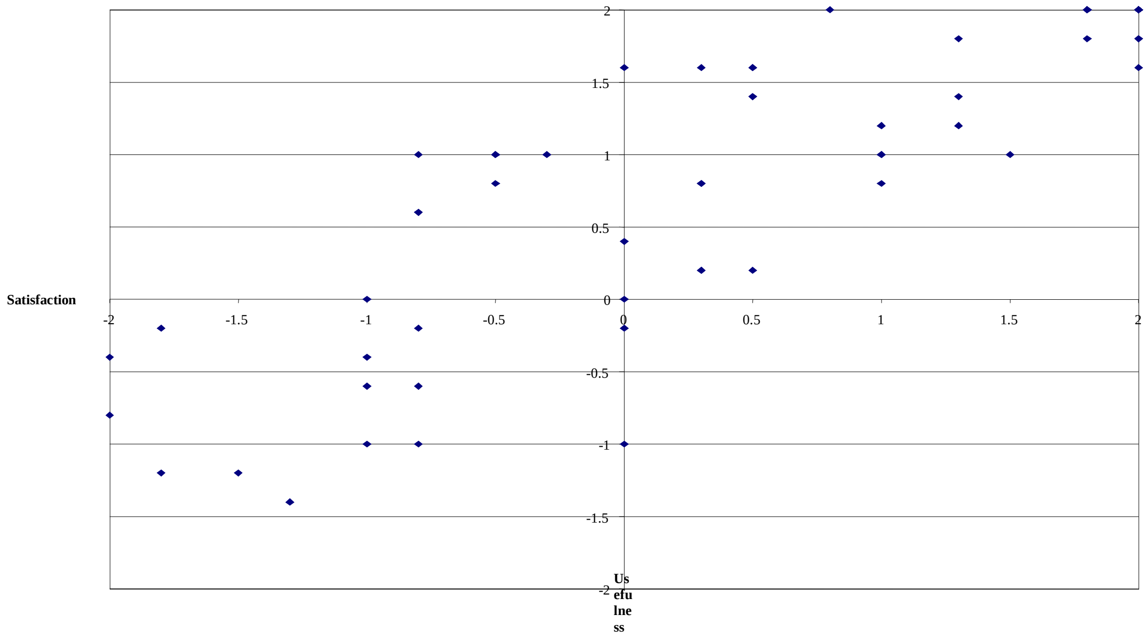


Figure 5-14. Driver Acceptance Scale Scores for FCW by "Usefulness" and "Satisfaction" Quadrants

[11] Note that, in some cases, more than one driver occupies the same point, so that the number of distinct points totals fewer than 66.

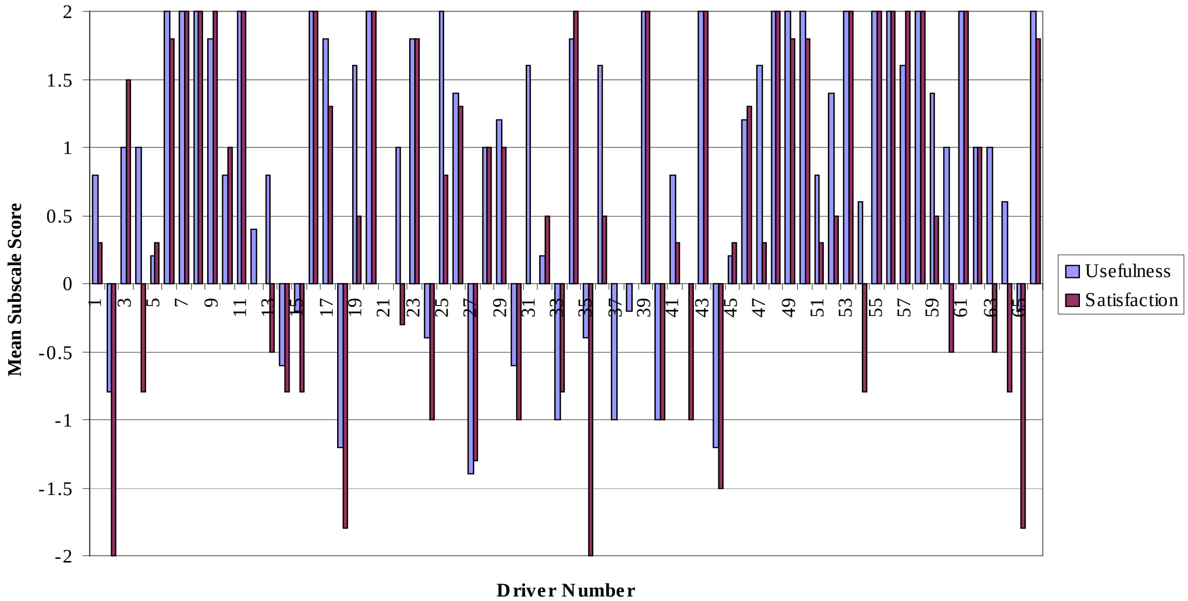


Figure 5-15. Driver Acceptance Scale "Usefulness" and "Satisfaction" Subscale Scores by Driver

Each usefulness and satisfaction subscale score is plotted by driver in Figure 5-15. Scores on the two subscales range from –2, least useful and least satisfied, to +2, most useful and most satisfied. The mean satisfaction subscale score was .52 (SD = 1.2), while the mean usefulness subscale score was .92 (SD = 1.0). The degree of variability in scores, resulting in large standard deviations is easily seen in the graph.

Figure 5-16 depicts an overall increase in ratings for satisfaction and usefulness as age increased. Scores on the two subscales range from –2, least useful and least satisfied, to +2, most useful and most satisfied. Between-group differences were not significant for usefulness. However, in the case of the satisfaction subscale, age did differentiate, whereby older drivers were found to be more satisfied than the middle-age and younger drivers ($F(2, 63) = 6.42$, $p = .02$; and $F(2, 63) = 6.42$, $p < .01$, respectively).

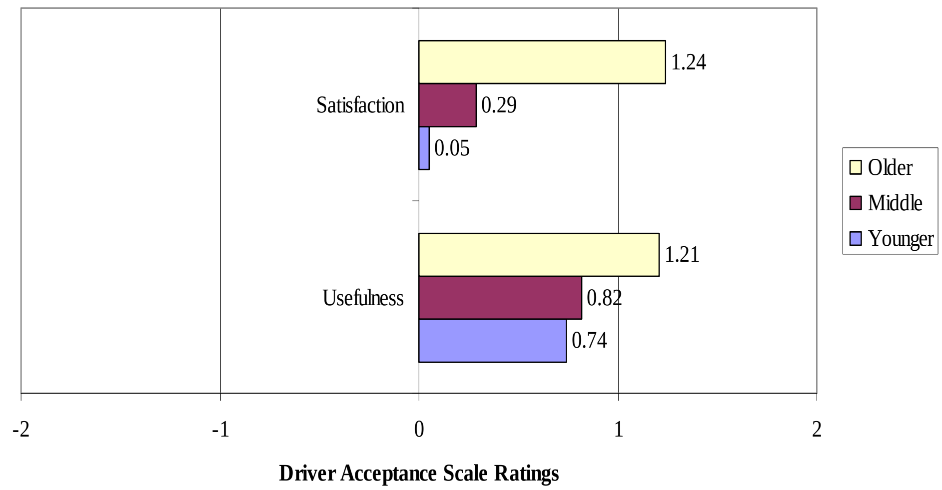


Figure 5-16. FCW "Usefulness" and "Satisfaction" Subscale Scores by Age Group

5.5.1.4 Consistency of driver response to FCW advocacy measures

In an effort to account for drivers' lack of uniformity of response to FCW survey measures, the independent evaluation created a variable to sort drivers who were consistently negative with regard to FCW from the consistently positive drivers. This variable, "consistency," was constructed by classifying responses to the three advocacy measures with the highest intercorrelations: the usefulness and satisfaction subscale scores and survey responses to the purchase intent item that asked "How likely would you be to consider purchasing FCW if you were purchasing a new vehicle today?" A driver was assigned "positive" consistency if scores were greater than zero on both the usefulness and satisfaction subscales, combined with either a rating of "probably" (4) or "definitely" (5) on the purchase intent survey question. "Negative" consistency was designated if scores were less than zero on both usefulness and satisfaction subscales, combined with either a rating of "definitely not" (1) or "probably not" (2) on the purchase intent survey question. The remaining drivers, who were either neutral or not consistent among measures, were classified as "mixed" consistency.

Figure 5-17 shows the relationship among driver age groups and consistency of FCW advocacy responses. The graph shows descriptively that the older age group was most positively consistent and that no older drivers were negatively consistent. However, approximately one quarter of each group of younger and middle-age drivers was negatively consistent. No relationships were apparent with regard to driver gender or trip behavior measures.

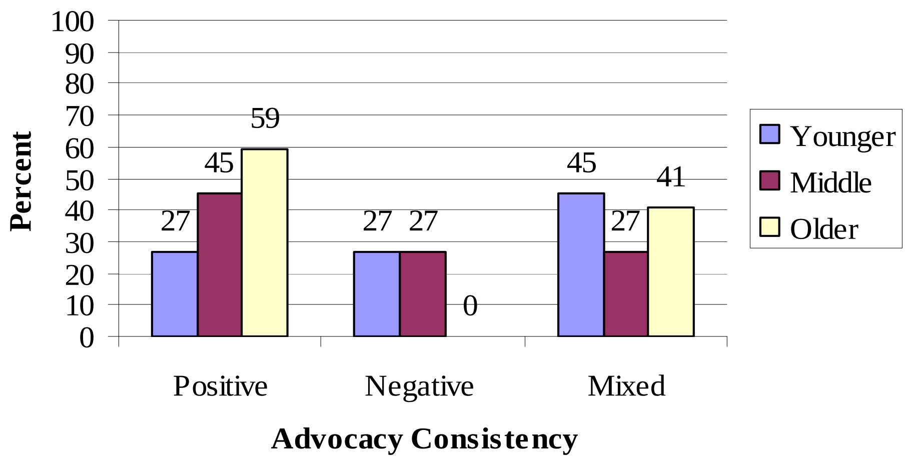


Figure 5-17. Consistency of FCW Advocacy Responses by Age Group

5.5.1.5 Interpretation of FOT debriefing video clips

During each driver's post-FOT debriefing, a selection of video clips were replayed, showing the forward and facial driving views when FCW crash-imminent alerts were received. Each driver was asked to retrospectively classify the alert in each clip as "useful" or "not useful" and was also asked to describe, in their own words, why they thought they received each alert. The value of this retrospective alert classification process lies in the ability to describe each FCW alert issuance situation in the driver's own words. The video clips replayed came from each subject's driving experience and the comments they offered pertain to their experience using the FCW system. This technique makes it possible to get as close as possible to the immediate situation when the FCW crash-imminent alert was issued, short of being present in time. Drivers viewed an average of 8.3 video clips.

As shown in Figure 5-18, overall, drivers rated 34 percent of the replayed FCW alerts as "useful." Among the age groups, a higher percentage of older drivers were inclined to have rated an alert as useful, compared to the younger and middle-age groups.

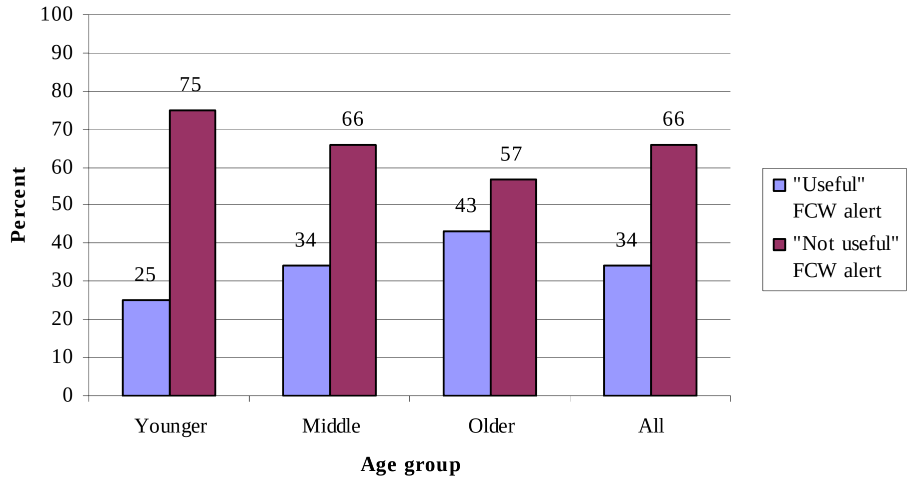


Figure 5-18. Usefulness of Video Clip Ratings for FCW Alerts by Age Group

Each driver's interpretation of the situation that triggered an FCW alert was also recorded during the debriefing and subsequently grouped qualitatively by the independent evaluation into a broader classification scheme. Figure 5-19 shows the classes of reasons as created for the FCW alerts. The most often cited reason was classified as related to the action of a "lead vehicle," and offered 37 percent of the time. "No apparent reason" was the second most frequent response at 16 percent, and "driver attention" was cited 14 percent of the time.

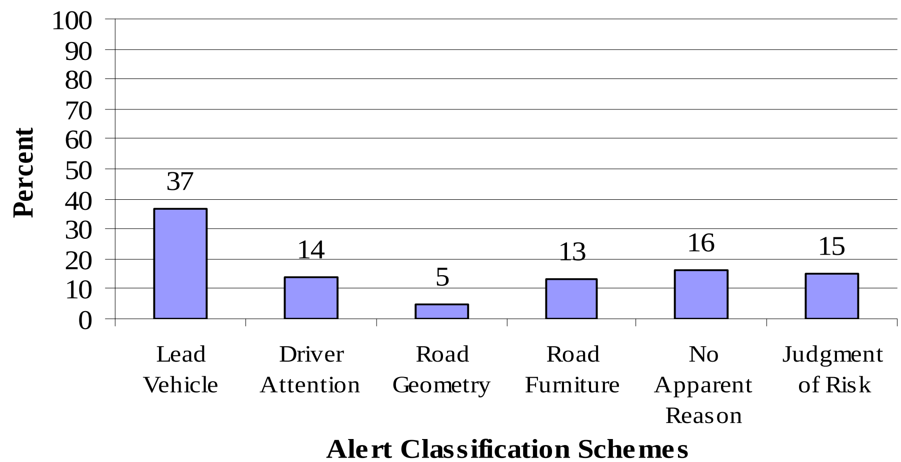


Figure 5-19. Classification Schemes for FCW Alerts in Debrief Video Clips

FOT subjects offered some anecdotes for FCW alerts that were classified as lead-vehicle related. Not useful lead vehicle alert situations were largely related to instances when the driver indicated that he/she was sufficiently aware of the forward scene, that the distance from their vehicle to the lead vehicle was adequate, or that the action of the lead vehicle was self-evident. Useful alerts were typically related to situations where drivers realized they were looking away from the forward scene, using a cell phone, or appearing otherwise distracted.

As a further breakdown, Figure 5-20 shows the distribution of drivers' ratings of FCW alerts assigned to each classification scheme as useful versus not useful. Drivers classified alerts that they received as useful for situations involving a lead vehicle 62 percent of the time. For driver attention situations, half of the alerts received were deemed useful.

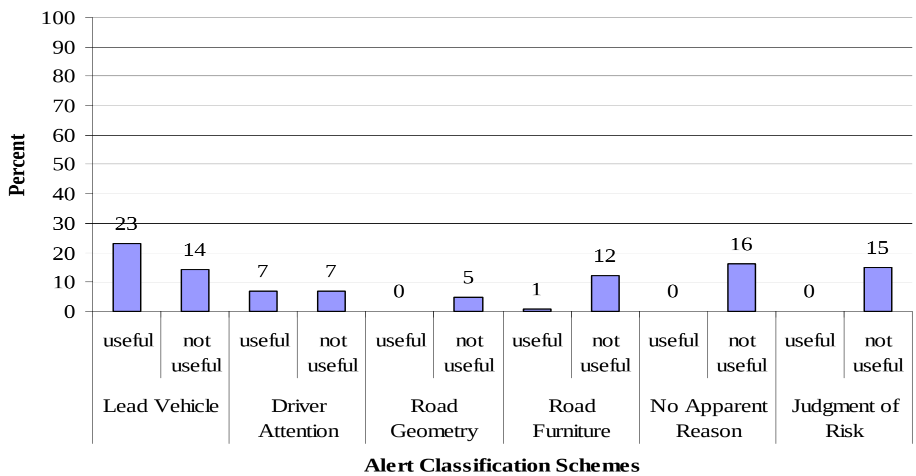


Figure 5-20. FCW Alert Classification Schemes by Useful/Not Useful Video Clip Ratings

It is also noteworthy to present usefulness ratings by the FCW consistency groups discussed previously (see Figure 5-21). Of particular interest is the negative group, which rated only 11 percent of their alerts as useful. The positive and mixed groups were more evenly divided in their usefulness ratings, though the mixed consistency group rated approximately two thirds of the viewed alerts as not useful. Given that drivers received a mean of 11.3 imminent alerts per driver and viewed 8.3 video clips on average, the assumption is that the video replays reviewed during debriefing were sufficiently representative of drivers' overall FCW alert experience.

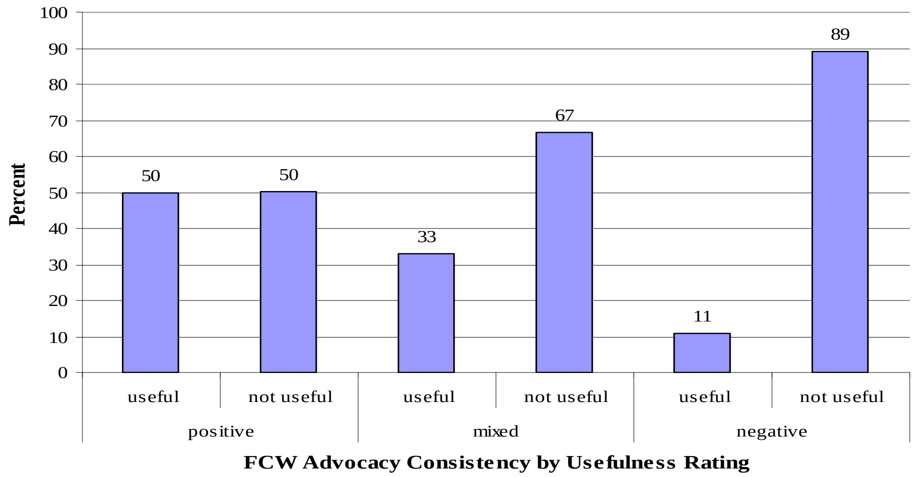


Figure 5-21. Advocacy Consistency by Useful/Not Useful Video Clip Ratings

5.5.1.6 Focus Group Comments Regarding FCW Advocacy

During each of the four focus groups, drivers were asked whether "FCW performed in the way you would expect it to if you bought this feature? If not, how should FCW perform differently?" Their comments can be classified as describing issues related to receiving too many false alerts, concern that the FCW alert timing was too late, difficulty understanding how FCW worked, interest in adding user adjustable features to FCW and extending the operating range of FCW to under 25 mph, as well as testimonials to the usefulness of FCW for learning about one's vehicle position in relation to a lead vehicle.

In some cases, it was clear that drivers did not understand the FCW sensitivity settings, and on occasion even mistakenly referred to "gap" settings (ACC) when discussing the FCW system. Drivers said they lacked a way to estimate and understand the FCW settings. The settings embody vehicle dynamics as well as time headway. Drivers tended to think of headway as distance and did not think in terms of closing rates.

Drivers suggested using a stored memory feature for geographic locations to suppress FCW imminent alerts and reduce false alerts. Other concerns relate to the timing of the FCW alert and the fact that it was not user adjustable. Coverage is a concern to drivers and they would like FCW available across a broader range of speeds, range given that rear-end collision threats often occur at lower speeds.

Drivers were asked whether they thought FCW was ready for production. They suggested alterations to make FCW production ready, which included reducing the incidence of false alerts, expanding FCW's capabilities to monitor a wider area, and add ways for drivers to adjust FCW to their own driving needs.

Focus group participants were asked, "Would you buy an FCW system? If not, why not? And if you would, why?" Of the 25 focus group participants, 28 percent said yes, 52 percent said no and 20 percent were uncertain. Drivers who said they would purchase FCW tended to identify a need it filled for them, such as a tendency to be distracted, need to travel a lot, and how it functioned with ACC. The drivers saying they would not purchase FCW mentioned the incidence of false alarms and the need to improve the coverage and utility of FCW as reasons not to purchase FCW. Drivers who were uncertain about purchasing FCW mentioned false alarms and their lack of a need for FCW.

5.5.1.7 Estimated FCW purchase intent

Analyses examined to what degree FCW experiences were related to interest in acquiring it. Using self-reported levels of buying intent as provided in the FOT survey item discussed earlier in this section and applying the “weighted box” methodology, it was possible to estimate what percentage of drivers who experienced FCW would choose to purchase it, thereby forecasting acceptance.

Buying intent was gauged by responses on a 5-point Likert response scale (1 = definitely not) to the survey item: “How likely would you be to consider purchasing FCW if you were purchasing a new vehicle today?” The “weighted box rule” for forecasting purchase using intent scales (Urban and Hauser, 1993) provides a way to translate subjective scale responses into purchase predictions.[12] It is important to note that this prediction is an estimate of future purchase, assuming 100 percent availability and awareness of the system. It is impossible to know exactly how buyer intent will translate into actual purchase (i.e., the conversion-rate), especially for new products, such as FCW.

Market researchers employ the weighted box method because the data are straightforward and positive correlations have been found between stated purchase intentions and purchase behavior (e.g., Juster, 1966, Morwitz, 1992). Using the FCW purchase intent survey question, drivers responded as follows: definitely would (15.2%), probably would (30.3%), definitely not (15.2%), probably not (22.7%). Applying the weighted box rule resulted in the prediction that 27.4 percent of the FOT drivers would purchase FCW.

It is useful to consider the likely diminution of purchase intent due to the novelty effect and the passage of time. The focus groups were held several weeks to 3.5 months after the drivers finished their FOT driving. When drivers were again asked if they would purchase FCW, there was 20 percent attrition in intent compared with survey responses to this question. As phrasing of the focus group item was not identical to the survey measure, and because only 39 percent of drivers returned for focus group sessions, a precise recalculation of purchase likelihood based on the weighted box rule was not possible. Nevertheless, it is the case that the initial calculated percentage would have decreased to some extent.

[12] The procedure to calculate purchase prediction, given intent level and probabilities of actual purchase, is the probability of purchase for given intent level multiplied by the number of respondents at that intent level. In this case, 90% of “definites," 40% of “probables,” and 10% of “mights” were summed. Marketers multiply this result by the expected “awareness-availability” percentage to predict what percent of the population will make an actual purchase. The awareness-availability percentage refers to the population segment that is both aware of the product and finds it available. The awareness-availability percentage value for FCW was not available for calculations as it is proprietary. Therefore, by default, 100% availability and awareness of the system was assumed.

5.5.1.8 Summary

Overall, driver attitudes pertaining to FCW advocacy, as assessed using available survey data, were in the positive to neutral range. Age-related findings with regard to positive advocacy of the FCW system were most consistent for the older driver group. They were the most positively consistent regarding FCW advocacy attitudes and reported a greater degree of overall satisfaction with FCW when compared with the younger and middle-age drivers. Additionally, the older group was more likely to consider purchasing the system than the younger drivers.

Analysis of the survey items regarding the imminent alerts indicated that, generally, each age group deemed a greater percentage of alerts as not useful, rather than useful. However, this divergence was smallest for the older driver group, which rated 43 percent of video-replay alerts as useful. This is in comparison to the middle and younger groups, which rated favorably approximately one third and one quarter of FCW-generated alerts, respectively. “Lead vehicle” and “driver attention” situations resulted in roughly half of all FCW alerts that drivers reviewed in video replays and comprised nearly all of alerts that were classified as useful. Drivers rated 16 percent of the FCW alerts that were replayed as both not useful and occurring for no apparent reason.

Predicted level of purchase intent with regard to the FCW system as it was experienced by the FOT drivers, was initially estimated at 27 percent. It is noteworthy that this percentage would have declined due to the novelty effect if the same calculations had been possible using subsequent purchase intent attitudes recorded during the focus group sessions. Logically, the assumption should be made that the more time that passes between an individual’s experience with a product and that product’s availability for purchase, the less salient such experiences become, and consequently, the less likely they are to translate into actual purchase behavior.

5.5.2 Advocacy – ACC

The advocacy objective examined the degree to which drivers were interested in the purchase and use of ACC. Advocacy was gauged using several subjective measures that paralleled those for FCW, as found in the FOT surveys, including those addressing rental or purchasing a vehicle equipped with FCW, endorsement of the system, and comfort with its use by others. Drivers also responded to a Driver Acceptance Scale (van der Laan et al., 1997; for a more complete discussion, see Appendix G) that was designed for the purposes of assessing attitudes toward new vehicle technologies.

This section presents the results of the ACC advocacy measures. It includes both descriptive and quantitative discussion of the advocacy survey items in tandem with Driver Acceptance Scale results, as well as driver anecdotes supplied during debriefing and focus group sessions. Finally, ACC advocacy as forecasted vis-à-vis purchase intent is discussed and conclusions are offered.

5.5.2.1 ACC Statistical Findings

Correlations were calculated among the advocacy measures and the Driver Acceptance Scale scores.[13] All of the measures that were significantly intercorrelated exhibited relationships in the expected direction (the full correlation matrix is located in Appendix I). The second survey item, "…consider purchasing ACC…" and the third, addressing comfort-level if loved ones drove with ACC, were most highly correlated with the "satisfaction" subscale, each at .61, while the subscales themselves were correlated at .69.

Table 5-7 presents descriptive statistics for responses to each of the survey measures as broken down by sub-objective. As responses were not always normally distributed, measures of central tendency in addition to the mean and standard deviation are provided for each measure.

Table 5-7. Advocacy Sub-Objective Survey Measure Descriptive Statistics

Sub-objective	Survey Item	Mean	Standard Deviation	Median	Mode
Acceptance in Rental Vehicle					
	Would you be willing to rent a vehicle equipped with ACC? *1 (very unwilling) - 7*	6.1	1.6	7.0	7.0
Interest in Purchasing					
	How likely would you be to consider purchasing ACC if you were purchasing a new vehicle today? *1 (definitely not) - 5*	3.9	1.0	4.0	4.0
Level of Trust					
	How comfortable would you feel if your child, spouse, parents – or other loved ones – drove a vehicle equipped with ACC? *1 (very uncomfortable) - 7*	6.2	1.3	7.0	7.0
Amount Willing to Pay					
	At $1,000, how likely would you be to consider purchasing ACC if you were purchasing a new vehicle today? *1 (definitely not) - 5*	2.9	1.4	3.0	3.0
Willingness to Endorse					
	Would you recommend to your child, spouse, parents – or other loved ones – to use ACC? *(% yes)*	87.9%	.	.	.
Driver Acceptance Scale					
	Usefulness subscale *(-2,…,+2)*	1.5	0.5	1.6	2.0
	Satisfaction subscale *(-2,…,+2)*	1.5	0.7	2.0	2.0

[13] Correlations were performed using Spearman's rho for nonparametric data.

Table 5-8 shows statistical relationships between driver age group and ACC advocacy, as broken down by sub-objective, with any significant group differences noted briefly in the rightmost "results" column and nonsignificant findings denoted using "NS." Analysis of variance[14] was performed for Likert-type survey measures and Chi square analysis was employed for dichotomous measures. Results showed that older drivers were significantly more likely than middle-age and younger drivers to consider purchasing a vehicle with ACC. Additionally, older drivers were more likely than the middle-age driver group to be comfortable with loved ones driving an ACC-equipped vehicle, and more likely to consider spending $1,000 to purchase ACC on a new vehicle. With regard to recommending ACC, in each case, age groups were more likely to recommend its use than not. Finally, the older driver age group found ACC both more satisfying and useful than the middle-age group. Driver gender was not significantly related to any of these measures. Significant findings are depicted graphically and discussed in more detail below.

[14] Parametric ANOVA results are reported here and throughout this report. A nonparametric version of this analysis, the Kruskal-Wallis test, was also run for the Advocacy objective and produced the same results. Further justification for the use of ANOVA in subsequent analyses is provided in the section on Data analysis (5.3.4).

Table 5-8. Statistical Comparison of ACC Advocacy Sub-Objective Measures by Driver Age Group

Sub-objective	Survey Item	Age Group	Mean	ANOVA, $\chi 2$ Results
Acceptance in Rental Vehicle				
	Would you be willing to rent a vehicle equipped with ACC?	Younger	6.3	NS
		Middle	5.5	
	1 (very unwilling) - 7	Older	6.5	
Interest in Purchasing				
	How likely would you be to consider purchasing ACC if you were purchasing a new vehicle today?	Younger	3.6	O more likely to consider purchasing than Y & M
	1 (definitely not) - 5	Middle	3.6	
		Older	4.3	
Level of Trust				
	How comfortable would you feel if your child, spouse, parents – or other loved ones – drove a vehicle equipped with ACC?	Younger	6.3	O more comfortable than M
		Middle	5.5	
	1 (very uncomfortable) - 7	Older	6.7	
Amount Willing to Pay				
	At $1,000, how likely would you be to consider purchasing ACC if you were purchasing a new vehicle today?	Younger	3.1	O more likely to consider ACC purchase than M
	1 (definitely not) - 5	Middle	2.4	
		Older	3.3	
Willingness to Endorse				
	Would you recommend to your child, spouse, parents – or other loved ones – to use ACC?	Younger	86.4%	Each group more likely to recommend ($\chi 2$)
		Middle	81.8%	
	(% yes)	Older	95.5%	
Driver Acceptance Scale				
	Usefulness subscale	Younger	1.4	O found more useful than M
		Middle	1.3	
	(-2,…,+2)	Older	1.7	
	Satisfaction subscale	Younger	1.4	O more satisfied than M
	(-2,…,+2)	Middle	1.2	
		Older	1.8	

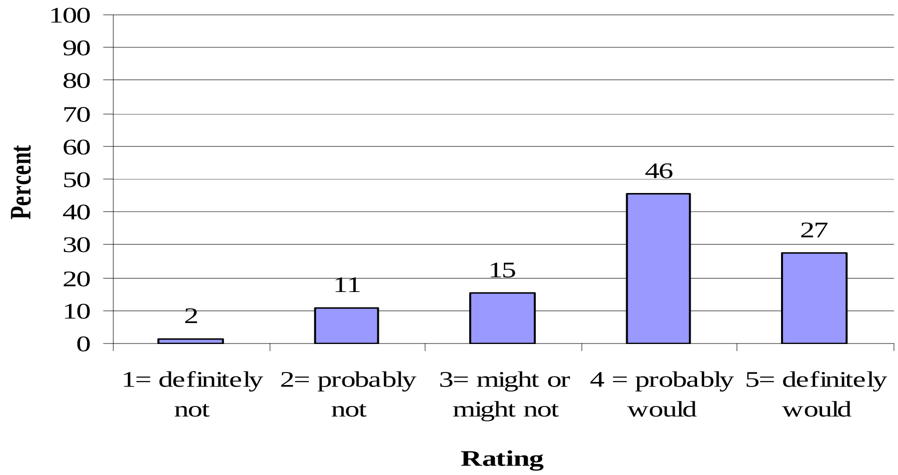


Figure 5-22. Likelihood of Considering ACC Purchase in a New Vehicle

Figure 5-23 shows the distribution of responses for this measure, where the older driver group was more likely to have indicated that they would consider purchasing ACC on a new vehicle than either the younger or middle-age driver groups ($F(2, 63) = 3.77$, $p = .05$; and $F(2, 63) = 3.77$, $p = .05$, respectively). More than nine out of 10 of the older drivers said that they would "probably" or "definitely" purchase ACC.

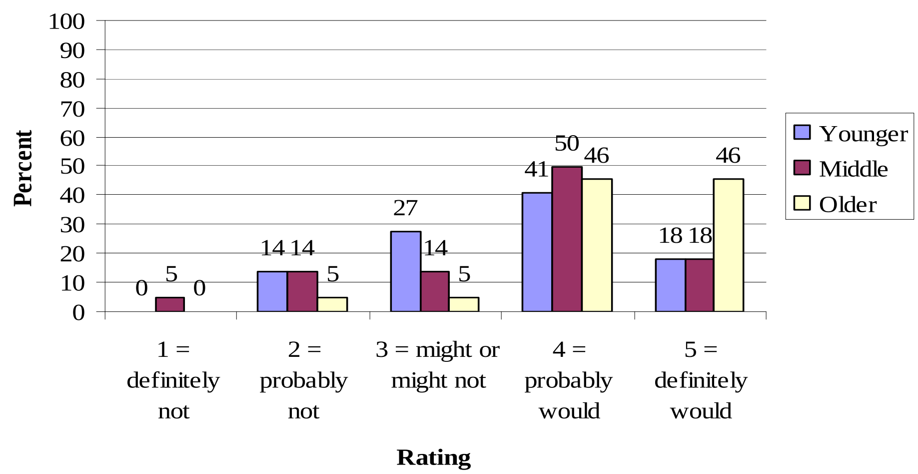


Figure 5-23. Likelihood of Considering ACC Purchase in a New Vehicle by Age Group

Older drivers also reported being more comfortable with the possibility of their loved ones driving an ACC equipped vehicle than the middle-age group ($F(2, 55) = 5.57$, $p < .01$). Figure 5-24 shows that 91 percent of the older drivers said they would feel very comfortable (a score of 6 or 7) if their loved ones drove a vehicle with ACC.

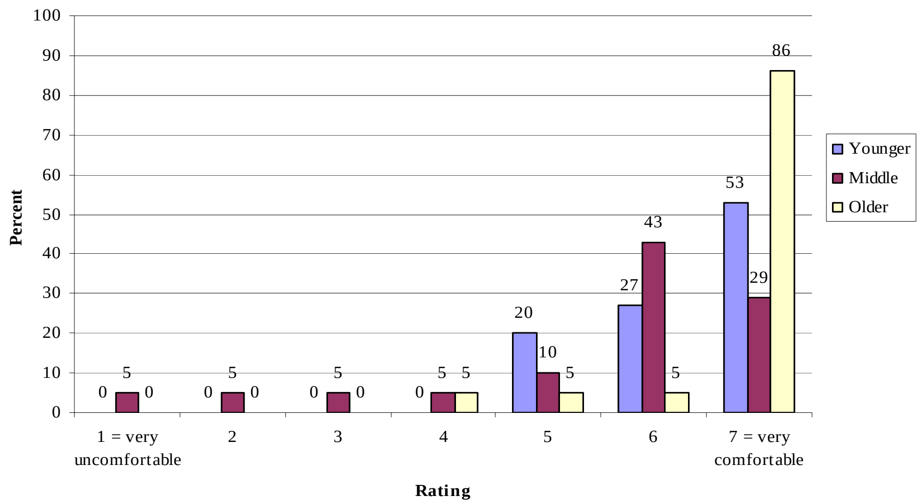


Figure 5-24. Comfort level if Loved Ones Drove an ACC-equipped Vehicle by Age Group

Drivers were asked if they would spend $1,000 for ACC if they bought a new vehicle. Figure 5-25 shows that slightly more than one third would "probably" or "definitely" consider the purchase, while just under one third, would "probably" or "definitely" not consider it or were neutral. Half of the older drivers compared to less than 20 percent of the middle-age group would "definitely" or "probably" consider ACC purchase at $1,000. The difference between the older and middle-age groups' mean scores were significant, however, as is depicted in Figure 5-26, attitudes especially in the middle-age group, were mixed ($F(2, 63) = 3.28$, $p = .05$).

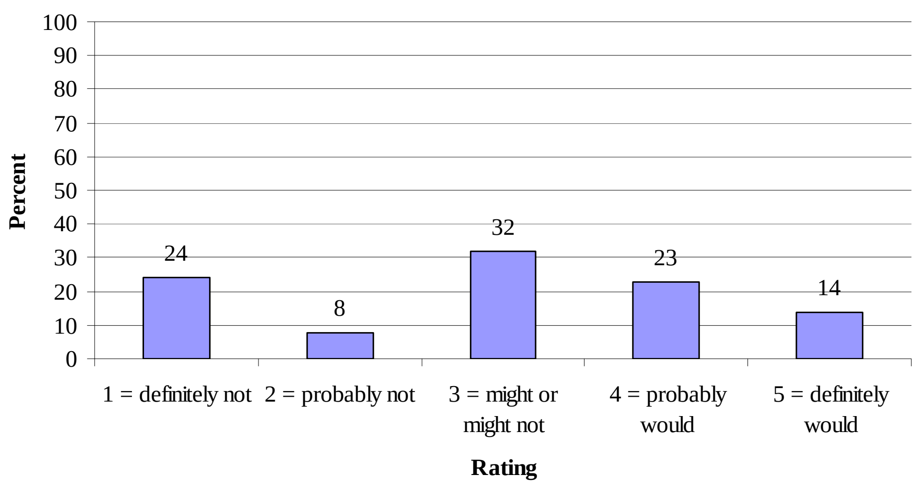


Figure 5-25. Likelihood of Considering ACC Purchase in New Vehicle for $1,000

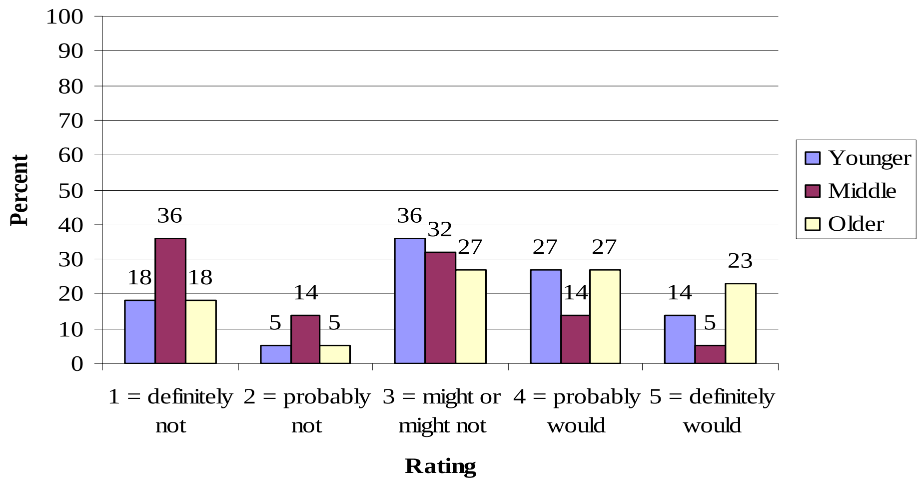


Figure 5-26. Response Distribution for Likelihood of Considering ACC Purchase in New Vehicle for $1,000 by Age Group

When asked how much they would pay to purchase ACC, the mean amount was $1,120. However, 15 percent of the sample did not reply to this question and responses that were obtained were varied greatly.[15] Some drivers claimed that they could not estimate the cost of a feature on a new car, as they only purchased used cars or did not know what various “options” sold for individually.

Eighty-eight percent of all drivers stated that they were willing to endorse ACC use to others (see Figure 5-27). For each age group, responses were statistically different between those who would and would not recommend using ACC (younger: χ^2 (1, N = 22) = 11.64, $p < .01$; middle: χ^2 (1, N = 22) = 8.91, $p < .01$; older: χ^2 (1, N = 22) = 18.18, $p < .01$).

[15] The range on this measure was from $0 to $9,000 with a standard deviation of $196. The median price was $501 and the mode was $1,000.

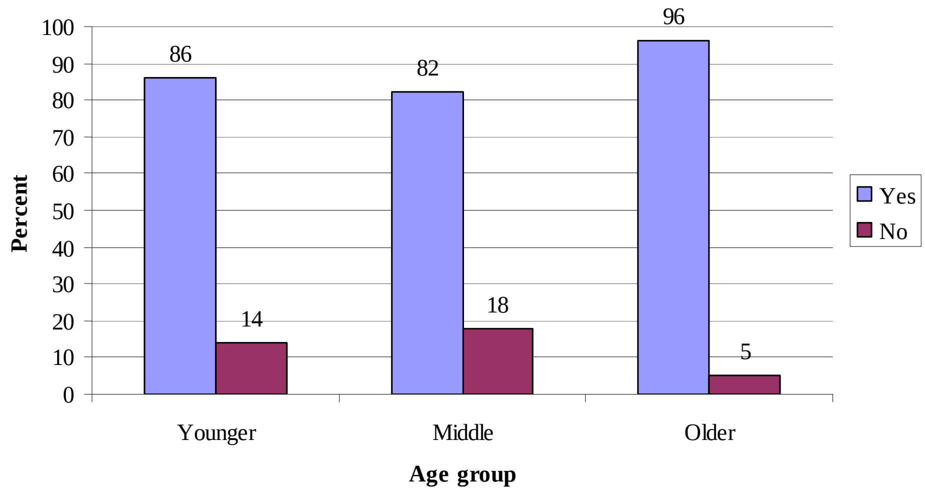


Figure 5-27. Recommend ACC Use by Loved Ones by Age Group

5.5.2.2 Investigating Travel Behavior and ACC Advocacy Measures

Follow-on analyses were conducted to see if relevant objective ACC travel behavior measures were correlated with the advocacy measures. The objective measures that encompassed ACAS-enabled driving and ACC use included ACC distance traveled (km) in valid trips and number of alerts with ACC engaged. However, as the distribution for number of alerts with ACC engaged contained more than 50 percent of the drivers with zero alerts, this correlation was not statistically sound. Using a related measure in its stead, there was no relationship between the mean number of alerts per 100 km during all ACAS-enabled driving and the ACC advocacy survey measures. Significant positive correlations existed between ACC distance traveled and two survey items: drivers' willingness to rent an ACC-equipped vehicle and the Driver Acceptance Scale satisfaction subscale ($r = .36$, $p < .01$; and $r = .25$, $p = .04$, respectively), suggesting that greater distances traveled using ACC were related to increased satisfaction with the system and greater propensity to want to rent an ACC-equipped vehicle.

5.5.2.3 Driver Acceptance Scale

The Driver Acceptance Scale and its resulting "usefulness" and "satisfaction" subscales provide a conceptually clear means of classifying ACC-related attitudes. Figure 5-28 shows the quadrants created by crossing the positive and negative ranges for the subscale scores. The cluster of drivers in the upper right quadrant rated ACC positively for both satisfaction and usefulness (n = 60),[16] while the upper left quadrant reflects drivers who exhibited positive usefulness combined with negative satisfaction ratings, suggesting that a small number of individuals recognized the usefulness of the FCW system, but were not satisfied with it (n = 4).[17]

[16] Note that, in some cases, more than one driver occupies the same point so that the number of distinct points does not total 66.
[17] Driver count per quadrant does not include individuals who rated the system neutral (subscale score = 0) for either usefulness and/or satisfaction (n = 2).

No drivers were negative on both subscales or negative with regard to ACC-usefulness and positive with regard to satisfaction.

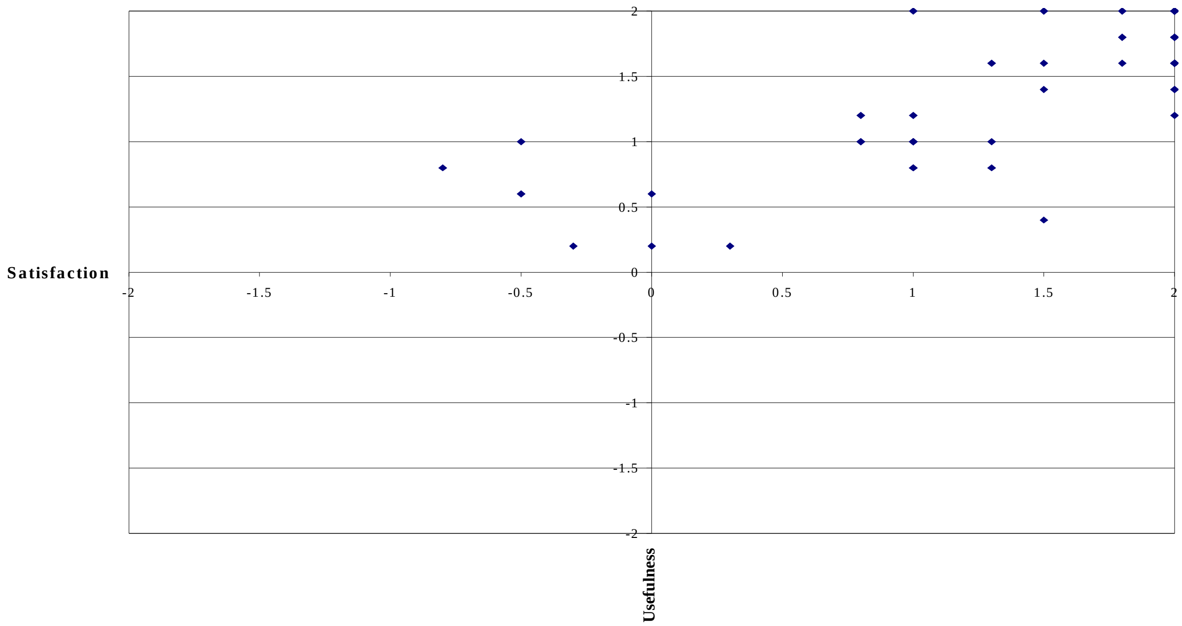


Figure 5-28. Driver Acceptance Scale Scores for ACC by "Usefulness" and "Satisfaction" Quadrants

Each driver's usefulness and satisfaction subscale score is plotted by driver in Figure 5-29. It is easily discerned from the graph that positive attitudes regarding ACC usefulness and satisfaction were dominant. Only 4 drivers (6% of the sample) rated ACC negatively on either scale.

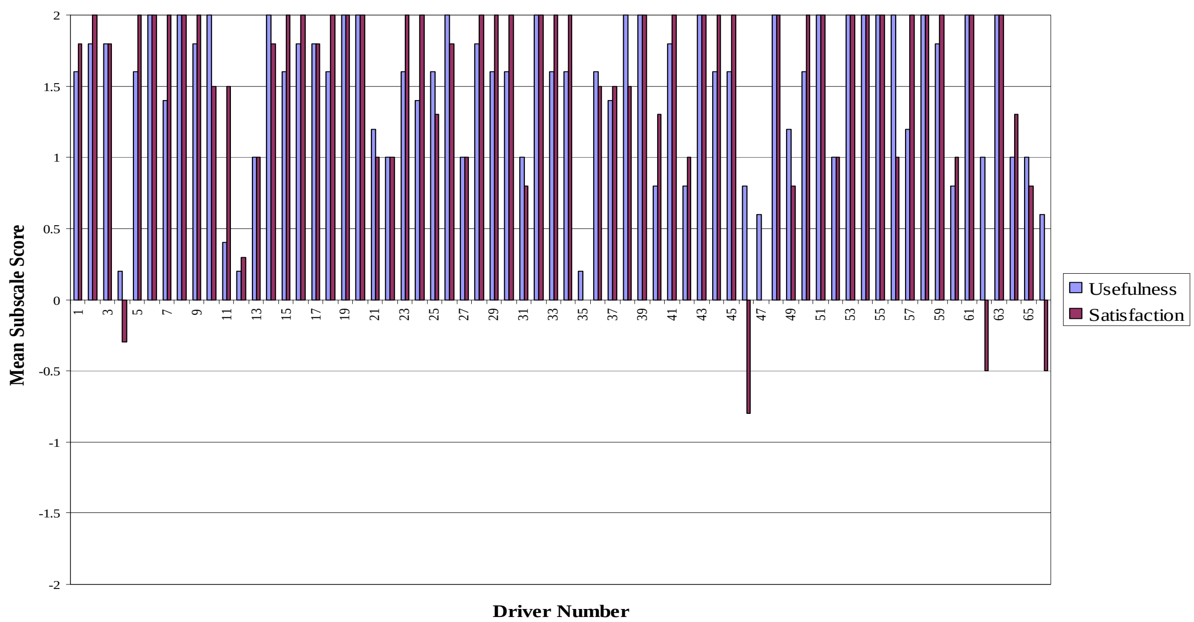


Figure 5-29. Driver Acceptance Scale "Usefulness" and "Satisfaction" Subscale Scores by Driver

Across the entire FOT sample, mean usefulness and satisfaction subscale scores were equal at 1.5; they are plotted in Figure 5-30 by age group. The older drivers in each case were significantly more satisfied and found ACC to be more useful than the middle-age group ($F(2, 63) = 4.78$, $p = .01$; and $F(2, 63) = 4.78$, $p = .01$, respectively). No significant between-group differences were found concerning the younger drivers.

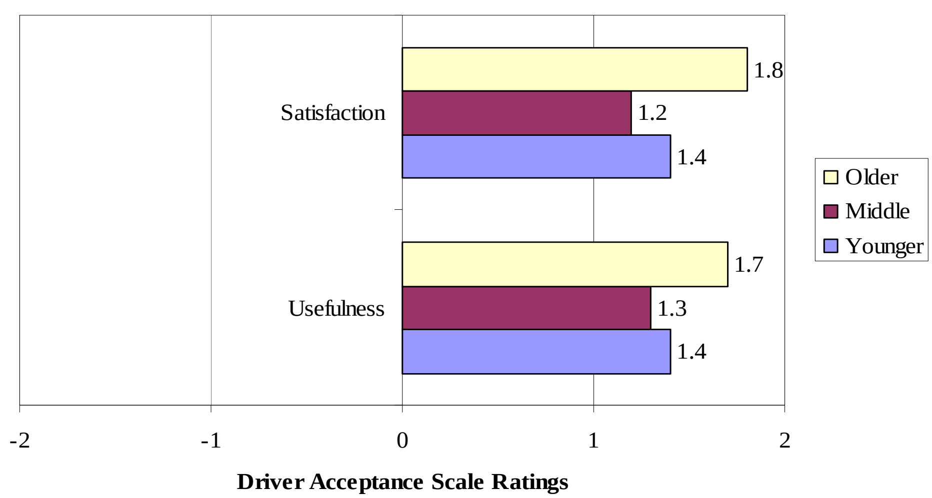


Figure 5-30. ACC "Usefulness" and "Satisfaction" Subscale Scores by Age Group

5.5.2.4 Focus Group Comments Regarding ACC Advocacy

Drivers participating in the four focus groups discussed several topics related to their interest in, and willingness to purchase, ACC. Their comments are summarized below.

Focus group participants were asked whether “ACC performed in the way you would expect it to if you bought this feature? If not, how should ACC perform differently?” Most drivers said that ACC performed as expected. Some drivers would like to be able to customize ACC including softening the perceived harshness of its braking. Another suggestion was to include the capability to switch ACC off and return to conventional cruise control.

Drivers’ most frequently mentioned concern about ACC relates to the logic of the operation of the brake lights in ACC. Drivers said there is a need to balance the potential disruption due to using brakes (and the brake lights) too often in freeway driving versus the need to alert other drivers when ACC is slowing the vehicle.[18]

When drivers were asked if they thought ACC was ready for production, their responses were very positive. Several drivers added that they would like the vehicle to accelerate faster when they changed lanes using ACC and the braking in ACC to be smoother and more like coasting. Drivers were asked whether they would purchase ACC. They expressed interest in purchasing ACC but wanted improvements. The most frequently mentioned improvement was less aggressive braking, braking authority more like coasting, and improved acceleration when making a lane change. Other proposed improvements include simplifying the HUD information by reducing the number of icons and expanding the range of brightness and dimness settings for the HUD.

5.5.2.5 Estimated ACC purchase intent

Analyses examined to what degree experiencing ACC was related to driver-expressed interest in acquiring this system. Using self-reported levels of buying intent as provided in the FOT survey item discussed earlier in this section and applying the weighted box methodology, it was possible to estimate what percentage of drivers would choose to purchase ACC, thereby forecasting acceptance. Additional detail regarding this methodology as used for FCW predictions may be found in Section 5.5.1.7.

For the survey item that assessed ACC purchase intent, drivers responded as follows: definitely would (27%), probably would (46%), might or might not (15%), definitely not (1%), and probably not (11%). Applying Urban and Hauser’s (1993) weighted box rule resulted in the prediction that, at the time the survey was completed, approximately 44 percent of the FOT sample would have been inclined to purchase ACC. As discussed in more detail with regard to the FCW system, a reduction in purchase intent and subsequent purchase behavior is likely over time, as the salience of ACC-driving experiences necessarily fades.

---

[18] The brake lights come on every time "brakes" are applied to comply with NHTSA safety standards. ACC however can ease up on the throttle as well; this does not light up the brakes. Thus, autobrakes applied imply brake lights on; throttle off only does not light up brake lights.

5.5.2.6 Summary

Generally, drivers were quite positive in their attitudes regarding ACC advocacy. Driver Acceptance Scale scores for usefulness and satisfaction were particularly telling, in that no drivers rated ACC negatively on both constructs. Of all of the advocacy survey measures, the question that asked how likely one would be to consider purchasing ACC at $1,000 received the most neutral response.

Attitudes regarding ACC system advocacy, as expressed by the older drivers, were more consistently positive than for the other age groups. They were more likely than both the younger and middle-age drivers to consider ACC purchase in a new vehicle, and more likely than the middle-age drivers to consider its purchase for $1,000. The older drivers also expressed a greater degree of overall satisfaction and found ACC more useful, compared with the middle-age group. Furthermore, older drivers were more comfortable than those in the middle-age group with the idea of a loved one driving an ACC-equipped vehicle; in fact, they recommended the use of ACC 96 percent of the time. At the point of survey administration, intent to purchase ACC was gauged to be 44 percent for the FOT sample.

While most drivers were positive in their advocacy of ACC, acceptance was tempered in some cases by reports of concerns pertaining to specific aspects of ACC operation. Discussion in the focus groups revealed that certain drivers perceived ACC braking to be harsh and its acceleration sluggish. Drivers also were concerned and/or did not understand when, or if the vehicle's brake lights were illuminated under ACC-deceleration conditions. This concern was most evident in expressway driving, when a number of drivers commented that slowing the vehicle in conjunction with brake light illumination is not always desirable. Despite these specific concerns, however, overall expressions of driver sentiment regarding ACC were positive.

5.5.3 Perceived Value – FCW

The perceived value objective examined driver satisfaction with the FCW system, awareness of safety, compatibility with an individual's mental model, and driving skill enhancement. This section includes both descriptive and quantitative discussion of perceived value, as well as driver comments provided during debriefing and focus group sessions, and a concluding summary. The focus of the discussion for perceived value of the FCW system is necessarily descriptive, as statistically significant differences among age groups were minimal.

5.5.3.1 FCW Statistical Findings

Nine survey items were used to measure perceived value for FCW. Table J-1, as found in Appendix J provides the intercorrelations among the perceived value measures and identifies the statistically significantly intercorrelated items. Two of the 9 items referred to manual driving situations and, as such, were used for comparative purposes only. The remaining 7 items were subjected to correlational analysis. Sixteen of the 21 resulted in significant findings in the expected direction, suggesting that the chosen measures were internally consistent in their assessment of the construct of perceived value.

Across the entire FOT sample, opinions of the perceived value of the FCW system were generally positive. Table 5-9 displays the measures of central tendency and standard deviations for each measure. Of the 9 items, the two assessing "overall" attitudes regarding satisfaction and the potential for increased driving safety were less positive than the others.

Table 5-9. Perceived Value Sub-objective Measure Descriptive Statistics

Sub-objective	Survey Item	Mean	Standard Deviation	Median	Mode
Overall					
	Overall how satisfied were you with the FCW system? *1 (very unsatisfied) - 7*	4.8	1.9	5.0	7.0
Compatibility with mental model					
	Overall, how easy was it to remember how to use and operate FCW while driving? *1 (not at all easy) - 7*	6.7	0.6	7.0	7.0
Driving skill enhancement					
	Did you feel more comfortable performing additional tasks, (e.g., adjusting the heater, operating the radio, talking on a cellular telephone, etc.) while using the FCW system as compared to manual driving? *1 (less comfortable) - 7*	5.2	1.3	5.0	4.0
Safety					
	How safe did you feel while driving the car using FCW? *1 (very unsafe) - 7*	6.0	1.1	6.0	7.0
	How safe did you feel driving the car manually? *1 (very unsafe) - 7*	6.7	0.6	7.0	7.0
	How easy or difficult did you find it to maintain a safe distance to the preceding vehicle when using FCW? *1 (very difficult) - 7*	6.2	1.1	6.0	7.0
	How easy or difficult did you find it to maintain a safe distance to the preceding vehicle when driving manually? *1 (very difficult) - 7*	6.4	0.9	7.0	7.0
	When using FCW, do you feel you drove more or less safely than when driving manually? *1 (less safe) - 7*	5.1	1.4	5.0	4.0
	Overall, I think that FCW is going to increase my driving safety *1 (strongly disagree) - 7*	4.6	1.9	5.0	7.0

As depicted in Figure 5-31, drivers reported a range of scores for overall satisfaction with FCW. At the positive end of the scale, a total of 49 percent of drivers responded with satisfaction ratings of 6 or 7. By contrast, a smaller percentage (16%) were unsatisfied with the system (values 1 or 2). More than one third of the sample had a neutral opinion (values 3, 4, or 5). The neutral-to-positive level of overall satisfaction with the FCW is reflected in the mean score of 4.8 for this item.

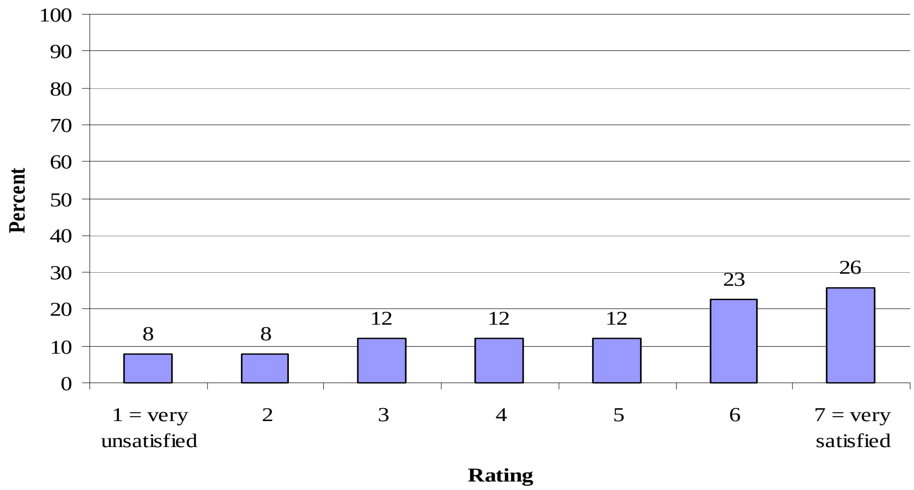


Figure 5-31. Overall, How Satisfied Were You with the FCW System?

Drivers rated FCW as easy to remember how to use and operate while driving, as illustrated in Figure 5-32. Almost three-quarters of the drivers gave FCW the highest score, 7, "very easy," and 94 percent rated FCW as 6 or 7, indicating that the FCW implementation was easy to comprehend.

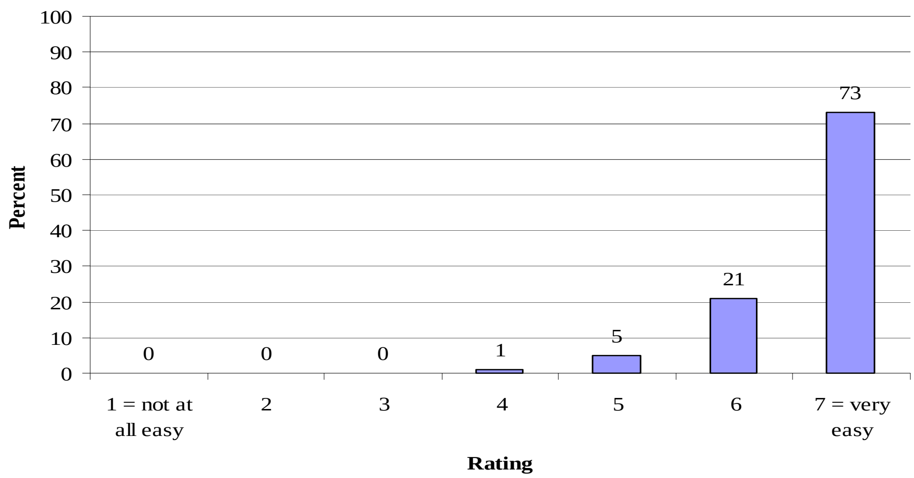


Figure 5-32. Overall, How Easy Was it to Remember How to Use and Operate FCW While Driving?

Because FCW provides an additional support to the driving task, individuals may have believed that they could perform additional actions safely while driving using the system. Drivers were asked if they felt more comfortable performing additional tasks, such as talking on the cell phone or adjusting the heater, when they drove using FCW. The mean score was 5.2 and the mode for responses was a neutral "4." Neutral zone responses of 3 – 5 represented 59 percent of the sample, indicating that most drivers felt equally as comfortable performing additional tasks while driving with FCW as when driving manually (see Figure 5-33). Importantly, no drivers indicated that they felt less comfortable (rating of 1 or 2), as compared to manual operations.

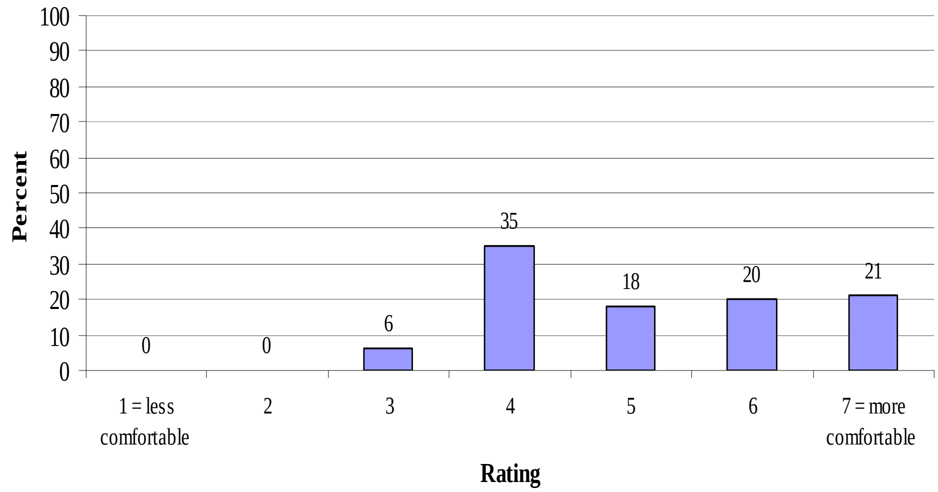


Figure 5-33. Did You Feel More Comfortable Performing Additional Tasks While Using the FCW System, as Compared to Manual Driving?

Drivers were asked to rate how safe they felt when they drove with FCW. More than three quarters of the drivers (77%) rated themselves as feeling very safe driving using FCW, responding with scores of 6 or 7 (see Figure 5-34). In fact, the mean score for this item was 6.0. Only 3 percent of the FOT drivers indicated that they felt unsafe to some degree.

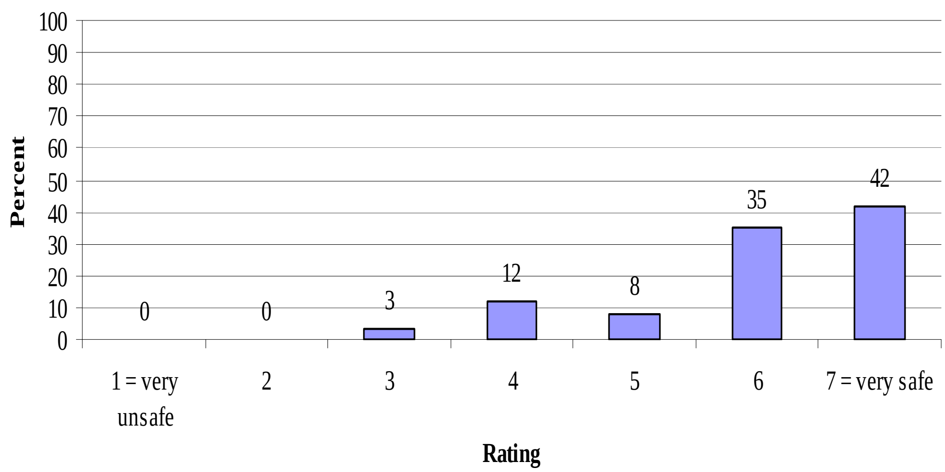


Figure 5-34. How Safe did You Feel while Driving the Car Using FCW?

Drivers were asked both how safe they felt driving the car during the first six days of the FOT (ACAS-disabled, manual driving) and using FCW. Figure 5-35 compares responses to these survey items, where, in each case, more the vast majority of the ratings show that drivers felt quite safe (scores of 6 or 7), though a greater percentage of respondents felt “very safe” driving manually versus with FCW (74% and 42%, respectively).

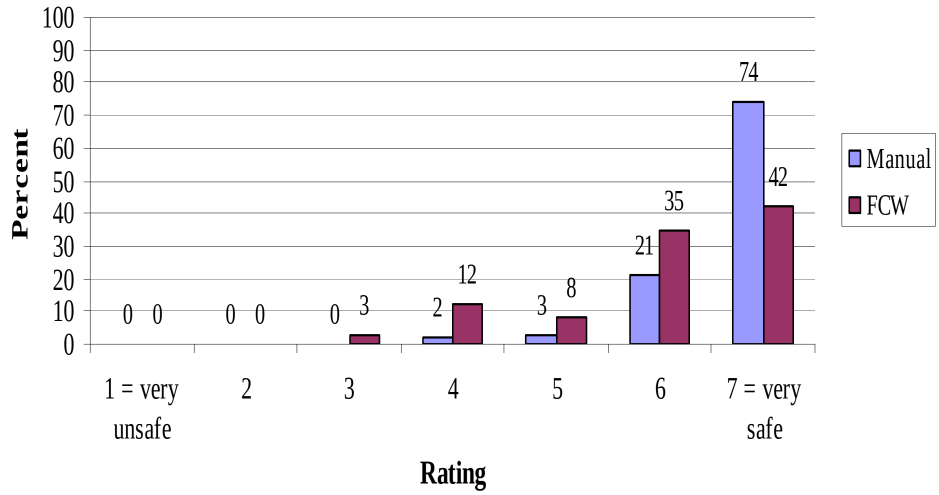


Figure 5-35. Comparison of How Safe Drivers Felt Driving the Car Driving Manually Versus Using FCW

Drivers were asked to rate how easy or difficult they found it to maintain a safe distance to the preceding vehicle when they drove the car manually, prior to when FCW was enabled, and then subsequently, using FCW. A comparison of responses, as depicted in Figure 5-36, indicates that in both cases more than 80 percent of the drivers found it very easy (scores of 6 or 7) to maintain a safe distance. A small percentage (2%) of respondents responded that they found it very difficult to maintain a safe distance using FCW.

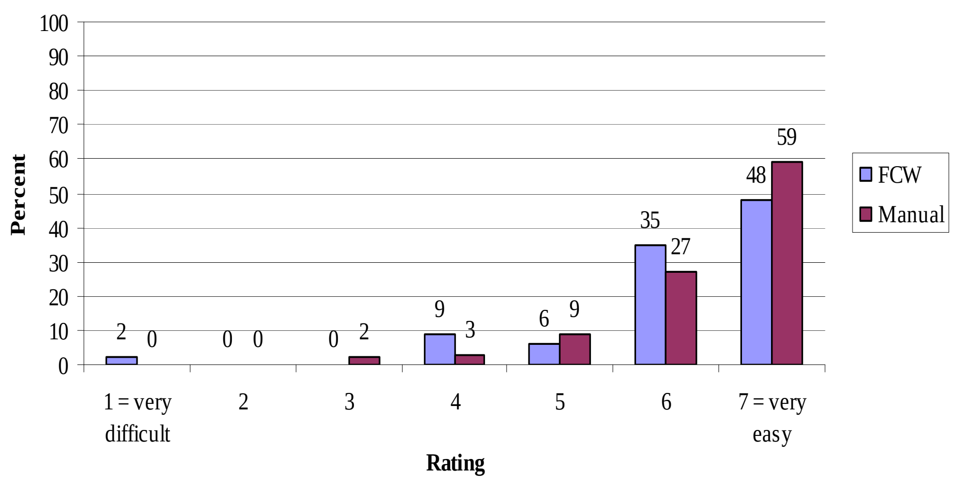


Figure 5-36. Comparison of Ease of Maintaining a Safe Distance to the Preceding Vehicle Driving Manually Versus Using FCW

A related survey item, used to compare attitudes regarding safety, asked drivers the degree to which they felt more or less safe using FCW, compared to manual driving. The mean score was 5.1, suggesting that drivers felt slightly safer driving with FCW. However most commonly, responses fell at neutral (4), indicating that there was no discernable difference. Figure 5-37 depicts the response distribution for this item, showing that a total of 7 percent of all drivers felt less safe (scores from 1 – 3) driving with the FCW system.

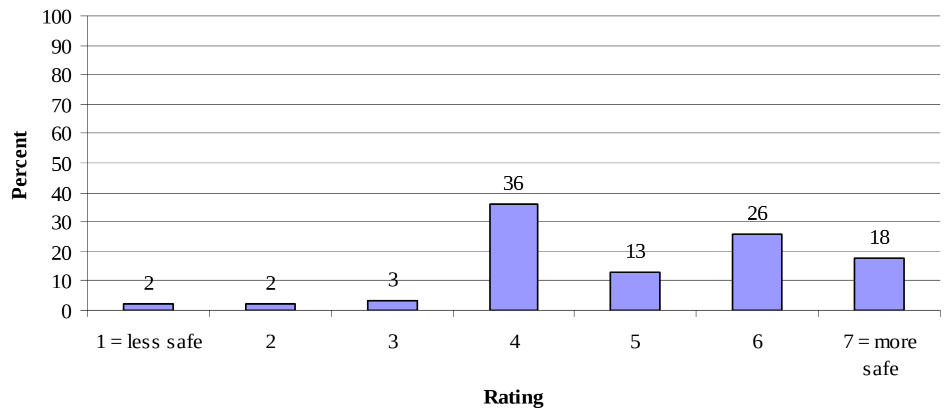


Figure 5-37. When Using FCW, Do You Feel You Drove More or Less Safely Than Manual Driving?

As a final means of assessing FCW safety issues, drivers were questioned regarding the degree to which they agreed that prospective use of FCW would increase their driving safety. Responses were distributed over the entire range of the item scale as shown in Figure 5-38. Overall, attitudes were largely neutral, as 43 percent of drivers responded in the 3 – 5 range and the mean score for this measure was 4.6. A total of 39 percent of all responses fell on the positive end of the scale (scores of 6 or 7), while 18 percent of responses fell at the opposite end of the scale (scores of 1 or 2).

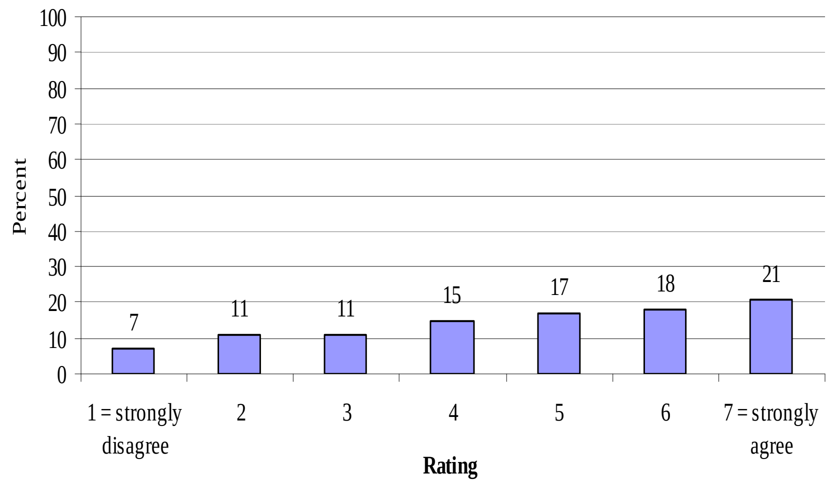


Figure 5-38. Overall, FCW Is Going to Increase My Driving Safety

Given the previously noted focus on potential age group differences, ANOVA was used to verify the nature of any statistical relationships. Table 5-10 reports the statistical relationships among driver age groups and attitudes regarding perceived value, as broken down by sub-objective, with any significant group differences noted briefly in the rightmost "Results" column and nonsignificant results denoted using "NS."

Table 5-10. Perceived Value Sub-objective Measures by Driver Age Group

Sub-objective	Survey Item	Age Group	Mean	ANOVA Results
Overall				
	Overall how satisfied were you with the FCW system? *1 (very unsatisfied) - 7*	Younger Middle Older	4.5 4.5 5.5	NS
Compatibility with mental model				
	Overall, how easy was it to remember how to use and operate FCW while driving? *1 (not at all easy) - 7*	Younger Middle Older	6.7 6.5 6.8	NS
Driving skill enhancement				
	Did you feel more comfortable performing additional tasks, (e.g., adjusting the heater, operating the radio, talking on a cellular telephone, etc.) while using the FCW system as compared to manual driving? *1 (less comfortable) - 7*	Younger Middle Older	5.0 5.0 5.5	NS
Safety				
	How safe did you feel while driving the car using FCW? *1 (very unsafe) - 7*	Younger Middle Older	5.7 6.1 6.2	NS
	How safe did you feel driving the car manually? *1 (very unsafe) - 7*	Younger Middle Older	6.5 6.7 6.8	NS

How easy or difficult did you find it to maintain a safe distance to the preceding vehicle when using FCW? *1 (very difficult) - 7*	Younger Middle Older	6.5 5.7 6.2	*Y found less difficult than M*
How easy or difficult did you find it to maintain a safe distance to the preceding vehicle when driving manually? *1 (very difficult) - 7*	Younger Middle Older	6.4 6.2 6.5	NS
When using FCW, do you feel you drove more or less safely than when driving manually? *1 (less safe) - 7*	Younger Middle Older	5.0 5.1 5.2	NS
Overall, I think that FCW is going to increase my driving safety. *1 (strongly disagree) - 7*	Younger Middle Older	4.5 4.4 4.9	NS

The single statistically significant finding for perceived value survey measures is depicted in Figure 5-39. Here, the younger driver age group reported finding it easier to maintain a safe distance to the preceding vehicle using FCW than those in the middle-age group ($F(2, 63) = 3.11$, $p = .04$). However, it may be noted from group means that the difference in attitudes is not striking.

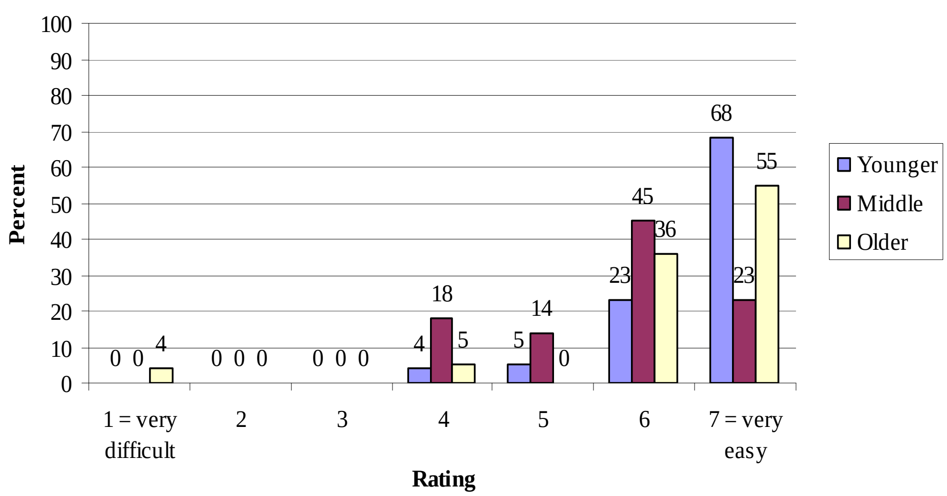


Figure 5-39. Ease of Maintaining a Safe Distance to Lead Vehicle while Using FCW by Age Group

5.5.3.2 Investigating Travel Behavior and FCW Perceived Value Measures

Follow-on analyses were conducted to determine the degree to which objective travel behavior measures were correlated with the perceived value survey measures. The objective measures encompassed ACAS-enabled driving and included FCW distance traveled (km) in valid trips, number of FCW alerts and mean number of FCW alerts per 100 km. The only statistically significant relationship that resulted ($r = -.26$, $p < .05$) indicated that the more total FCW alerts received, the less likely a driver was to feel comfortable performing additional tasks when driving with FCW.

5.5.3.3 Debriefing and Focus Group Comments Regarding Perceived Value of FCW

Drivers' comments, excerpted from the focus group and debriefing sessions, provide a fuller understanding of the perceived value of FCW. Drivers had mixed responses when asked if they thought that use of FCW made them safer drivers. Some thought FCW use made no difference due to their years of driving experience while others said FCW made them less vulnerable to other drivers' mistakes. The drivers who said that FCW made them safer drivers credited their increased safety to the ability of FCW to improve their alertness as well as reinforcing good driving habits.

When asked "Were there situations when you got an alert when you were not paying enough attention?", drivers recalled instances when FCW alerted them to danger. Given the sharpness of their recall of these events, if FCW alerted drivers to a situation when they were at risk, due to driver distraction, they were likely to rate FCW positively. Because these kinds of events occur infrequently, many drivers did not experience them.

Some drivers said that they were troubled by FCW's inconsistent threat detection. If drivers saw FCW fail to alert, or were not able to provoke an alert when they thought one was required, their confidence in FCW's safety was undermined due to its perceived unreliability.

Focus group drivers described situations when they did not get an alert when they felt it was required such as merging traffic during the rush hour, approaching a truck, and motorcycle pulling out from a side road.

Focus group participants generally agreed that FCW will reduce the harm caused by rear-end crashes when it becomes a product. They identified reasons why FCW will be helpful to reduce rear-end crashes such as counteracting driver distraction and age-related slowing of reaction time.

Drivers were asked if they experienced situations when FCW operated in a way they did not understand or was opposite of what they expected. Some drivers mentioned situations when they did not understand FCW. Typically these situations involved false, late, and unexpected alarms; FCW failing to operate properly; and FCW malfunction. However, when asked this, some drivers responded that they felt safer driving using FCW.

Drivers described situations when they did not understand FCW information due to issues with FCW system characteristics, false messages, and driving feedback.

5.5.3.4 Summary

Many of the FCW perceived value measures were significantly intercorrelated, which indicates that the perceived value objective was largely internally consistent. Drivers provided generally positive ratings regarding FCW safety and understandability, but overall satisfaction was somewhat variable. Slightly less than half the drivers expressed high satisfaction with FCW (6 or 7), over one third of the drivers expressed a neutral-level of satisfaction, and 16 percent were dissatisfied.

Driver age did not statistically differentiate ratings on the perceived value measures, with the exception of younger drivers having found it less difficult than the middle-age group to maintain a safe distance to the preceding vehicle using FCW. Generally, the middle-age group of drivers expressed a wide range of ratings for the FCW perceived value measures, which may have been related to their varied experiences with the system during daily trips on local roads, in that they used ACC less than the older drivers did.

For this reason, it is recommended that future analyses explore how differential driver use of ACC is related to the evaluation of FCW. Drivers reported that FCW was valuable to the degree that it helped them to maintain alertness and counteract distraction. In fact, the more FCW alerts that were received, the less comfort drivers expressed regarding performing additional tasks while driving, including those that are potentially distracting, such as using a cell phone. Anecdotally, drivers who experienced an FCW alert while distracted appeared to clearly recognize FCW benefits.

5.5.4 Perceived Value – ACC

The perceived value objective examined driver satisfaction with the ACC system, awareness of safety, compatibility with an individual's mental model, and driving skill enhancement. Both descriptive and quantitative discussion of perceived value is offered in this section, as well as driver comments as provided in debrief and focus group sessions and a concluding summary.

5.5.4.1 ACC Statistical Findings

Nine survey items were used to measure perceived value for ACC. Table K-1, as found in Appendix K, provides the correlations among the perceived value measures and identifies the significantly intercorrelated items. One of the nine items referred to manual driving in isolation and was therefore used for comparative purposes only. Of the remaining eight items, 25 of the 28 resulted in significant findings in the expected direction, suggesting that the chosen measures were internally consistent in their assessment of the construct of perceived value.

Across the entire FOT sample, opinions regarding the perceived value of the ACC system were generally positive. Table 5-11 displays the measures of central tendency and standard deviations for each measure. Of the nine items, the measure that addressed the degree of concern regarding the traffic behind the driver when using ACC resulted in the least positive overall attitude. The mean for this item was 4.0, with the most prevalent response, a score of 3, indicating a greater level of concern among the largest number of drivers in the sample.

Table 5-11. Perceived Value Sub-Objective Measure Descriptive Statistics

Sub-objective	Survey Item	Mean	Standard Deviation	Median	Mode
Overall					
	Overall how satisfied were you with the ACC system? *1 (very unsatisfied) - 7*	6.0	1.1	6.0	7.0
Compatibility with mental model					
	Overall, I felt the operation of the ACC system was predictable. *1 (strongly disagree) - 7*	5.9	1.1	6.0	6.0
	When I was using ACC, I understood when I had to take control - either by accelerating or braking *1 (strongly disagree) - 7*	6.5	0.9	7.0	7.0
	How distracting did you find the ACC system operation (e.g., automatic acceleration and deceleration or warnings)? *1 (very distracting) - 7*	5.4	1.7	6.0	7.0
Driving skill enhancement					
	Did you feel more comfortable performing additional tasks, (e.g., adjusting the heater, operating the radio, talking on a cellular telephone, etc.) while using the FCW system as compared to manual driving? *1 (less comfortable) - 7*	5.6	1.2	6.0	6.0
Safety					
	How safe did you feel while driving the car using ACC? *1 (very unsafe) - 7*	6.0	1.3	6.0	7.0
	How safe did you feel driving the car manually? *1 (very unsafe) - 7*	6.7	0.6	7.0	7.0
	When using ACC, do you feel you drove more or less safely than when driving manually? *1 (less safe) - 7*	5.5	1.4	6.0	7.0
	Relative to manual driving, how concerned were you about the traffic behind you when using ACC? *1 (much more concerned) - 7*	4.0	1.9	4.0	3.0
	Overall, do you think that ACC is going to increase your driving safety? *1 (strongly disagree) - 7*	5.5	1.5	6.0	6.0

As depicted in Figure 5-40, the scores for overall satisfaction with ACC were mostly positive. More than three-quarters of the drivers gave satisfaction ratings of 6 or 7. By contrast, less than 25 percent expressed a more neutral opinion (values 3, 4, or 5) and no drivers reported being unsatisfied with the system (scores of 1 or 2). A positive level of overall satisfaction with the ACC is reflected in the mean score of 6.0 for this item and a mode of 7.

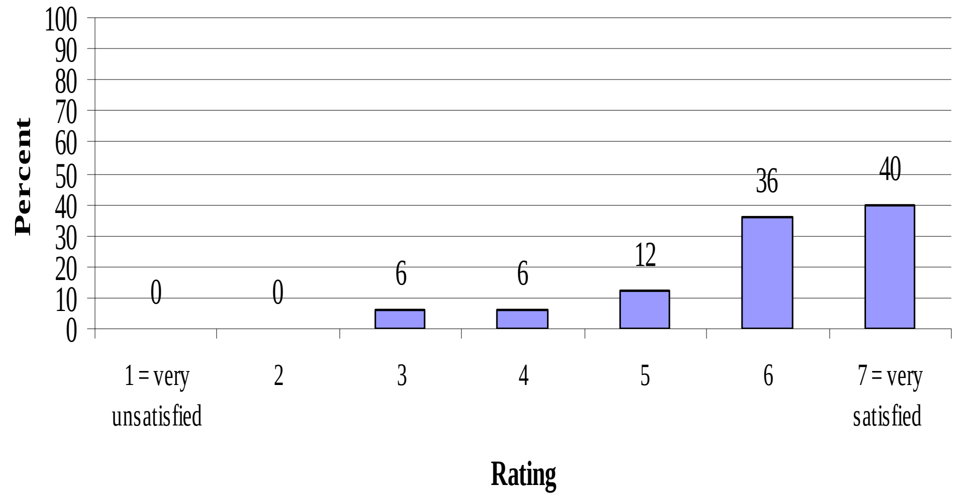


Figure 5-40. Overall, How Satisfied Were You with the ACC System?

With regard to the degree to which ACC operation matched drivers' expectations (i.e., mental model) for how such a system should operate, responses indicated that, overall, drivers found ACC predictable (see Figure 5-41). Nearly three-quarters of respondents (71%) indicated that they strongly agreed (scores of 6 or 7) that ACC operation was predictable and no one strongly disagreed (scores of 1 or 2) with this statement.

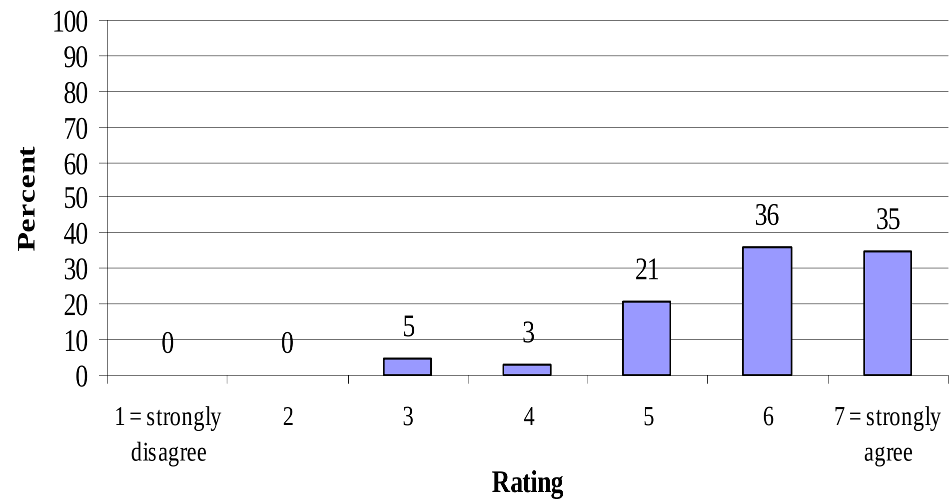


Figure 5-41. Overall, I Felt the Operation of the ACC System was Predictable

Perhaps as a result of finding ACC operation predictable, there were cases when drivers understood when they had to take control and override the system (see Figure 5-42). The large majority, 90 percent, of the drivers indicated that it was quite obvious when a system override was necessary (scores of 6 or 7).

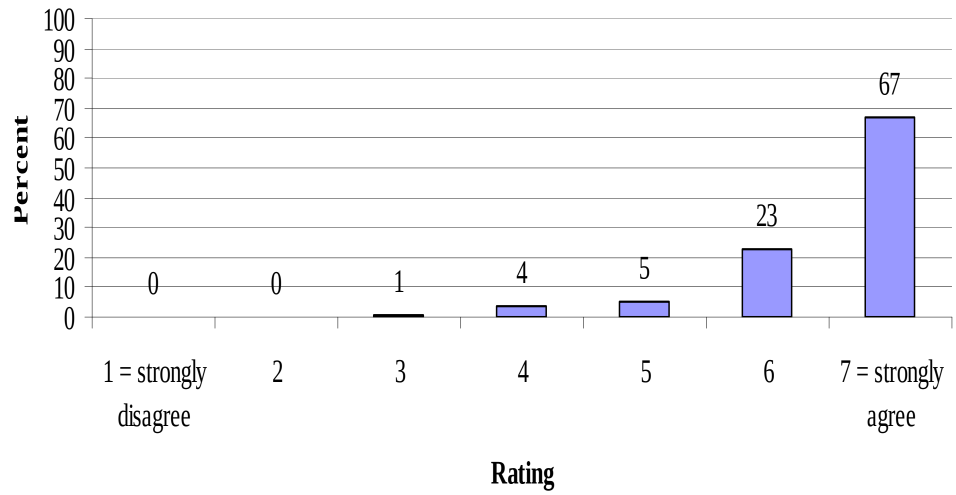


Figure 5-42. When using ACC I Understood When I Had to Take Control, Either by Accelerating or Braking

Drivers were asked to rate how distracting they found ACC operation in terms of its automatic acceleration and deceleration. As shown in Figure 5-43, close to two-thirds of the sample did not find this function distracting and responded at the positive end of the scale (scores of 6 or 7). However, it is important to note that approximately 22 percent of drivers responded in the negative range (scores of 2 or 3), suggesting that they found aspects of the automatic acceleration and braking distracting to their driving.

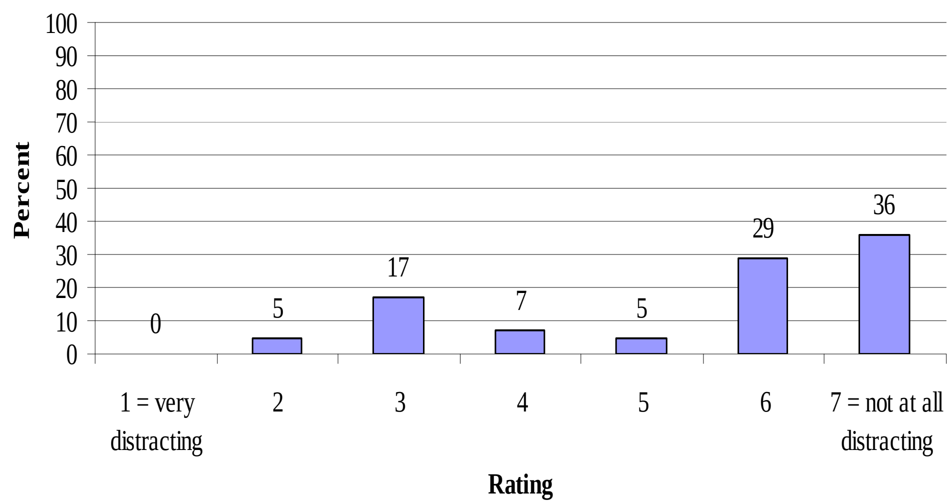


Figure 5-43. How Distracting Did You Find the ACC System Operation?

Because ACC provides support to the driving task, individuals may have believed that they could perform additional actions safely while driving using the system. Drivers were asked if they felt more comfortable performing additional tasks, such as talking on a cell phone or adjusting the heater, when they drove using ACC, compared to manually. The mean score was 5.6. Figure 5-44 shows that 61 percent of drivers responded at the positive end of the scale (rating of 6 or 7), indicating that they were more comfortable performing additional tasks while driving using ACC. Importantly, no drivers indicated that they felt less comfortable (rating of 1 or 2), as compared to manual operations. However, 26 percent responded neutrally (4) that they were neither more, nor less comfortable performing additional tasks using ACC.

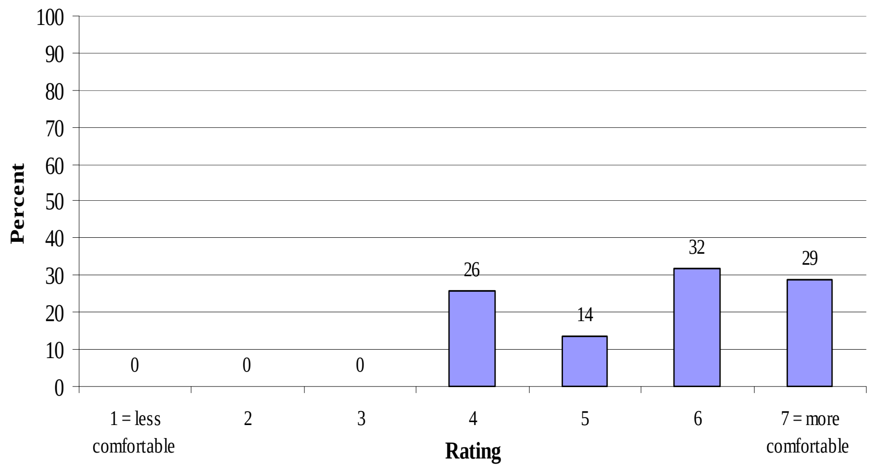


Figure 5-44. Did You Feel more Comfortable Performing Additional Tasks While Using the ACC System, as Compared to Manual Driving?

With respect to a comparison of manual versus ACC driving safety, respondents were asked the same survey question for each driving situation. A comparison of responses as provided in Figure 5-45 indicates that in both cases, the vast majority (from 74% - 95%) of all drivers felt that they were quite safe (scores of 6 or 7) on the road. However, 27 percent more drivers felt "very safe" driving manually, compared to driving with ACC.

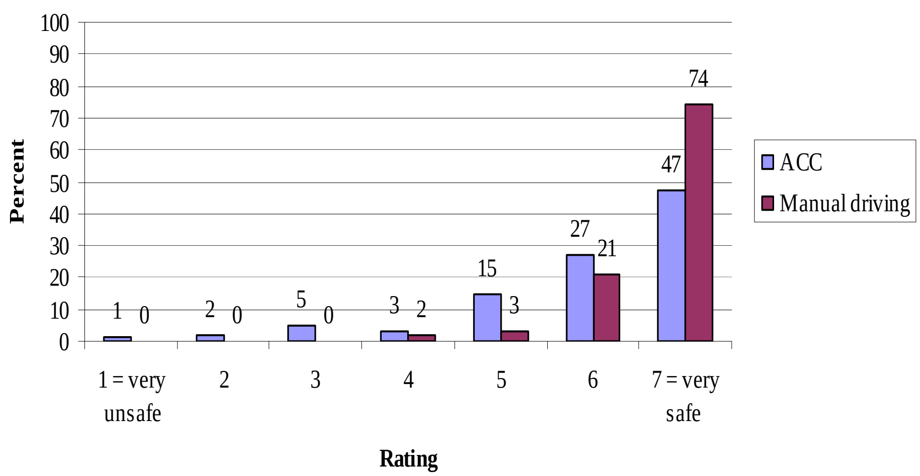


Figure 5-45. Comparison of How Safe Drivers Felt Driving the Car Using ACC versus Driving the car Manually

Using a different approach, a related survey item asked drivers the degree to which they felt more or less safe using ACC, as compared to manual driving. As depicted in Figure 5-46, over half of the sample (55%) responded at the positive end of the scale (scores of 6 or 7), indicating that they felt safer driving with ACC. However, the mean score was only somewhat positive, at 5.5, as 43 percent of drivers responded in the neutral range of the scale (scores of 3, 4, or 5). Nevertheless, only a very small percentage (2%) responded at the "less safe" end of the scale (scores of 1 or 2).

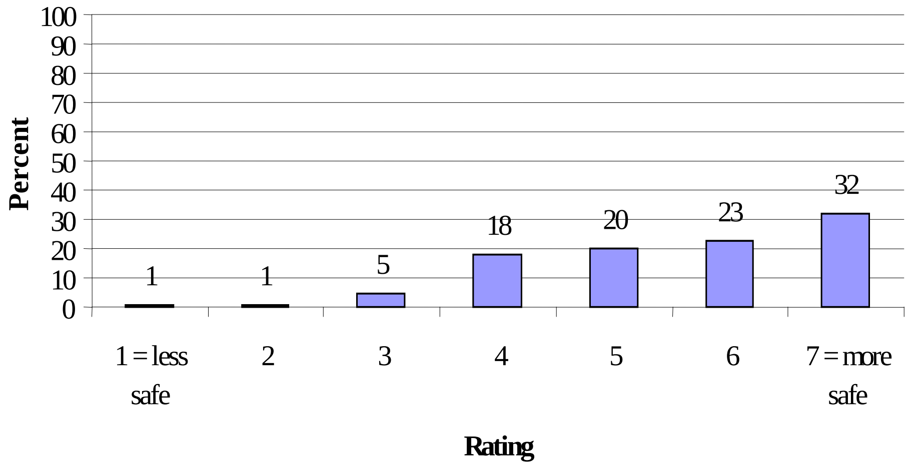


Figure 5-46. When Using ACC, Do You Feel You Drove More or Less Safely than Manual Driving?

In another safety-related measure, drivers rated their concern about the traffic behind them when using ACC as compared to manual driving. As depicted in Figure 5-47, 45 percent of the sample expressed some level of concern about the traffic behind them when they were using ACC and 12 percent were much more concerned than when driving manually. It should be noted that one fifth of the respondents said that they were much less concerned about the traffic behind them than as compared to when they drove manually.

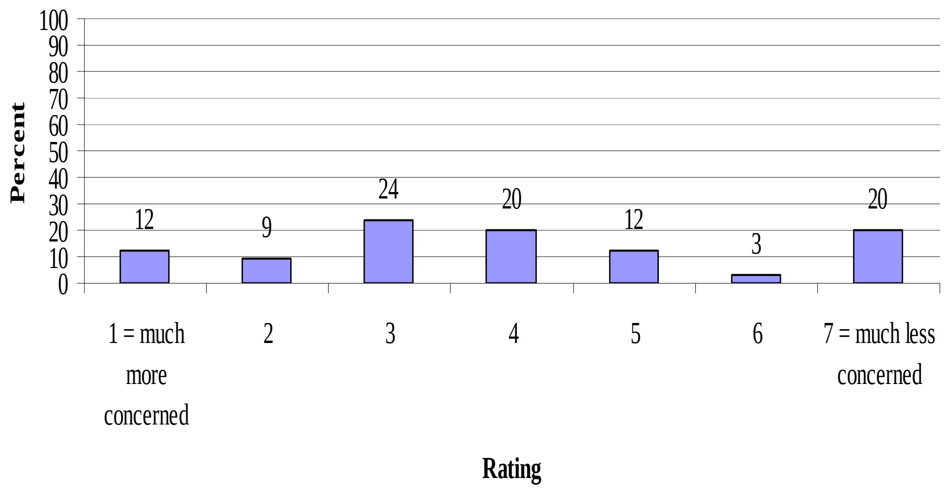


Figure 5-47. Relative to Manual Driving, How Concerned were You About the Traffic Behind You when Using ACC?

Finally, drivers were asked, overall, if they believed that use of ACC would increase their driving safety. Nearly two-thirds of the drivers responded using the positive end of the scale (scores of 6 or 7) as shown in Figure 5-48; however, the mean was quite neutral at 4.6. In fact, almost one-third of the sample responded in the neutral range (scores of 3, 4, or 5). Five percent of drivers did not agree that using ACC would improve their driving safety (scores of 1 or 2).

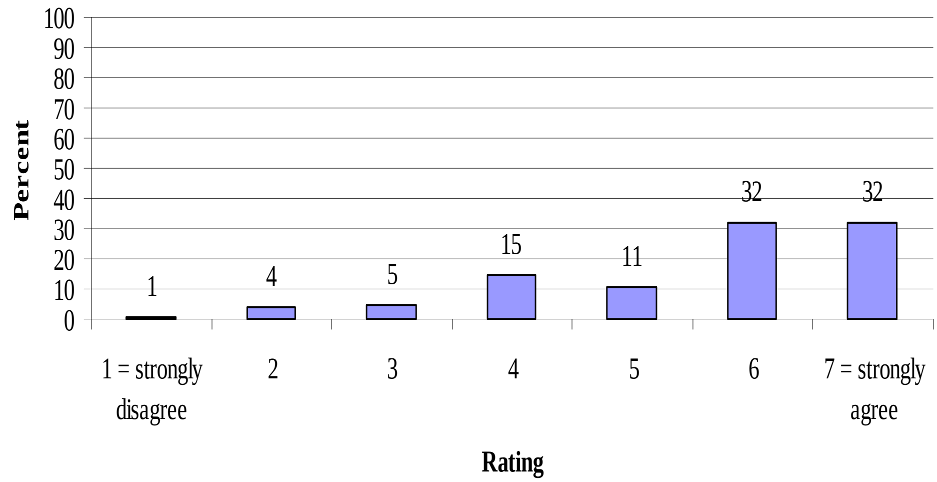


Figure 5-48. Overall, do You Think that ACC is Going to Increase Your Driving Safety?

As previously noted, driver acceptance analyses were narrowed to a focus on potential age group differences. ANOVA was used to verify the nature of any statistical relationships. Table 5-12 reports the statistical relationships among driver age groups and attitudes regarding perceived value, as broken down by sub-objective, with any significant group differences noted briefly in the rightmost "Results" column and nonsignificant results denoted using "NS."

Driver age group was significantly related to five of the ACC perceived value measures; i.e., overall satisfaction and safety, the degree of system predictability and level of distraction related to ACC features, such as automatic acceleration and deceleration, and a comparison of ACC versus manual driving with regard to level of driving safety. Each statistical finding is depicted graphically and discussed below.

Table 5-12. Perceived Value Sub-Objective Measures by Driver Age Group

Sub-objective	Survey Item	Age Group	Mean	ANOVA Results
Overall				
	Overall how satisfied were you with the ACC system? *1 (very unsatisfied) - 7*	Younger Middle Older	5.7 5.6 6.6	O more satisfied than Y and M
Compatibility with mental model				
	Overall, I felt the operation of the ACC system was predictable. *1 (strongly disagree) - 7*	Younger Middle Older	5.5 5.9 6.5	O agreed more so than Y
	When I was using ACC, I understood when I had to take control - either by accelerating or braking *1 (strongly disagree) - 7*	Younger Middle Older	6.6 6.3 6.8	NS
	How distracting did you find the ACC system operation (e.g., automatic acceleration and deceleration or warnings)? *1 (very distracting) - 7*	Younger Middle Older	4.8 5.1 6.2	O found less distracting than Y
Driving skill enhancement				
	Did you feel more comfortable performing additional tasks, (e.g., adjusting the heater, operating the radio, talking on a cellular telephone, etc.) while using the FCW system as compared to manual driving?	Younger Middle Older	5.8 5.4 5.7	NS
Safety				
	How safe did you feel while driving the car using ACC? *1 (very unsafe) - 7*	Younger Middle Older	5.6 5.8 6.5	NS
	How safe did you feel driving the car manually? *1 (very unsafe) - 7*	Younger Middle Older	6.5 6.7 6.8	NS
	When using ACC, do you feel you drove more or less safely than when driving manually? *1 (less safe) -7*	Younger Middle Older	5.3 5.0 6.1	O felt drove more safely than M, when using ACC
	Relative to manual driving, how concerned were you about the traffic behind you when using ACC? *1 (much more concerned) - 7*	Younger Middle Older	4.2 3.8 4.0	NS
	Overall, do you think that ACC is going to increase your driving safety? *1 (strongly disagree) - 7*	Younger Middle Older	5.3 5.0 6.2	O agreed more strongly than M

Figure 5-49 depicts the overall satisfaction levels for ACC by age group. Drivers in the older age group reported greater satisfaction with the ACC system than drivers in the middle and younger age groups ($F(2, 63) = 5.49$, $p = .01$; and $F(2, 63) = 5.49$, $p = .02$, respectively). In fact, 73 percent indicated that they were very satisfied with the system (7).

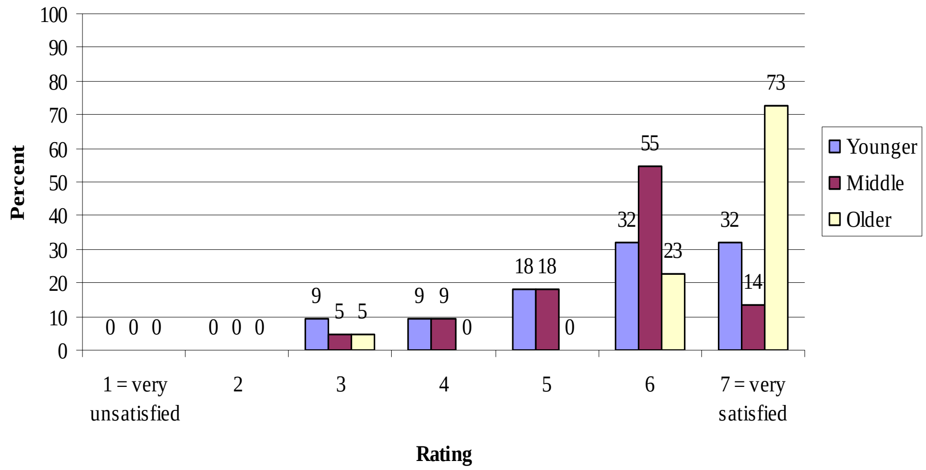


Figure 5-49. Overall Satisfaction with the ACC System by Driver Age Group

As presented in Figure 5-50, drivers in the older age group were significantly more likely to agree that the ACC operated in a predictable manner than drivers in the younger age group ($F(2, 55) = 3.45$, $p = .04$), suggesting that the system matched the mental model of the older drivers more so than those who were younger.

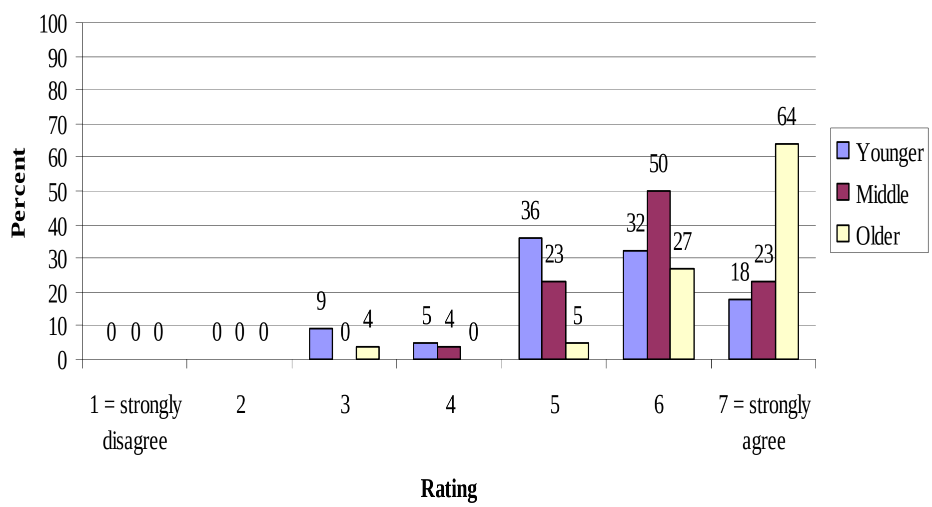


Figure 5-50. Overall ACC System Predictability by Driver Age Group

Results pertaining to the level of distraction experienced by drivers as related to ACC features, such as automatic acceleration and deceleration, are depicted in Figure 5-51. This figure indicates that older drivers found ACC system operation significantly less distracting than drivers in the younger age group ($F(2, 55) = 3.45$, $p = .03$). Older drivers who found that ACC was not at all distracting in its operation (59% with a score of 7) made up the largest percentage of responses.

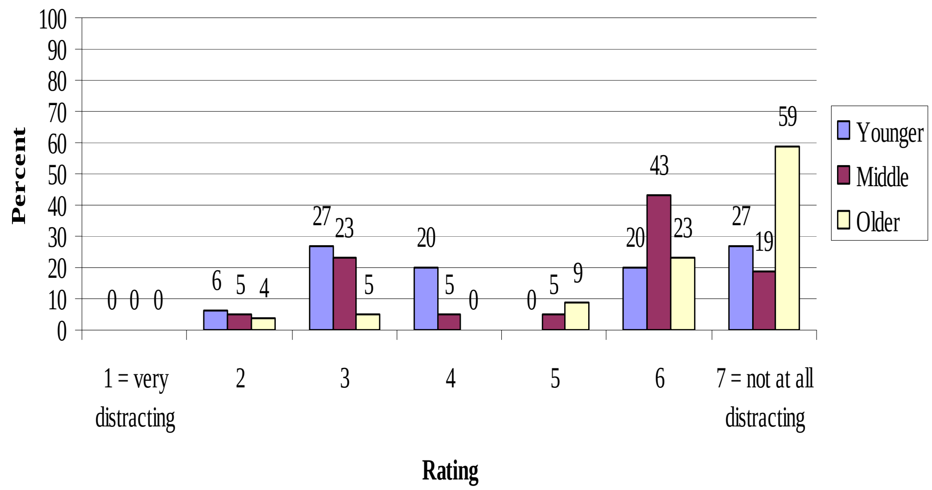


Figure 5-51. How Distracting Did You Find the ACC System Operation by Driver Age Group

Figure 5-52 presents results for the survey item that asked respondents to compare how safe they felt driving using ACC, compared to manual driving. A significant difference existed, in that older drivers reported feeling more safe than those in the middle-age group ($F(2, 63) = 3.41$, $p = .04$). More than half of the sample of older drivers (55%) reported feeling safer (7), compared to 9 percent of the middle-age group who responded at the most positive end of the scale.

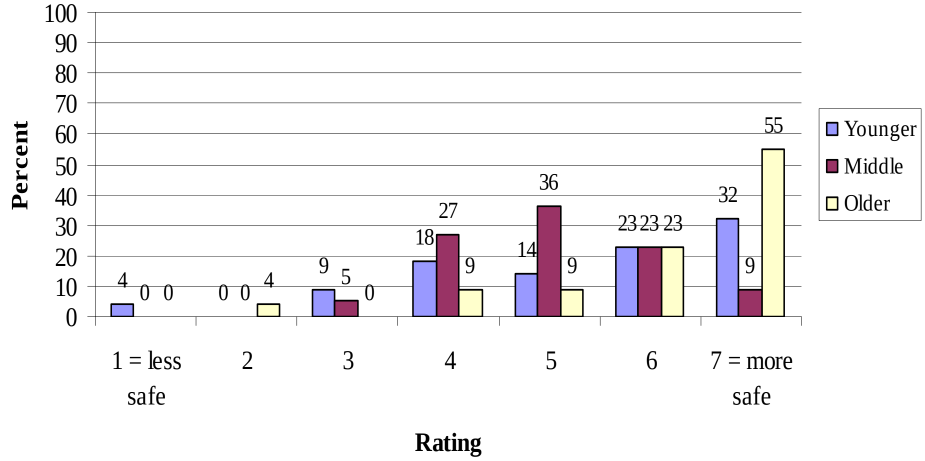


Figure 5-52. Comparison of How Safe Drivers Felt Driving the Car Using ACC versus Driving the Car Manually by Driver Age Group

In an additional item that addressed overall ACC system safety, Figure 5-53 depicts the significant finding that older drivers were more likely to agree than those in the middle-age group that using ACC would increase their driving safety ($F(2, 63) = 3.56$, $p = .03$). Older drivers represented the largest percentage of responses for any scale value, with 55 percent indicating that they strongly agreed (score of 7) that the ACC system would improve their driving safety.

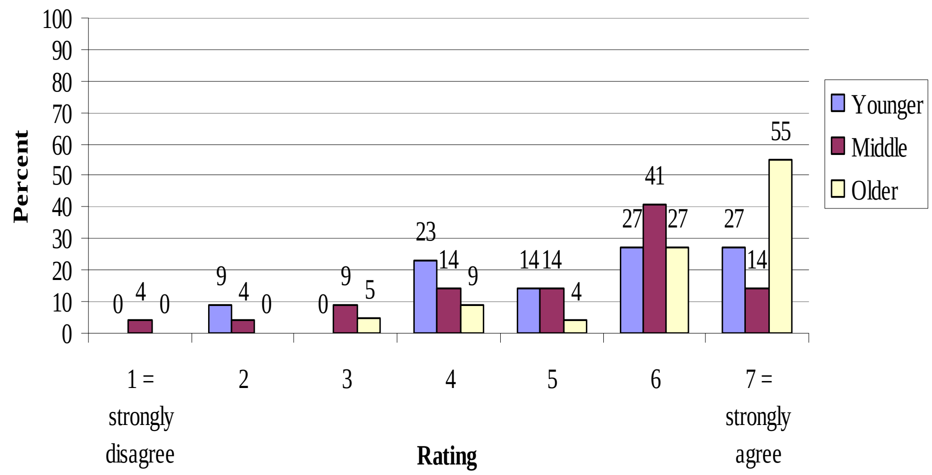


Figure 5-53. Overall Belief that ACC would Increase Driving Safety by Driver Age Group

5.5.4.2 Investigating Travel Behavior and ACC Perceived Value Measures

Follow-on analyses were conducted to determine the degree to which objective travel behavior measures were correlated with the perceived value survey measures. The objective measures that encompassed ACAS-enabled driving and ACC use included ACC distance traveled (km) in valid trips and number of alerts with ACC engaged. However, as the distribution for number of alerts with ACC engaged contained over 50 percent of drivers with zero alerts, this correlation was not statistically sound. Using a related measure in its stead, there was no relationship between the mean number of alerts per 100 km during all ACAS-enabled driving and the ACC perceived value measures.

Significant, positive correlations existed between total distance traveled in ACC mode and the following variables: the degree to which individuals found ACC predictable ($r = .26$, $p = .03$), level of safety felt while driving using ACC ($r = .32$, $p = .01$), and overall attitudes regarding the degree to which ACC would increase driving safety ($r = .29$, $p = .02$). Each relationship was in the expected direction, in that greater distances traveled using ACC were associated with a greater degree of feeling that the system was predictable and safe.

5.5.4.3 Debriefing and Focus Group Comments Regarding Perceived Value of ACC

Drivers' comments excerpted from focus groups and debriefing sessions provide a fuller understanding of the perceived value of ACC. Drivers were almost unanimous in endorsing ACC use.

Drivers liked the way that ACC made their vehicle resume its speed when the preceding car was out of the way.

Another feature drivers liked about ACC was its ability to maintain the desired speed.

The enthusiasm extended to drivers who admitted they had made little prior use of conventional cruise control. When asked to compare ACC with conventional cruise control, drivers preferred ACC to CCC.

Drivers were asked in what traffic conditions they would use ACC. Some drivers said they would use, or try to use, ACC in almost all traffic conditions. Other drivers said that they did not want to use ACC in heavy congested traffic or inclement weather. Some drivers mentioned special uses for ACC such as maintaining speed in areas where there are police traffic enforcement traps.

Drivers were asked if they thought using ACC made them safer drivers. Several drivers anticipated that ACC use would reduce road rage incidents in heavy traffic. Overall, drivers agreed that ACC made them safer drivers.

Drivers had conflicting opinions as to whether they thought that ACC use would reduce harm. Some drivers remembered that they were instructed not to use ACC in congested local traffic yet thought that rear-end crashes are more likely in these conditions. Drivers were confused as to where there are risks of rear-end crashes versus the appropriate locations using ACC.

5.5.4.4 Summary

Almost all of the ACC perceived value measures were significantly intercorrelated, which indicates that the objective was largely internally consistent. Drivers were quite satisfied with ACC overall and reported that they felt quite safe using it, though were somewhat less convinced that they drove more safely using ACC as compared to manually. As a whole, drivers also rated ACC highly with regard to understanding when overriding system acceleration and/or deceleration was necessary. While still positive, drivers did rate ACC slightly lower on predictability, and the degree to which system functioning was distracting and would increase driving safety.

Almost half of the sample reported some concern as to the degree to which the traffic behind would understand the operation of an ACC-equipped vehicle. This points to the issue of driver expectations regarding vehicle actions, as road safety requires a common set of behavioral expectations that form over time in the case of implementing new or emerging vehicle technologies.

Driver age was related to ratings on some of the perceived value measures. The older driver age group reported a greater degree of overall satisfaction with ACC than both the younger and middle-age groups. Additionally, older drivers agreed that ACC operation was more predictable and were less distracted by ACC than the younger driver group. Finally, in comparison to the middle-age group, older drivers felt that they drove more safely using ACC, as compared to manually, and agreed more strongly that ACC use would increase their driving safety.

With regard to trip behaviors, travel using ACC was related to the level of safety felt while driving using ACC, the degree to which individuals felt the system was predictable, and would increase driving safety. Generally, with increased use, it appears that drivers tended to become more positive toward the value of various aspects of the ACC system.

5.5.5 Ease of Use – FCW and ACC

Examination of the ease of ACAS use explored the degree to which drivers found the system easy to set up, understand, adjust, and use. Ease of use considerations were specified with regard to several sub-objectives. These included how drivers rated ACAS in comparison to conventional in-vehicle systems, what demands system use placed on drivers, how drivers used ACAS, their understanding and regard for warnings and nuisance alerts (FCW), as well as overall usability, including the HUD.

5.5.5.1 FCW Statistical Findings

This section presents the results associated with analyses performed for the FCW ease of use measures. It includes a descriptive and quantitative discussion of the ease of use survey items. Driver comments as obtained during focus group and driver debriefing sessions are provided to give a fuller understanding of how drivers assessed FCW ease of use. This section concludes with a summary of findings.

As appropriate, correlations were calculated among the FCW ease of use measures by sub-objective and are found in Appendix L. Relationships for Likert scale items, where significant, were in the expected direction.

Drivers responded to survey items that assessed attitudes regarding FCW ease of use. Appendix M includes tables with descriptive statistics for responses to each of the survey measures, broken down by sub-objective. As responses were not always normally distributed, measures of central tendency, in addition to the mean and standard deviation, are provided for each measure, where appropriate. For items that elicited dichotomous responses, the percent of "yes" replies to the measure is provided.

As indicated in the methods section of this report, driver acceptance analyses were targeted where there were differences among age groups and/or age and gender groups, as appropriate. Where statistically significant, meaningful findings that differentiated groups on FCW ease of use are discussed. For reference purposes, tables containing mean responses by age group are presented in parallel with the overall descriptive statistics for all survey measures in Appendix M. Significant group differences are noted briefly in the rightmost "Results" column, while nonsignificant results are denoted using "NS." Analysis of Variance was performed for Likert-type survey measures and Chi square analyses were used for dichotomous measures.[19]

Compared to conventional safety systems, such as ABS and airbags, ratings for FCW were neutral (i.e., neither better, nor worse; mean score = 3.9). Moreover, there were no significant between group differences among the age groups.

Additional demands on drivers, necessitated by interacting with the FCW system, were assessed. A survey item asked participants how much stress they felt while using FCW compared to manual driving. The mean score for all drivers was 4.7, indicating a slight tendency toward less stress using FCW over manual driving. Figure 5-54 depicts a percent distribution of scores for this item, overall and by age group. Almost one half of the drivers, 49 percent, reported less stress driving with FCW (scores of 5 – 7), while one quarter of the drivers reported more stress (scores of 1 – 3). ANOVA results indicated that the younger driver age group was more stressed than the older drivers by FCW, compared to manual driving ($F(2, 55) = 4.66$, $p = .01$).

[19] Parametric ANOVA results are reported here and throughout this report as justified in the section on Data analysis (5.3.4).

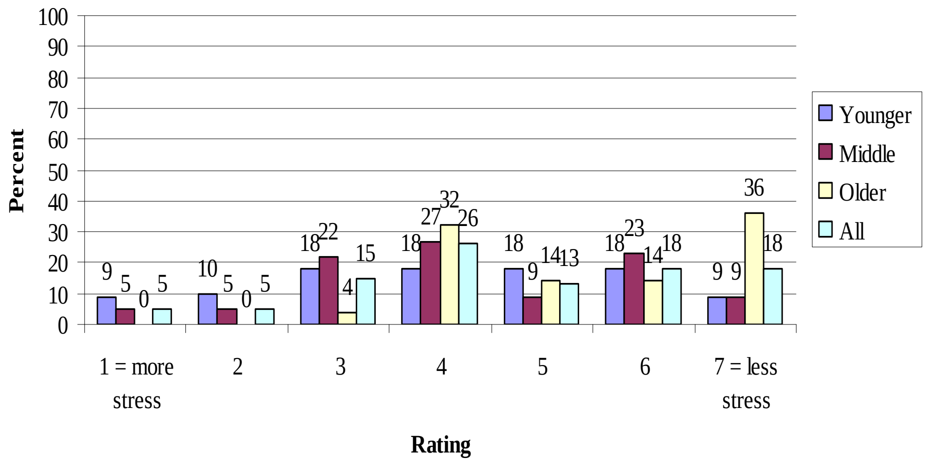


Figure 5-54. Did You Experience More or Less Stress When Driving With FCW as Compared to Manual Driving by Driver Age Group?

Additionally, drivers were asked if the visual display of FCW cautionary alerts was distracting. The mean was 5.4, indicating that the visual cautionary alerts were not considered extremely distracting, however there were a wide range of responses to this item.

Figure 5-55 shows the percent age distribution of drivers' scores overall and by age group. Sixty-nine percent replied that the cautionary visual alerts were toward the "not at all distracting" end of the item response scale (scores of 5 – 7), while 19 percent of respondents fell at the "distracting" end of the scale (scores of 1 – 3). In a comparison of the age groups, younger drivers reported finding the visual alerts more distracting than did the older driver age group ($F(2, 55) = 4.99$, $p < .01$). However, it is important to note that the mean for the younger group (4.5) was quite neutral. The mean score for the older driver group (6.2) suggests that older drivers did not view the visual FCW cautionary alerts as very distracting.

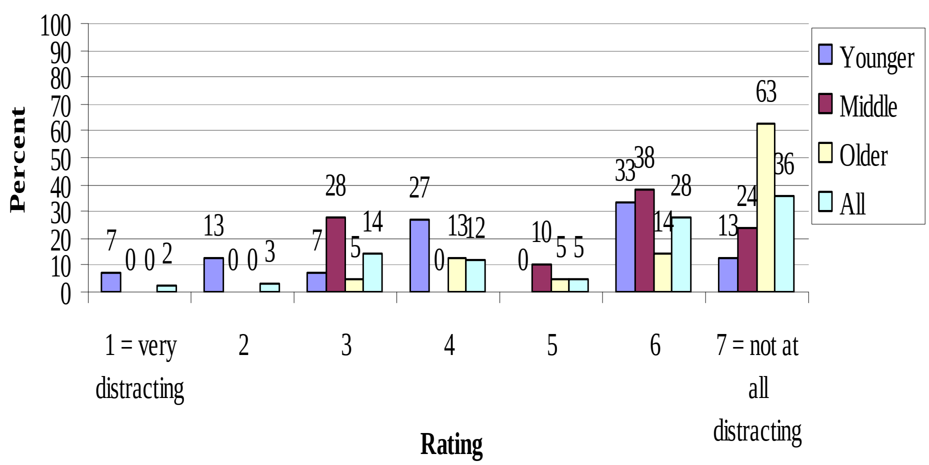


Figure 5-55. How Distracting were the Visual Alerts that Signaled a Cautionary Situation by Driver Age Group?

Drivers were asked a series of questions to identify what types of driving conditions precipitated adjustments to the FCW alert timing. Traffic conditions were a reason for changing FCW settings by the largest percentage of "yes" responses by drivers, at 77 percent (see Figure 5-56). Weather conditions were the next most frequent reason for FCW alert timing adjustments, 41 percent, with smaller percentages of respondents indicating that being in a rush, tired, or concerned about alertness warranted a change.

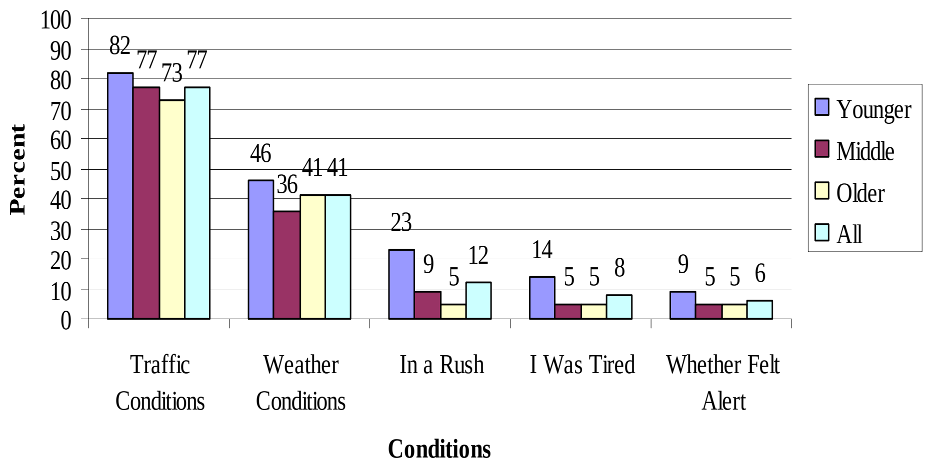


Figure 5-56. Percent "Yes" Responses to FCW Alert Timing Changes by Conditions, Overall and by Driver Age Group

Use patterns for the FCW system were assessed by measuring driver comfort utilizing FCW in adverse weather conditions. More than 10 percent of drivers never experienced system operations in poor weather. However, for those who did drive in adverse weather, the mean response to a seven-point scale (1 = very uncomfortable) was 5.5, suggesting that drivers felt moderately comfortable using FCW. Age was not found to significantly differentiate between groups on this measure.

With the knowledge that FCW issued false imminent warnings, it was important to address the level of tolerance drivers exhibited toward what could be considered "nuisance" alerts. Figure 5-57 depicts response distributions for the entire sample and by age group for the measure assessing overall annoyance regarding alerts that were deemed "unnecessary." Overall, 27 percent of the drivers reported that they were "not at all" annoyed by unnecessary FCW alerts, while slightly more than one third, 35 percent, of the drivers reported marked annoyance. The mean response for this item was 3.4, indicating that, on average, attitudes toward unnecessary alerts fell between "tolerable" and "slightly annoying." Using ANOVA to differentiate among the age groups, results indicated that the younger and middle-age drivers reported being more annoyed by what they deemed as unnecessary FCW alerts, compared to the older drivers ($F(2, 60) = 17.25$, $p < .01$; $F(2, 60) = 17.25$, $p < .01$). Mean scores by group were 2.6 for younger drivers, 3.1 for middle-age drivers, and 4.4 for older drivers.

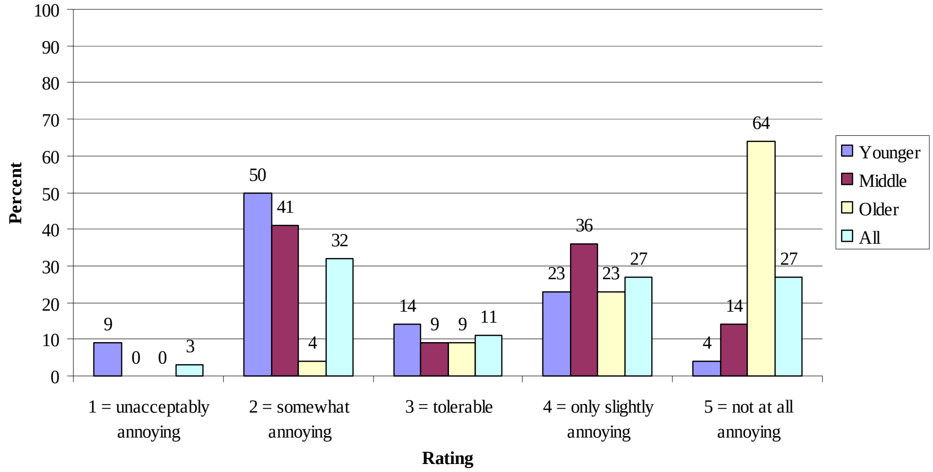


Figure 5-57. Overall, Indicate the Annoyance Level Associated with Unnecessary FCW Alerts Overall and by Driver Age Group

The degree to which drivers felt "annoyed" by various driving situations that could have resulted in unnecessary FCW alerts was also investigated (1 = unacceptably annoying – 5). Drivers rated as "only slightly annoying" unnecessary FCW alerts resulting from when they cut in behind another vehicle (mean = 4.0) or changed lanes (mean = 4.0). The highest annoyance ratings were associated with passing a sign, light post, or guardrail, though the mean score of 3.1 indicated that, in actuality, drivers as a whole found even such alerts "tolerable."

Analyses were also performed to determine whether age differentiated among annoyance ratings for the various driving situations. There was no significant between-age group difference in responses to passing a parked vehicle. However, age did differentiate attitudes with regard to the remaining seven scenarios. Figure 5-58 and Figure 5-59 depict mean annoyance ratings by age group where there were significant differences. In four of the scenarios, both younger and middle-age driver groups were significantly more annoyed than the older drivers. These included "when a vehicle ahead of me turned" ($F(2, 60) = 11.62$, $p < .01$); "when a vehicle ahead changed lanes" ($F(2, 60) = 10.16$, $p < .01$); "when a vehicle cut in front of me" ($F(2, 60) = 5.70$, $p < .05$); and "when my vehicle changed lanes" ($F(2, 60) = 6.71$, $p < .05$). For two of the remaining scenarios, younger drivers were significantly more annoyed than the older drivers. These included "when I passed a moving vehicle" ($F(2, 60) = 6.49$, $p < .01$) and " when I cut in behind another vehicle" ($F(2, 60) = 5.85$, $p < .01$). Finally, the middle-age group reported greater annoyance than older drivers with regard to false FCW alerts associated with signs, light posts, and guard rails ($F(2, 60) = 3.89$, $p < .05$).

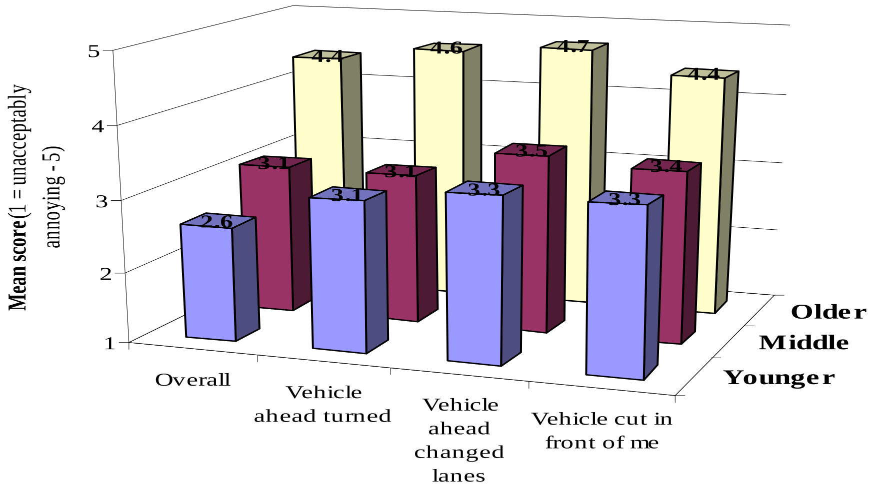


Figure 5-58. Mean Annoyance with Unnecessary FCW Alerts Overall and for Lead Vehicle Scenarios by Driver Age Group

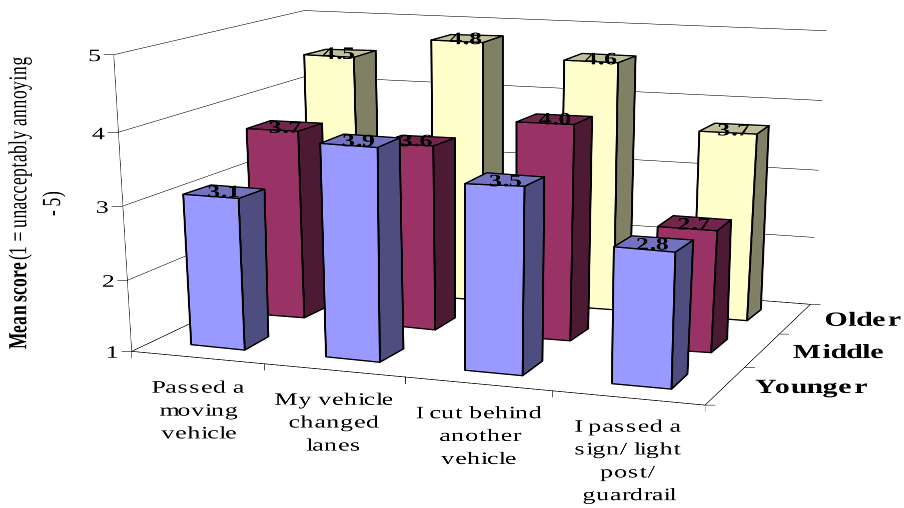


Figure 5-59. Mean Annoyance With Unnecessary FCW Alerts for Host Vehicle Scenarios by Driver Age Group

The understanding of warnings sub-objective addressed driver comprehension of FCW warnings. The goal of this objective was to assess driver self-reported ability to recognize and discriminate various features of the FCW alerts while driving. Data pertaining to objective components of the alerts are addressed in the safety benefits section of this report.

Briefly, the FCW system functioned by generating imminent crash-warning icons on the HUD, accompanied by an auditory alert to warn drivers that they were too close to a lead vehicle and should apply the brake. As further elucidated in the section on ease of learning, there is evidence that some drivers did not understand how FCW functioned, even at the culmination of their FOT participation. Given the fact that the system was not always fully comprehended or intuitive for drivers to use, it is important to determine the degree to which various aspects of the warnings were acceptable to and understood by the user.

In the case of visual alerts, drivers were asked how well they could identify a warning for a cautionary situation versus an imminent threat. The mean response to this item was 6.3 on a scale of 1 (not well at all) – 7, suggesting that drivers did not have a problem discriminating between cautionary and imminent alerts. There was no significant difference between age groups for this measure.

With regard to alert triggers, drivers were asked how often FCW provided an alert where the source could not be determined. As depicted in Figure 5-60, nearly 40 percent of drivers reported that they could not identify the source of a FCW alert once or twice, while 29 percent reported receiving from three to twenty such alerts. One-third of the drivers indicated that they felt that they were always able to identify the source of the FCW alert.

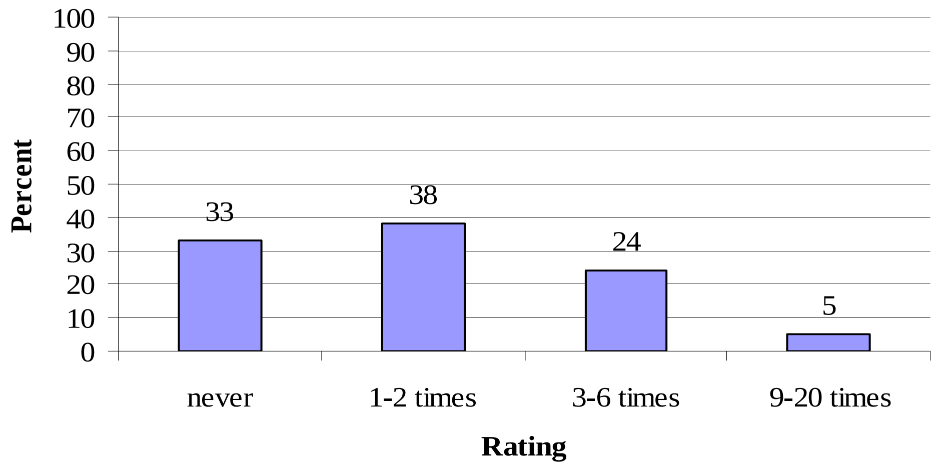


Figure 5-60. Rating of How Often Drivers Could not Identify Source of FCW Alert

Disaggregating these data by age and gender, as shown in Figure 5-61, indicates that the majority of the older males, 55 percent, and the older females, 64 percent, felt that they could always identify the source of an FCW alert. In contrast, only 18 percent of the younger and middle-age males and the middle-age females responded that they felt as though they could always identify the source of the FCW alert.

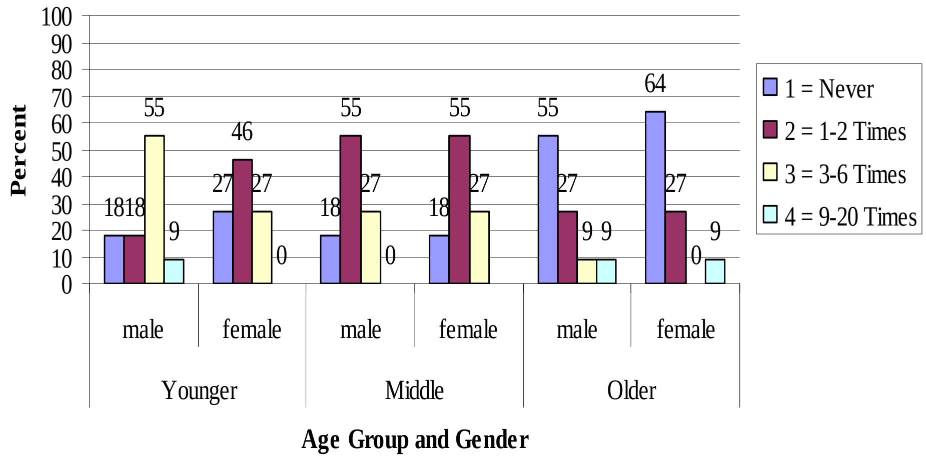


Figure 5-61. Rating of How Often Could Not Identify Source of FCW Alert by Driver Age Group and Gender

Drivers were also questioned regarding the degree to which they found the FCW auditory alert startling. Although the mean response for this item was 4.6, slightly less startling than neutral on the 7-point scale, Figure 5-62 depicts a wide distribution of scale scores. Over one-quarter of the drivers, 26 percent, responded that the auditory alert was not at all startling, whereas 7 percent indicated that the alert was very startling. Driver age group differentiated these responses statistically. Younger drivers rated the auditory alert significantly more startling (mean = 3.6) than the older drivers (mean = 5.4; $F(2, 55) = 3.92$, $p = .02$).

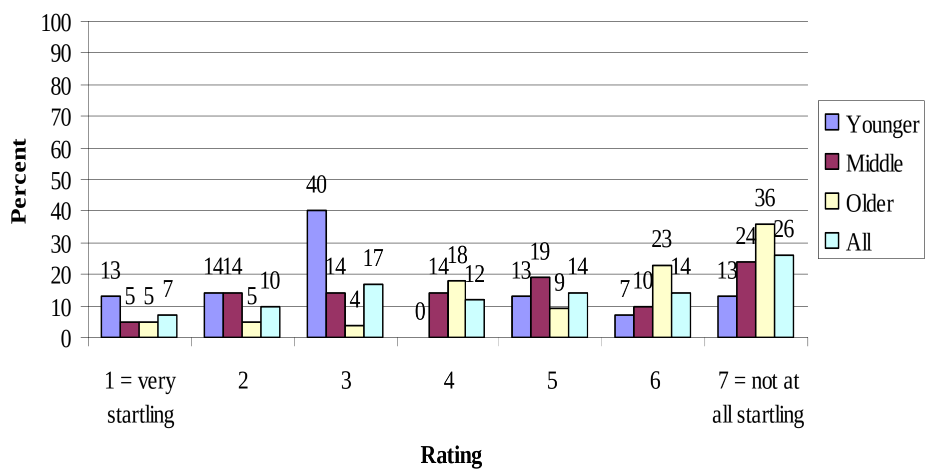


Figure 5-62. How Startling did You Find the Auditory Alert when it Occurred Overall and by Driver Age Group?

The remaining measures that comprised the understanding of warnings sub-objective addressed the effectiveness of the visual and auditory alerts, as well as the use of color for the alert icons. None of these items were differentiated statistically among driver age groups. For drivers as a whole, with regard to the degree to which using color improved the understanding of the FCW information presented in the HUD, the overall mean response was 6.2 (7 = strongly agree), indicating that the use of color was deemed beneficial. In terms of the effectiveness of the alerts (7 = very effective), overall mean responses were each nearing the positive scale anchor. As it pertained to the visual component, drivers indicated that the warnings were effective at getting their attention quickly (mean = 6.2). Regarding the audio component, drivers responded similarly as to the effectiveness of the audio alert in communicating imminent threats (mean = 6.2) and getting their attention quickly (mean = 6.5).

The usability sub-objective gauged aspects of driver comfort level and ease of adjusting and driving with the FCW system. For two items, responses differed statistically by age group. These pertained to the degree of annoyance associated with the imminent visual and auditory alerts (see Figure 5-63 and Figure 5-64). Overall, the imminent visual and auditory alerts were rated as tolerable, slightly annoying, or not at all annoying by 76 percent and 71 percent of drivers, respectively. As depicted in Figure 5-63, among the age groups, younger and middle-age drivers reported being significantly more annoyed by the imminent visual alert than older drivers ($F(2, 35) = 4.77$, $p < .05$), though their degree of annoyance was moderate (mean = 3.2 for both younger and middle-age groups, compared to the older group mean = 4.8).

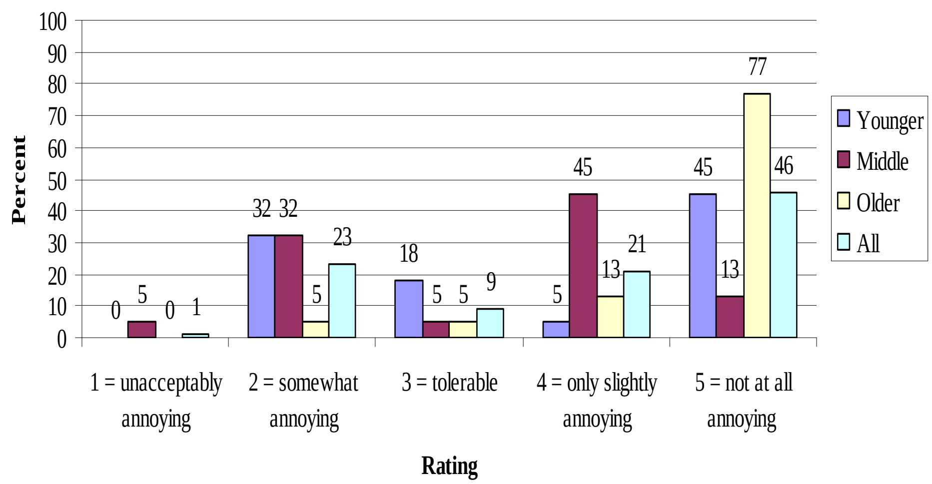


Figure 5-63. "How Annoying Was the Visual Alert That Signaled a Situation in Which You May Be About to Crash?" Overall and by Driver Age Group

As shown in Figure 5-64, when drivers were questioned regarding the degree to which they found the auditory alert indicating an imminent crash risk situation annoying, nearly 30 percent responded that the alert was either somewhat or unacceptably annoying. Again in this case, younger (mean = 2.9) and middle (mean = 3.4) age drivers were significantly more annoyed by the FCW auditory alert for imminent crash situations, finding them in the range of "tolerable", compared to the older drivers (mean = 5.0; $F(2, 35) = 6.06$, $p < .05$).

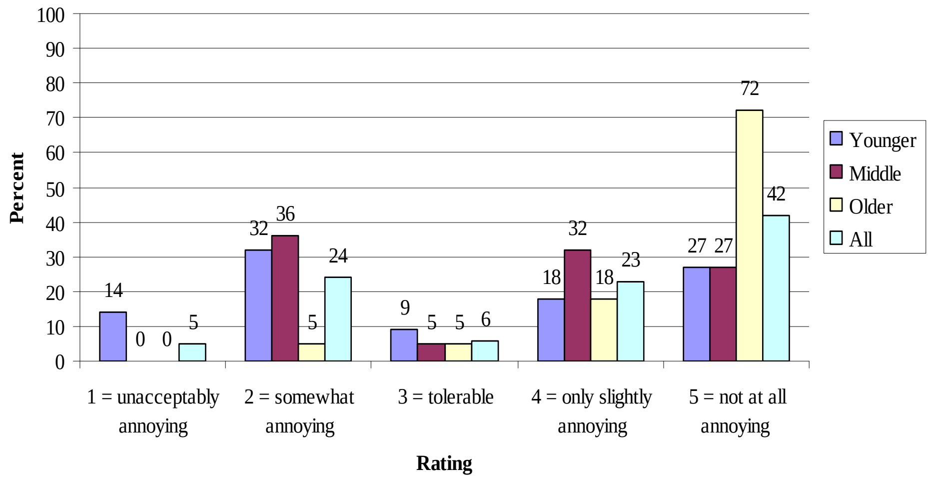


Figure 5-64. "How Annoying Was the Auditory Alert That Signaled a Situation in Which You May Be About to Crash?" Overall and by Driver Age Group

Additional usability measures that did not differentiate age groups, but were nevertheless of interest, included an item assessing driver comfort level using FCW (1 = very uncomfortable – 7), which resulted in an overall mean score of 5.5, indicating a moderate level of comfort with FCW use across the sample. Regarding the amount of time it took for participants to reach this level of comfort, the mean response for the sample was 2.0 indicating that, on average, drivers took 2-3 days. Finally, with regard to the usability of the alert timing adjustment, on average, drivers reported that it was easy to understand and use (7 = very easy; sample mean = 6.3). Additionally, drivers indicated that they changed the alert timing adjustment on average a bit more frequently than 2-3 times over the three weeks FCW was enabled (5 = I changed the setting every day; sample mean = 3.3).

5.5.5.2 HUD Statistical Findings

Drivers were asked which aspects of the HUD they would prefer to see moved to the head-down instrument panel, or have visible only when adjustments were made, rather than being continually displayed. The majority of drivers did not recommend any change to the HUD in terms of removing information and displaying it in the head-down instrument panel. As it pertained to displaying information only while adjustments were being made, 46 percent suggested displaying the ACC gap setting/headway only during adjustments, 26 percent would have preferred that the FCW alert timing setting was visible only while being adjusted, and 14 percent indicated that only displaying the ACC set speed during adjustments would have been adequate. Additionally, drivers were asked how frequently they intentionally adjusted the HUD location to hide the information display and drove with it in that position for an extended period. The majority of drivers, 83 percent, stated that they never adjusted the HUD in this way, while 3 percent of the sample responded that they adjusted the HUD "very frequently" in this manner.

5.5.5.3 Investigating Travel Behavior and FCW Ease of Use Measures

Follow-on analyses were conducted to see if objective travel behavior measures were correlated with the subjective Likert-type ease of use survey measures. The objective measures encompassed ACAS-enabled driving and included FCW distance traveled (km) in valid trips, number of FCW alerts and mean number of FCW alerts per 100 Km. No meaningful statistical relationships were obtained among the survey and objective travel behavior measures.

5.5.5.4 Interpretation of Debriefing and Focus Group Comments

Drivers' ease of use related comments during the focus groups and driver debriefings are discussed to enhance the understanding of their rating of FCW's ease of use.

Drivers, participating in focus groups after completing the FOT, discussed, "When you got the (FCW) imminent alert, what did you typically do in response to that? Did you apply the brakes?" They framed their answers in several ways. Some described how they handled the car mechanically, others described how their reaction to FCW evolved through time, and others classified their responses depending on whether they were attending to the forward scene or not.

Drivers associated the FCW crash-imminent alert with the audible sound and some, but not all, associated it with the large visual icon. A few drivers noticed that the audible alert is not unique and that other infrequently occurring alerts use the same sound, i.e., when ACC is no longer available because the vehicle speed is too slow. Using the same sound for multiple conditions may require the driver to devote more attention to discriminating the meaning of the sound as well as respond to it.

Some drivers used the color and size shifts in the icons to signal a change in risk. Drivers said that it took time to understand the imminent FCW alert because it happened infrequently, suggesting that they had a learning curve for FCW.

The comments raise a question about the utility of cautionary alerts as some drivers said they learned to ignore the "early ones." Typically, most drivers hover their foot over the brake while assessing the forward scene to react to an imminent alert.

Some drivers mentioned that they needed time to learn how to use FCW.

Comments recorded during the focus groups and in the debriefings convey that some drivers felt shock when they received a crash-imminent alert because it happened so infrequently.

Drivers were asked how their response to imminent alerts changed through time, "do you think the way you responded differed depending on the scenario? or change with more experience?". They said that they became more comfortable using FCW, they initially did not know what to expect and overcame this feeling, they grew to like and use the slow warning system more than the imminent alert itself, and they learned that to do something is response to an imminent alert. i.e. checking the forward scene, etc., and made more adjustments to the FCW settings for weather etc. over time.

Other drivers mentioned how they used FCW according to their situation. For example, some drivers said that, if they were distracted and FCW alerted them, they immediately applied the brake. However, if they were attending to the forward scene and saw a lead vehicle make a right turn and got an imminent FCW alert in response, they learned to pay no attention because the situation was safe.

Some drivers used FCW as instruction about their driving, commenting that FCW modified their driving. They viewed an alert as beneficial because it reminded them to monitor the road situation as well as remedy distraction.

If a driver disagreed with the threat being warned about, he/she had to identify the risk, if any, about which they were being warned. They found having to look for the source of the alert to be annoying because it required added effort.

During their debriefing, drivers made comments about their comfort using FCW. Drivers' comfort was improved because FCW reinforced their need to maintain a forward view. Their comfort was also impaired by false warnings, FCW's failure to detect threats, the time needed to get used to FCW, difficulty in testing FCW and finding a suitable FCW setting, obscure meaning of each setting option, distraction caused by the icons, misleading detection of non-threatening vehicles, and the late onset of FCW alerts at higher speeds.

During the debriefings, drivers were asked what annoyed them about FCW. Drivers said FCW warnings were annoying because they occurred in conjunction with false warnings. They were interrupted and had to identify a source for the alert and then regain their driving composure. Drivers found the combination of needless interruption, with its insistent intrusive sensory characteristics, annoying.

When drivers were asked what annoyed them about FCW using an open-ended response format, their answers can be categorized as FCW's auditory tone; the size and color of the FCW icons; the unexpected, distracting, or startling character of the FCW alert; and the FCW timing, in terms of the lateness of the alert because, often, they were already reacting to the threat situation.

When asked about the HUD, drivers said that they liked seeing their vehicle speed on the HUD, even though the changing digits could be distracting. They also mentioned that the HUD was useful for night driving. Some commented that bright sunlight could wash out the HUD display. Other drivers mentioned being annoyed initially by the icons on the HUD but learned to overlook them with time.

5.5.5.5 Summary

Although ease of use ratings for FCW ranged from neutral to positive overall, the distributions of the ratings and their association with driver age are informative. Compared to manual driving, mean stress levels when using FCW were reported as neutral to slightly positive, however the ratings were widely distributed. One quarter of the drivers indicated that FCW use led them to experience more stress, compared to 49 percent reporting less stress.

With regard to the cautionary visual icons, the distribution of scores is also quite revealing. While, overall, drivers did not rate the alerts as very distracting, those who did (scores of 1 or 2) were part of the younger age group (20%, compared to 0% of middle and 5% of older drivers). Pertaining to the FCW alert timing settings, drivers reported, overall and with no significant age group differences, that traffic and weather conditions were the most frequent reasons for changing the setting. Age group did differentiate responses regarding level of annoyance with the incidence of false FCW alerts, however. While, as a group, over one quarter of the drivers reported being not at all annoyed by the false alerts, slightly more than one-third experienced marked annoyance. Further, the younger and middle-age groups expressed greater annoyance than the older drivers regarding alerts that were deemed unnecessary. Similarly, younger drivers tended to report greater annoyance by false FCW alerts in most driving situations, while older drivers tended to report being less annoyed. Overall, one third of the drivers said they were always able to identify the reason for the FCW imminent alert and older drivers were over-represented among those able to identify the source of the alert. Three fifths of the older drivers said they were always able to identify the source of the FCW imminent alert compared to just under one quarter of the younger drivers and less than one fifth of the middle-age drivers. With regard to the auditory component of the FCW alert, as a group, drivers did not find it to be overly startling, though younger drivers rated the alert more startling and also more annoying than did older drivers. Additionally, the younger and middle-age groups expressed greater annoyance by the imminent visual alert than older drivers.

Other findings included reports that drivers were generally in favor of the HUD implementation and the vast majority, 83 percent, never intentionally adjusted and drove with the HUD in a way that hid information in the display. Changes to the HUD that did receive some element of support included displaying the ACC gap/headway and FCW alert timing settings only when adjustments were being made.

Any nascent anecdotal reports of annoyance with FCW alerts appeared to be aggravated to the degree that they turned out to be false. These alerts interrupted drivers, obligated them to identify a source for the alert, and to subsequently regain their driving composure. Some drivers expressed that the combination of needless interruption, especially with its insistent, intrusive, sensory characteristics, was annoying.

5.5.5.6 Ease of Use – ACC

The ACC ease of use objective, similar to that for FCW, assessed the degree to which drivers found FCW easy to set up, understand, adjust, and use in various circumstances. For reference purposes, Appendix N – Appendix O present results for ACC ease of use measures in a form parallel to that used for FCW, where possible. This includes survey item intercorrelations, descriptive statistics, and ANOVA results for analyses investigating potential age group attitudinal differences. Data about drivers’ assessment of the ease of use of ACC are provided in the appendices cited. No detailed analyses are provided due to scope limitations.

5.5.6 Ease of Learning – FCW and ACC

The ease of learning objective assessed whether drivers were able to learn and retain knowledge regarding ACAS use. Ease of learning is an important aspect of driver acceptance of vehicle technologies, since a feature that is easy to learn and understand is more likely to be used appropriately and frequently over time. This objective encompassed both the effectiveness of the instructions and the time required to understand and become comfortable with its use.

5.5.6.1 FCW Statistical Findings

This section presents the results of the FCW ease of learning measures. It includes both descriptive and quantitative discussion of the subjective measures from the FOT surveys, as well as driver anecdotes supplied during debriefing and focus group sessions. Finally, a summary of the analysis of ease of learning FCW is offered.

Correlations were calculated among the ease of learning measures.[20] The items, "How long did it take before you became comfortable with the operations of FCW?" and "How long did it take before your understood the operations of FCW?" were significantly intercorrelated in the expected direction (see Table 5-13), suggesting that drivers who more quickly understood the operation of FCW were also more likely to feel comfortable with the operation of FCW in less time.

Table 5-13. Ease of Learning Sub-Objective Survey Measure Intercorrelations (Spearman's rho)

Sub-objective	***Survey Item***	1.	2.	3.
1. ***Time to learn***	How long did it take before you became comfortable with the operations of FCW? *1 (comfortable with FCW within 1st day) - 5*	—	.46	NS
2.	How long did it take before you understood the operation of FCW? *1 (understood operations of FCW within 1st day) - 5*		—	NS
3. ***Utility of instructions/training***	How useful was the training video in understanding how to use ACC and FCW? *1 (not at all useful) - 7*			—

Note: All correlations significant at $p \leq .05$ except where denoted as nonsignificant (NS)

Table 5-14 presents descriptive statistics for responses to each of the survey measures, broken down by sub-objective. As responses were not always normally distributed, measures of central tendency, in addition to the mean and standard deviation, are provided for each measure.

[20] Correlations were performed using Spearman's rho for nonparametric data.

Table 5-14. Ease of Learning Sub-Objective Survey Measure Descriptive Statistics

Sub-objective	Survey Item	Mean	Standard Deviation	Median	Mode
Time to learn					
	How long did it take before you became comfortable with the operations of FCW? *1 (comfortable with FCW within the first day) - 5*	2.0	1.0	2.0	2.0
	How long did it take before you understood the operation of FCW? *1 (understood operations of FCW within 1st day) - 5*	1.5	0.8	1.0	1.0
Utility of instructions/ training					
	How useful was the training video in understanding how to use ACC and FCW? *1 (not at all useful) - 7*	6.6	0.7	7.0	7.0

As indicated previously in the methods section of this report, driver acceptance analyses were targeted at existing differences among age groups and/or age and gender groups, as appropriate. Along those lines, Table 5-15 shows statistical relationships between driver age group and FCW ease of learning by sub-objective, with any significant group differences noted briefly in the rightmost "Results" column and nonsignificant findings denoted using "NS."[21]

Table 5-15. Statistical Comparison of FCW Ease of Learning Sub-Objective Measures by Driver Age Group

Sub-objective	Survey Item	Age Group	Mean	ANOVA Results
Time to learn				
	How long did it take before you became comfortable with the operations of FCW? *1 (comfortable with FCW within 1st day) - 5*	Younger Middle Older	1.8 2.0 2.1	NS
	How long did it take before you understood the operation of FCW? *1 (understood operations of FCW within 1st day) - 5*	Younger Middle Older	1.6 1.3 1.6	NS
Utility of instructions/ training				
	How useful was the training video in understanding how to use ACC and FCW? *1 (not at all useful) - 7*	Younger Middle Older	6.5 6.5 6.7	NS

ANOVA results of the survey items suggested that driver age group was not a factor with regard to the time required to become comfortable with the operation of FCW, nor with the time needed

[21] Parametric ANOVA results are reported here and throughout this report as justified in the section on Data analysis (5.3.4).

to understand FCW operation. Parallel analyses indicated that driver gender also did not yield significantly different responses on any of these measures.

Descriptively, as it pertains to the ease of use survey items above, it is interesting to note that within the first day of use, 60 percent of the drivers reported that they understood FCW. A smaller percentage of the sample, 35 percent, became comfortable with its operation within that same timeframe. Within 2 to 3 days, over three quarters of the sample, 76 percent, reported that they felt comfortable using FCW, however, 3 percent indicated that they never became comfortable with the operation of FCW, and one young male driver reported that he never understood FCW. Overall, drivers felt that the instructional video was very useful, as 89 percent rated this item with a score of 6 or 7.

5.5.6.2 Investigating Travel Behavior and FCW Ease of Learning Measures

Follow-on analyses were conducted to see if relevant objective FCW travel behavior measures were correlated with the ease of learning measures. The objective measures that encompassed ACAS-enabled driving and FCW use included FCW distance traveled (km) in valid trips and number of alerts with FCW engaged. A significant negative correlation existed between FCW distance traveled (km) in valid trips and the survey item, “How long did it take you before you felt comfortable with the operations of FCW?” ($r = -.30$, $p < .05$). A significant positive correlation existed between the number of alerts with FCW engaged and the same survey item ($r = .28$, $p < .05$). These relationships suggest that the greater overall distance traveled in FCW mode, the more quickly a driver felt comfortable using the FCW system. Additionally, higher numbers of FCW alerts, normalized for distance traveled, were associated with drivers needing more time to feel comfortable using FCW.

5.5.6.3 Debriefing and Focus Group Comments Regarding Ease of Learning of FCW

As a result of examining the qualitative data acquired from the debriefing and focus groups, it is evident that ease of learning of FCW may only be fully explained by incorporating the results of the survey measures with anecdotal findings.

It became apparent from comments during debriefings that, although the vast majority of drivers responded in the surveys that they understood how to use FCW in a short amount of time, many did not truly comprehend how FCW functioned. Drivers were asked during the debriefing about their understanding of the timing of the FCW imminent alert. Of the 49 drivers who answered this question, 41 percent replied incorrectly, stating that changing the FCW settings altered the timing of the imminent alert. Examining the responses by driver indicates that the frequency of erroneous interpretations of FCW imminent alert timing decreased among the later subjects, although it still occurred. This is most likely a result of the fact that FOT administrators revised their instructions to subjects during the FOT to emphasize that the imminent alert timing was fixed. Some comments by later drivers mentioned that this point was stressed to them, yet earlier participants did not have the same understanding of the system, which may have affected overall driver acceptance of FCW. Given that two-fifths of drivers’ responses indicated that they did not understand how FCW imminent alerts were triggered, individuals were likely to experience frustration resulting from the assumption that they were affecting the FCW imminent alert timing by altering FCW sensitivity settings.

As a result of using the FCW system, drivers reported anecdotes explaining in what ways they also learned about their driving behavior. Instances that referred to proper spacing in between the FOT and lead vehicles, in addition to a better understanding of the various stopping distances required to be safe given different travel speeds, and indications regarding how often, as drivers, they let their attention wander were all highlighted as important contributions that the FCW system made to participants' driving behavior. FOT participants also described ways in which the FCW system fostered good driving behavior in terms of learning how to use the sensitivity settings by going through a process to find the most suitable setting for various driving conditions and their individual driving style. Participants also reported gaining a more complete understanding of what FCW alert feedbacks they could or should ignore and which they should attend to.

As a final indication of the learning drivers needed to understand the full ACAS system, it was not uncommon in the debriefings and focus groups for drivers to confuse FCW with ACC. Typically, such errors were corrected by the experimenter during a debriefing or focus group session; however, there is at least one documented case of a discussion that referred to FCW, where ACC function was being described.

5.5.6.4 Summary

Most drivers reported that they learned to use, and felt comfortable using, FCW very quickly. Driver age and gender were not related to the ease of learning measures. Travel behavior variables were related to how long it took drivers to become comfortable with FCW use. The more participants drove with FCW engaged, the sooner they reported feeling comfortable using FCW. Additionally, the more FCW alerts drivers received, as normalized by distance driven, the longer it took them to feel comfortable using FCW.

Anecdotal evidence provided by drivers suggested that it is important to distinguish between learning to use a system versus understanding a system. Debriefing comments indicated that 41% of drivers did not understand the FCW crash-imminent alert timing. This misunderstanding could have contributed to dissatisfaction with FCW to the extent that the system did not meet expectations, in that some drivers were not able to set the imminent alert timing as they believed they could. Additionally, some drivers reported gaining an unexpected benefit from their FCW use, as they felt that it provided them with an opportunity to learn about their driving.

5.5.6.5 Ease of Learning – ACC

The ACC ease of learning objective, similar to FCW, assessed the degree to which drivers were able to easily learn and retain knowledge regarding how to use the ACC system. For reference purposes, Table P-1 in Appendix P presents results for ACC ease of learning measures in a form parallel to that used for FCW, where possible. This includes survey item intercorrelations, descriptive statistics, and ANOVA results for analyses investigating potential age group attitudinal difference. Data about drivers' assessment of the ease of learning to operate ACC are provided in the appendices cited. No detailed analyses are provided due to scope limitations.

5.5.7 Driving Performance – FCW and ACC

The driving performance objective assessed to what degree, and how, drivers adjusted their driving with respect to ACAS. Driver performance considerations were specified with regard to four sub-objectives[22]. These included awareness, which addressed driver vigilance; vehicle control inputs, to examine driver behavior with regard to adjusting ACAS settings; and trip patterns, to evaluate potential changes in travel behavior associated with ACAS-enabled driving.

Changes in driving performance were expected across the duration of the FOT, given incremental exposure to ACAS. Initial driving occurred with ACAS disabled and was segmented by the independent evaluation into two periods, P1 and P2 (median split of distance traveled per driver). Subsequent ACAS-enabled driving was also divided into two periods (P3 and P4) using a median split of distance traveled on a per-driver basis. Analysis of driving parameters given this breakdown is performed as a means of investigating changes in driving performance associated with ACAS exposure.

5.5.7.1 FCW Statistical Findings

This section presents the results of the ACAS driving performance measures. Driving performance was gauged using subjective measures from the FOT surveys, as well as objective data from the data acquisition system (DAS) and driver anecdotes supplied during debriefing and focus group sessions. This section concludes with a summary of the analysis of driving performance.

5.5.7.1.1 Awareness

Correlations were calculated for the subjective measures of the awareness sub-objective.[23] Table Q-1 in Appendix Q contains the correlation matrix for the awareness sub-objective survey items. The significant associations revealed that drivers who, when using FCW, considered themselves more responsive to the actions of other vehicles, also assessed themselves as more aware of their driving situation and felt slightly more comfortable performing additional tasks while driving. Additionally, drivers who felt that they did not over-rely on FCW also deemed themselves more aware of the surrounding driving situation and more comfortable performing additional tasks while driving. The three items referring to manual driving were included for comparison with the measures of awareness while driving with FCW.

Table 5-16 presents descriptive statistics for responses to survey measures of the awareness sub-objective. As responses were not always normally distributed, measures of central tendency, in addition to the mean and standard deviation, are provided for each measure.

---

[22] The driving style/risk compensation sub-objective was proposed to address the possibility that driver behavior was affected in a way that was not consistent with the goals the ACAS system. At present, the proposed analysis of variables including headway distance and driver distraction require an additional effort.
[23] Correlations were performed using Spearman's rho for nonparametric data.

Table 5-16. Driving Performance Sub-Objective Survey Measure Descriptive Statistics

Survey Item	Mean	Standard Deviation	Median	Mode
Awareness				
When using FCW, how responsive were you to the actions of other vehicles around you? *1 (very unresponsive) - 7*	6.4	0.8	7.0	7.0
When driving manually, how responsive were you to the actions of vehicles around you? *1 (very unresponsive)- 7*	6.3	0.8	6.0	7.0
Overall, I found myself relying too much on the FCW system *1 (strongly disagree) - 7*	2.0	1.3	1.0	1.0
When using FCW, how aware were you of the driving situation (surrounding traffic, posted speed, traffic signals, etc)? *1 (very unaware) - 7*	6.5	0.7	7.0	7.0
When driving manually, how aware were you of the driving situation (surrounding traffic, posted speed, traffic signals) *1 (very unaware) - 7*	6.2	0.8	6.0	7.0
While using FCW, please tell us the number of times, if ever, you came close to experiencing a rear-end collision? *open-ended # response*	0.8	1.3	0.0	0.0
While driving manually, please tell us the number of times, if ever, you came close to experiencing a rear-end collision? *open-ended # response*	0.4	1.3	0.0	0.0
Did you feel more comfortable performing additional tasks while using the FCW system as compared to manual driving? *1 (less comfortable) - 7*	5.2	1.3	5.0	4.0

As indicated previously in the methods section of this report, driver acceptance analyses were targeted at differences among age groups and/or age and gender groups, as appropriate. For reference purposes, Table 5-17 depicts statistical relationships between driver age group and FCW driving performance, by sub-objective, with significant group differences noted briefly in the rightmost Results column and nonsignificant findings denoted using NS. Analysis of variance[24] was performed for Likert-type survey measures were statistically significant, meaningful findings that differentiated groups on FCW driver performance are discussed in the below text.

[24] Parametric ANOVA results are reported here and throughout this report as justified in the section on data analysis (5.3.4).

Table 5-17. Statistical Comparison of FCW Driving Performance Sub-Objective Measures by Driver Age Group

Sub-objective	Survey Item	Age Group	Mean	ANOVA Results
Awareness				
	When using FCW, how responsive were you to the actions of other vehicles around you? *1 (very unresponsive) - 7*	Younger Middle Older	6.2 6.1 6.9	O more responsive than Y and M
	When driving manually, how responsive were you to the action of vehicles around you? *1 (very unresponsive)- 7*	Younger Middle Older	6.0 6.3 6.5	NS
	Overall, I found myself relying too much on the FCW system *1 (strongly disagree) - 7*	Younger Middle Older	2.0 2.2 1.9	NS
	When using FCW, how aware were you of the driving situation (surrounding traffic, posted speed, traffic signals, etc)? *1 (very unaware) - 7*	Younger Middle Older	6.2 6.3 6.9	O more aware than Y and M
	When driving manually, how aware were you of the driving situation (surrounding traffic, posted speed, traffic signals) *1 (very unaware) - 7*	Younger Middle Older	6.0 6.1 6.5	NS
	While using FCW, please tell us the number of times, if ever, you came close to experiencing a rear-end collision? *open-ended # response*	Younger Middle Older	1.1 0.9 0.5	NS
	While driving manually, please tell us the number of times, if ever, you came close to experiencing a rear-end collision? *open-ended # response*	Younger Middle Older	0.5 0.6 0.1	NS
	Did you feel more comfortable performing additional tasks while using the FCW system as compared to manual driving? *1 (less comfortable) - 7*	Younger Middle Older	5.0 5.0 5.5	NS

The awareness sub-objective addressed driver responsiveness to the actions of surrounding vehicles in cases of FCW and also manual driving. In both situations, overall mean responses suggested that drivers felt quite responsive and no scores on this measure fell below the scale midpoint (see Figure 5-65). When driving using FCW, 88 percent of the sample rated themselves toward the "very responsive" end of the rating scale (score of 6 or 7). Similarly, 85 percent of drivers responded with scores of 6 or 7 for manual driving.

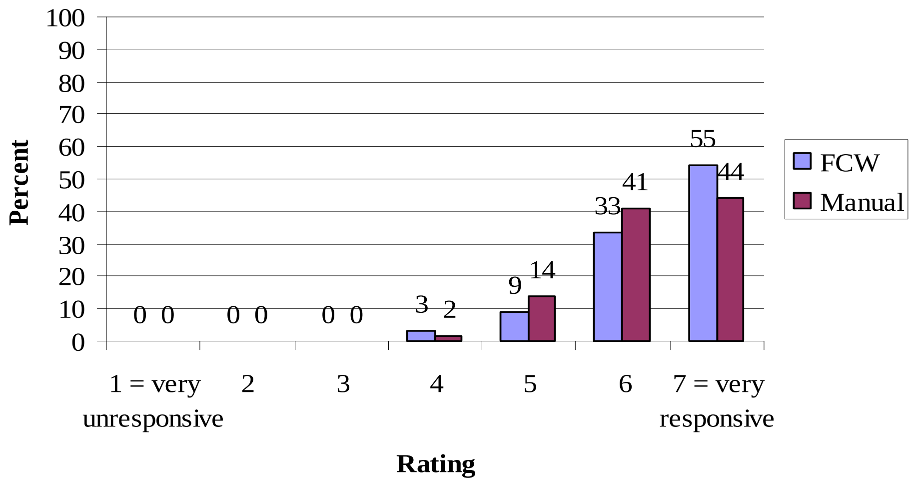


Figure 5-65. "How Responsive Were You to the Actions of Other Vehicles Around You?" Using FCW and During Manual Driving

Figure 5-66 depicts the distribution of scores and significant differences among age groups regarding responsiveness to surrounding vehicles while using FCW. Older drivers rated themselves as significantly more responsive to the actions of other vehicles than the younger or middle-age groups ($F(2, 63) = 9.02$, $p < .01$). The means for the three age groups were all at the positive end of the scale; the average score for the older driver age group was 6.9, middle-age drivers, 6.1, and younger drivers, 6.2.

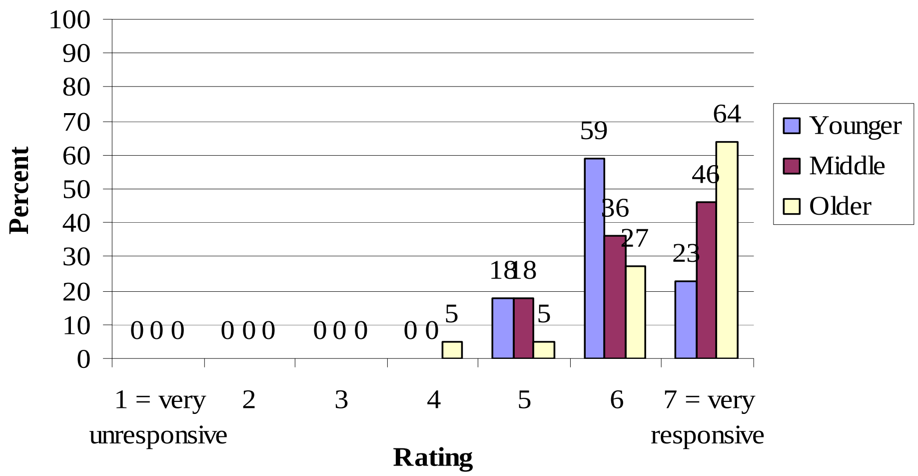


Figure 5-66. "When Using FCW, How Responsive Were You to the Actions of Other Vehicles Around You?" by Driver Age Group

Drivers rated how aware they felt driving with FCW and manually, as shown in Figure 5-67. Mean responses to the two parallel items were similar, in that drivers regarded themselves as quite aware in both driving conditions and no responses fell below the scale midpoint.

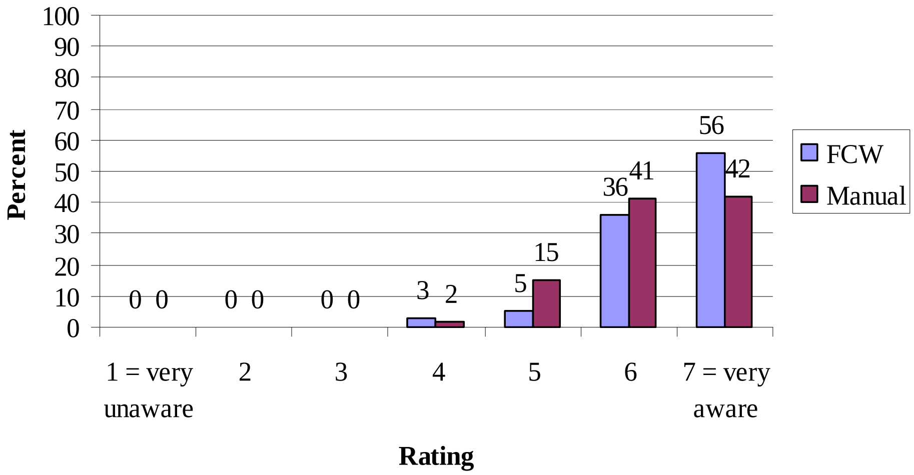


Figure 5-67. "…How Aware Were You of the Driving Situation…?" Using FCW and During Manual Driving?

As illustrated in Figure 5-68, among age groups, older drivers considered themselves to be significantly more aware of the traffic situation using FCW, compared to younger and middle-age drivers ($F(2, 63) = 7.93$, $p < .01$). The mean score on this measure for the older driver age group was 6.9, compared to a mean of 6.3 for the middle-age group and 6.2 for the younger driver age group.

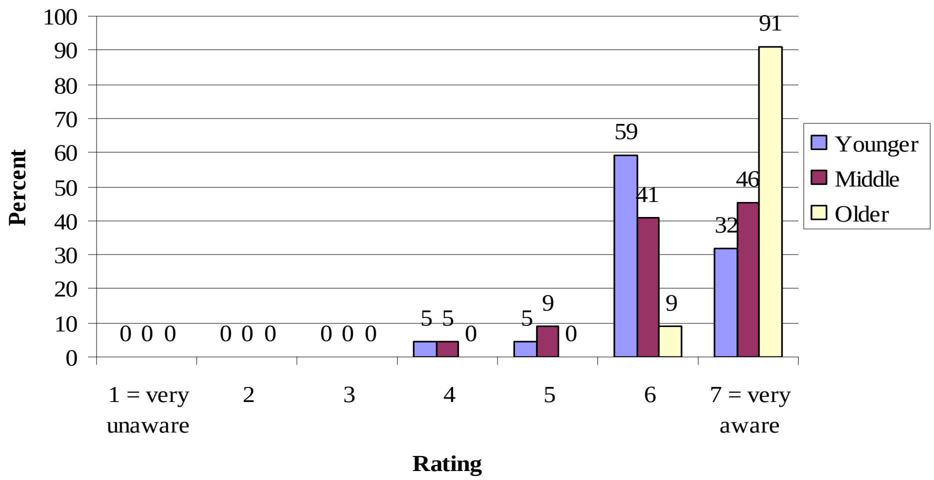


Figure 5-68. "When Using FCW, How Aware Were You of the Driving Situation?" by Driver Age Group

Figure 5-69 shows the percent distribution of responses to parallel survey items asking drivers to estimate the number of times they felt that they came near to experiencing a rear-end collision driving with FCW and also when driving manually. Using FCW, the mean number of reported near rear-end collisions was 0.84 (SD = 1.3), compared to a mean of 0.41 (SD = 1.3) for manual driving. Age differences were nonsignificant, but were inversely related; the younger driver age group reported a mean of 1.1 near-collisions, compared to 0.9 for the middle-age group and 0.5 for the older age group.

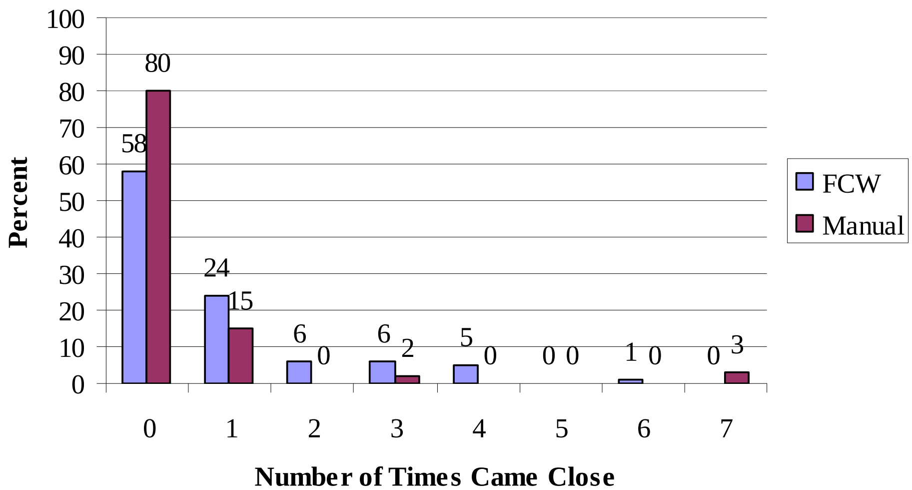


Figure 5-69. Estimated Number of Times Drivers Came Close to Experiencing a Rear-End Collision Using FCW and During Manual Driving

Finally, while there was no significant difference in responses by age group to the item assessing the degree to which drivers found themselves relying too much on the FCW system, it is interesting to note that the sample as a whole felt quite strongly that they did not over-rely on FCW (mean score = 2.0; 1 = strongly disagree – 7).

5.5.7.1.2 Vehicle Control Inputs

Another aspect of driver performance is the manipulation of vehicle controls that were associated with ACAS. For example, frequency of use of the HUD position adjustment and brightness controls, in addition to frequency of manipulation of FCW sensitivity settings were obtained from the DAS in the FOT vehicle.

HUD Position Adjustments

As illustrated in Figure 5-70, the mean number of position adjustments to the HUD per 1,000 km decreased over time during ACAS-enabled driving. Collapsing across light and dark driving, comparing P3 and P4, HUD adjustments per 1,000 km traveled decreased from 6.5 to 1.5. A comparison of P3 and P4 driving in conjunction with time of day evidenced that the frequency of adjustments made during daylight decreased 80 percent, while adjustments during darkness decreased 78 percent. During ACAS-enabled P3 driving, individuals tended to adjust the HUD position nearly twice as frequently while driving at night, compared to day, and maintained the day-night differential in P4.

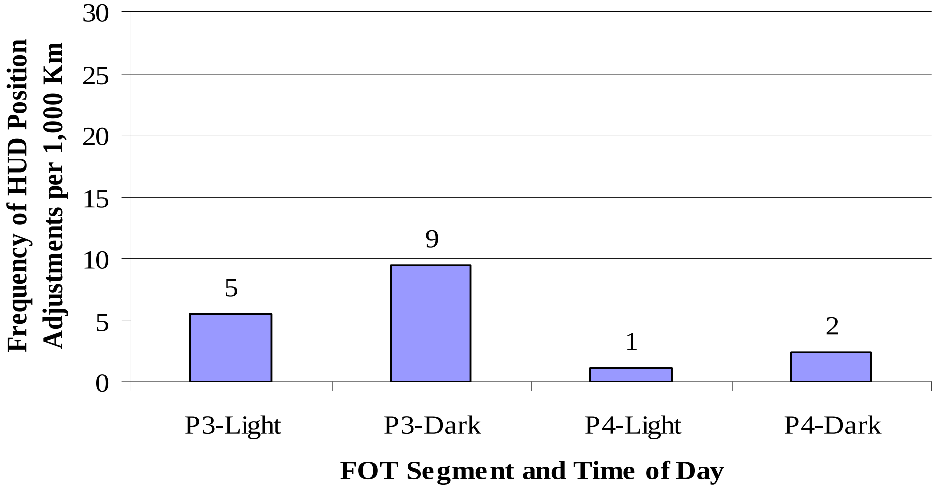


Figure 5-70. HUD Position Adjustments per 1,000 Km Traveled by FOT Segment and Time of Day

Figure 5-71 and Figure 5-72 show that during P3 and P4 driving and light and dark periods, older and female drivers appeared more likely to adjust the HUD position. For each category of drivers, proportionally, the largest decrease in HUD position manipulation occurred for driving in the dark. Older drivers made 24.8 changes to the HUD position per 1,000 km driven in darkness, whereas the incidence decreased to 2.6 in P4.

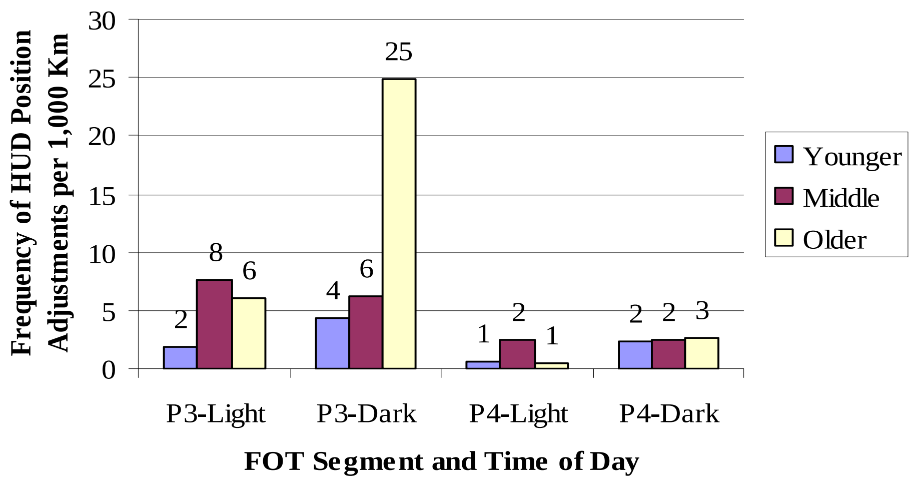


Figure 5-71. HUD Position Adjustments per 1,000 Km Traveled by FOT Segment and Time of Day by Driver Age Group

As depicted in Figure 5-72, female drivers also markedly reduced the number of changes they made to the position of the HUD, particularly while driving in darkness, from 16 to 3.6 per 1,000 km traveled.

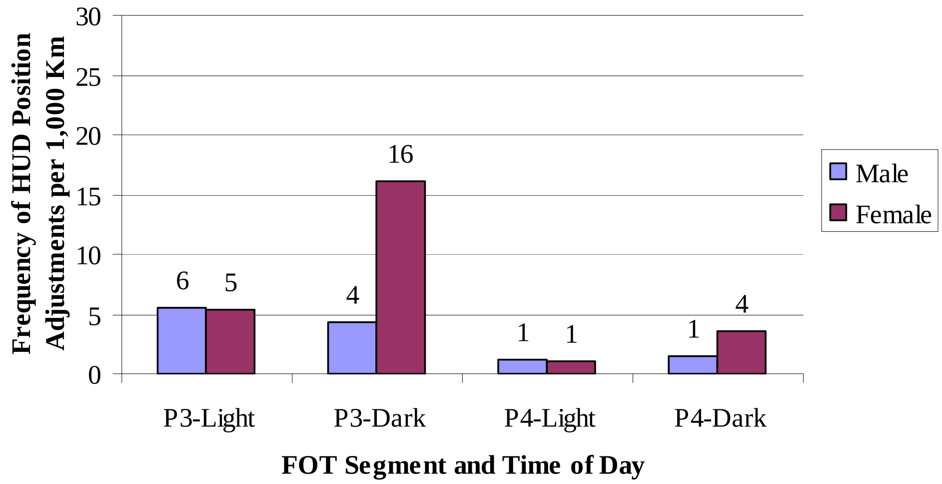


Figure 5-72. HUD Position Adjustments per 1,000 Km Traveled by FOT Segment and Time of Day by Gender

HUD Brightness Adjustments

As illustrated in Figure 5-73, descriptive comparison indicates that HUD brightness adjustments were made more frequently during night driving than during the day and that the mean number of manipulations to HUD brightness settings decreased over time during ACAS-enabled driving. Overall, per 1,000 km, drivers made an average of 15.3 brightness adjustments in P3, evidencing a reduction in frequency to 11 in P4, a 28 percent decrease. The frequency of brightness adjustments made during day and night driving from P3 to P4 also decreased. The daytime rate of brightness adjustment decreased from 12.5 to 8.9 and the nighttime brightness adjustments decreased from 23.3 to 17 per 1,000 km.

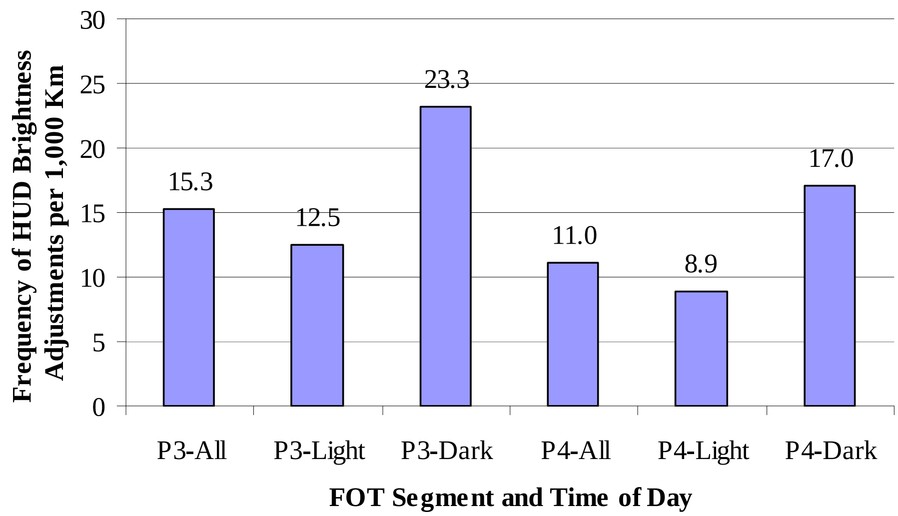


Figure 5-73. HUD Brightness Adjustments by FOT Period and Time of Day

Brightness adjustments by time of day and FOT segment are further broken down by gender in Figure 5-74. Descriptive comparison evidences that female drivers adjusted the HUD brightness controls more frequently per 1,000 km for all segments examined, with the exception of daytime driving in P3.

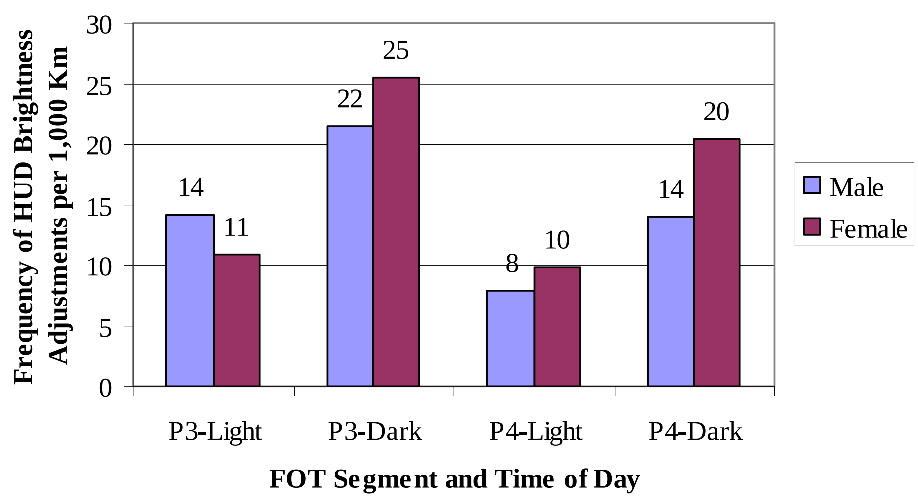


Figure 5-74. HUD Brightness Adjustment by FOT Period, Time of Day, and Gender

FCW Sensitivity Setting Adjustments

FCW provided six sensitivity settings, with setting 1 (S1) representing the least sensitive setting and S6 the most sensitive setting. In S1, the cautionary icons were suppressed altogether, providing only the imminent alerts (for additional detail, see General Motors Corporation, 2005). By contrast, S6 was most sensitive, where icons changed in size and color as the distance to the lead vehicle decreased, culminating in an imminent auditory alert. The ACAS vehicle was set at S4 by default when the driver received the car.

During the twenty days of ACAS-enabled driving, participants adjusted the FCW sensitivity settings frequently, an average of 10 times per day per 1,000 km. Descriptive comparison of "all" FCW sensitivity-setting adjustments per 1,000 km in Figure 5-75 indicates that the overall number of adjustments decreased 42 percent between P3 and P4, where younger and older drivers made the most frequent adjustments in P3, while older drivers made the most changes in P4. The most marked reduction between P3 and P4 was for younger drivers, at 52 percent. As illustrated in Figure 5-75, when considering road type, during both P3 and P4, drivers made approximately four times as many changes to FCW sensitivity settings on arterial roads compared to highway driving.

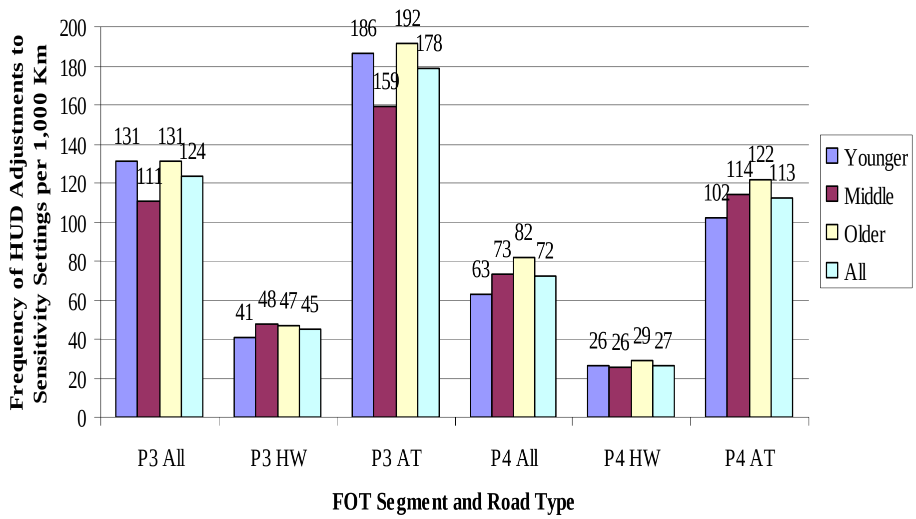


Figure 5-75. Changes to Sensitivity Settings by FOT Period and Road Type

In Figure 5-76, the percent distribution of kilometers driven by setting during P3 and P4 depicts how drivers allocated their preferred sensitivity settings over the duration of the FOT. In P3, the two most sensitive settings accounted for slightly more than one third, 35 percent of km traveled, compared to 28 percent in P4. Similarly, the two least sensitive settings, S1 and S2, accounted for 30 percent of km traveled in P3 and increased to just over one third of travel distances, 34 percent, in P4.

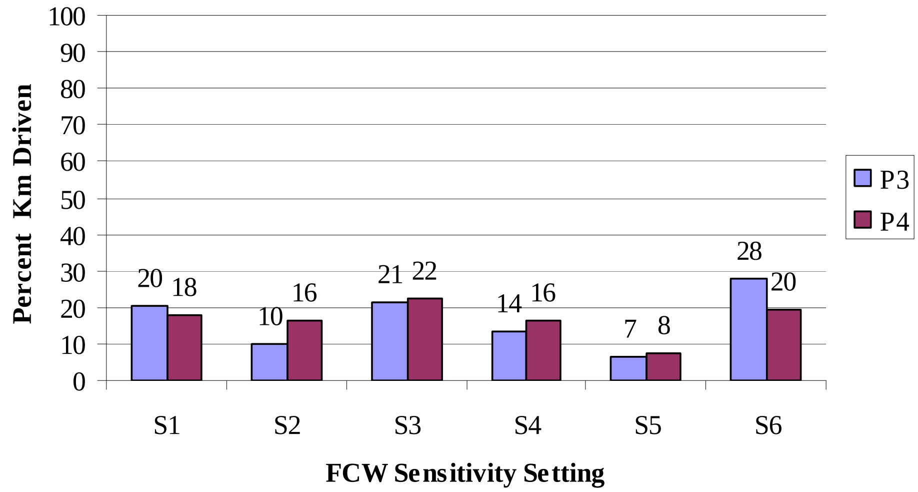


Figure 5-76. Percent Distribution of Km Driven by FCW Sensitivity Settings and FOT Period

With regard to gender, Figure 5-77 illustrates that use patterns for each of the sensitivity settings were similar for both men and women. Over time, the tendency was to move away from the most sensitive setting, S6. Additionally, there was a slight increase in the use of S2 and S4 across P3 and P4 by both men and women, with women preferring this setting over men in general. Further, whereas men sharply decreased their use of S1, women did not alter their use of this setting over time.

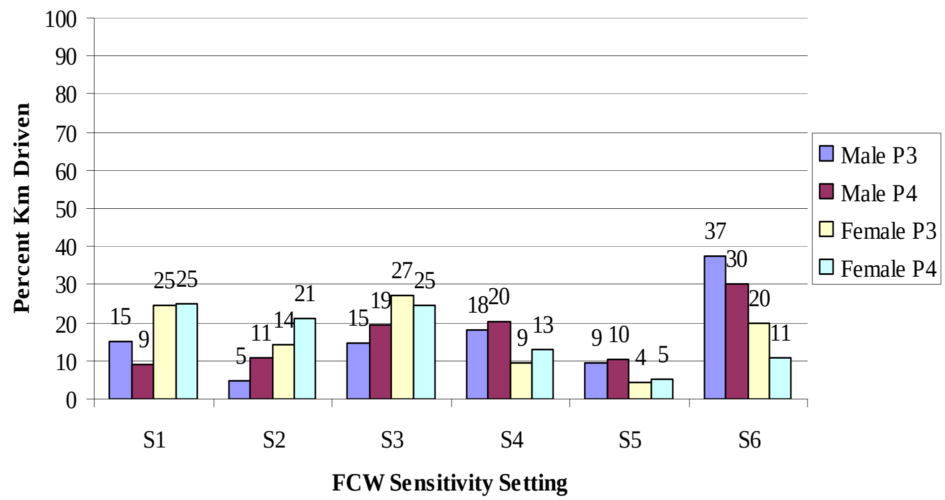


Figure 5-77. Percent Distribution of Km Driven by FCW Sensitivity Settings, FOT Period and Gender

In Figure 5-78, the percent distribution of kilometers traveled using each sensitivity setting is presented descriptively for age groups and overall, by FOT period. Older drivers drove a mean of 41 percent of their travel distances during P3 in S6, reducing travel in this setting to 34 percent for P4. Similarly, middle-age drivers reduced the percent of their driving in setting 6 from 23 percent to 16 percent; younger drivers evidenced the largest reduction, dropping to 12 percent from 22 percent. For the least sensitive setting, S1, younger drivers drove the greatest percentage of their P3 travel distances in this setting, at 29 percent. There was a slight reduction to 26 percent for P4. In contrast, older drivers rarely used this setting, a mere 3 percent of their travel over P3 and only 4 percent in P4. Middle-age drivers reduced their use of S1 from 26 percent to 21 percent over the FOT duration.

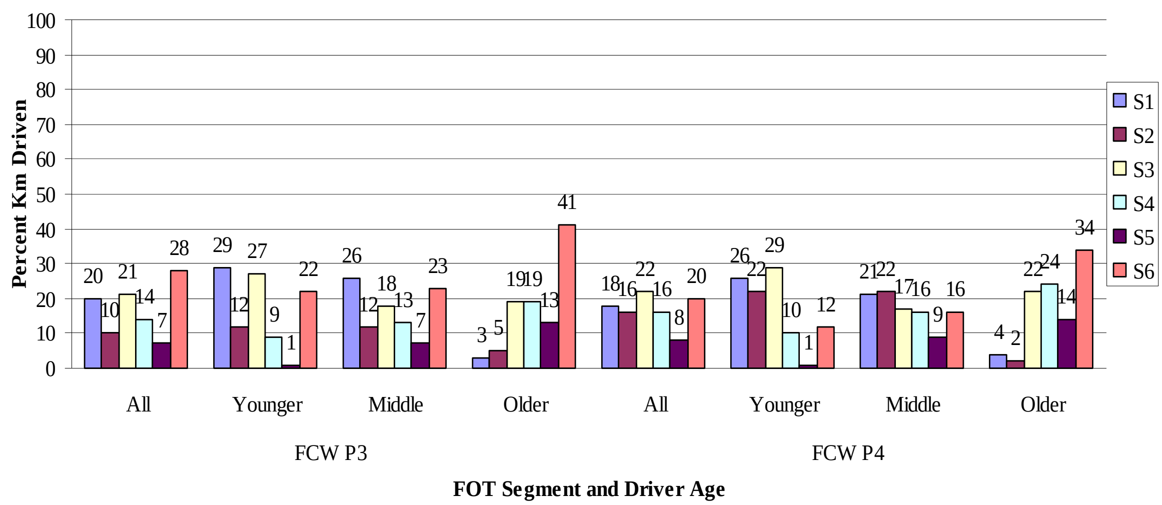


Figure 5-78. Percent Distribution of Km Driven for FCW Sensitivity Settings by FOT Period and Age Group

5.5.7.1.3 Trip Patterns

Patterns of travel were examined to evaluate changes associated with the availability of ACAS during the twenty days it was available. Figure 5-79 compares the percent distribution of distance traveled by age and gender groups for the time when ACAS was disabled (P1 and P2) with the time when ACAS was enabled (P3 and P4). There is not a large amount of variability overall, however, older males traveled a greater percent of FOT distances in the ACAS-disabled period, while older females traveled a larger percent of the distance during ACAS-enabled driving.

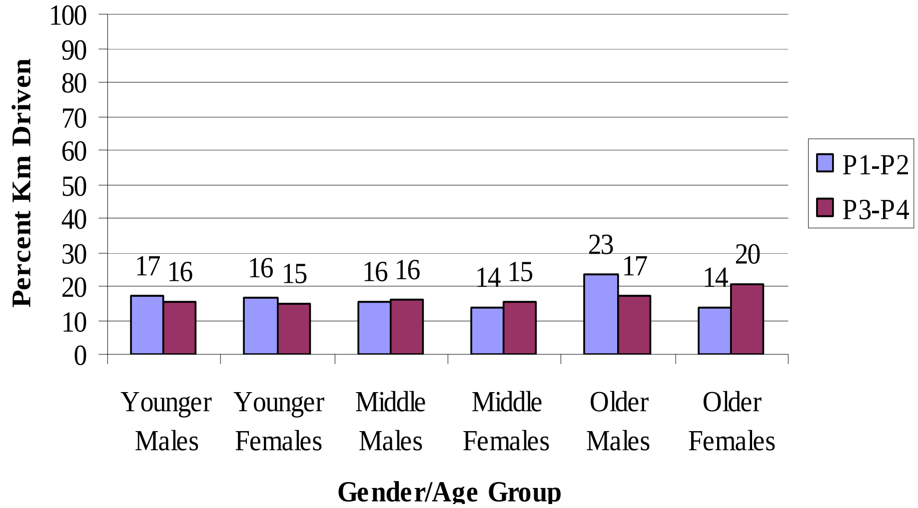


Figure 5-79. Percent Km Driven for P1-P2 and P3-P4 by Age Group and Gender

Additionally, Table 5-18 compares the mean number of trips per day and distance traveled per day by driver and ACAS-disabled versus ACAS-enabled periods. No differences resulted in the mean number of trips or distance traveled per day using ACAS as compared to ACAS-disabled driving.

Table 5-18. Number of Valid Trips and Distance (Km) per Day ACAS-Disabled Versus Enabled

	Distance (km) /day/driver	Trips
ACAS disabled (P1+P2)	91.5	4.8
ACAS enabled (P3+P4)	92.0	4.6

5.5.7.2 Investigating Travel Behavior and FCW Driving Performance Measures

Travel behavior was significantly intercorrelated with the measure of driving performance that assessed the degree to which drivers felt comfortable performing additional tasks while using the FCW system as compared to manual driving ($r = -.26$, $p < .05$). This suggests that drivers who received more FCW imminent alerts were less comfortable performing additional tasks while driving, and may have been related to concerns regarding receiving additional alerts or a need to respond to alerts.

5.5.7.3 Debriefing and Focus Group Comments Regarding Driving Performance with FCW

Drivers made comments when they were asked during debriefings to describe situations in which they came close to having a rear-end collision. Their comments suggest that they became more aware of threats due to FCW. In many of these comments, drivers described the utility of FCW, most typically in terms of gaining their attention when they were distracted.

Although the duration of the FOT was not long enough to establish if FCW use changed drivers' behavior, a comment made during one of the focus groups suggests that this occurred.

5.5.7.4 Summary

Survey responses indicated that drivers felt very responsive to, and aware of, traffic when they used FCW. This may have been attributed to the way FCW operates, in that it explicitly called their attention to potential threats. Among the age groups, older drivers rated themselves as more responsive and aware than the younger and middle-age drivers. On the other hand, participants did not describe themselves as relying too much on the FCW system.

On average, drivers estimated they came close to rear-end collisions 0.84 times using FCW, compared to an estimated incidence of 0.41 when driving the FOT vehicle in the ACAS-disabled, or manual, mode. The increased estimate for the incidence of close calls may, in part, be related to increased awareness of traffic and/or experimentation with the FCW system. In neither ACAS-enabled, nor -disabled driving, did age group differentiate responses to these survey items.

Particularly when first experiencing the FCW system, drivers made more frequent adjustments to the HUD interface. The incidence of adjustments tapered off during the three weeks of ACAS-enabled driving. On a descriptive basis, it was evidenced that older and female drivers appeared to adjust the vehicle controls most frequently. Additionally, time of day appeared to be a factor with regard to variations in frequency of HUD manipulations, in that drivers made more adjustments to the HUD position and brightness when they drove in the dark. Factors such as an individual's height and eyesight may have contributed to the occurrence of these adjustments. Drivers also made frequent changes to the FCW sensitivity settings, however this activity decreased markedly over time, as participants became accustomed to driving with the activated system. It also appeared as though drivers as a group migrated away from the least and most sensitive settings over the duration of the FOT. Initially, older drivers selected the most sensitive setting with the greatest frequency, and while a decrease was evidenced over time, the trend toward driving in S6 was nevertheless maintained in P4.

Driver comments suggested that they often felt that they became more aware of traffic threats while using FCW. In cases where individuals realized that they were not sufficiently attentive to the driving task, they tended to express appreciation with regard to the FCW alert. In addition, some drivers viewed FCW providing feedback on the safety of their driving practices, enabling them to learn more about and improve their driving.

5.5.7.5 Driving Performance – ACC

The ACC driving performance objective, similar to that for FCW, assessed to what degree, and how, drivers adjusted their driving with respect to ACC. Driver performance considerations were specified with regard to four sub-objectives.[25] These included awareness, which addressed driver vigilance; vehicle control inputs, to examine driver behavior with regard to adjusting ACC settings; and trip patterns, to evaluate potential changes in travel behavior associated with ACAS-enabled driving. For reference purposes, Appendix R – Appendix T present results for ACC driving performance measures in a form parallel to that used for FCW, where possible. This includes survey item intercorrelations, descriptive statistics, and ANOVA results for analyses investigating potential age group attitudinal differences. Additionally, Appendix U presents figures that support the vehicle control inputs and trip patterns sub-objectives. Data about drivers' assessment of their driving performance with ACC are provided in the appendices cited. No detailed analyses are provided due to scope limitations.

5.6 CONCLUSIONS

This chapter assesses the subjective opinions of FOT participants with regard to overall acceptance of ACAS and its system components: FCW, to a greater extent, and ACC. Because there is no recognized approach to driver acceptance, the independent evaluation developed a framework, building on previous research, to guide the driver acceptance analyses. The five objectives of this framework structured the driver acceptance assessment.

5.6.1 Advocacy

Most generally, analysis of the advocacy survey data suggested that driver attitudes, overall, regarding acceptance of the ACC system were positive and that those regarding FCW were somewhat less so. However, it is important to consider that there was often variability in responses that was masked by summary statistics and borne out in analyses investigating age group differences, in particular.

While the majority of drivers reported moderately positive attitudes toward FCW, anywhere from 14 percent - 36 percent of younger and middle-age drivers expressed negative opinions regarding their intent to purchase FCW. Older drivers were more likely to consider purchase, on average, than younger drivers. However, it is relevant to note that older drivers made significantly greater use of the ACC system, which served to reduce the number of imminent alerts received, and in turn may have an impact on attitudes.

Drivers' reported experiences with FCW alerts appeared to be associated with attitudes regarding the system, as expressed in focus groups and during debriefings. For instance, imminent FCW alerts that served to refocus the driver on the road, or alerted him/her to "actual" perceived threats, tended to garner positive regard for the system. Additionally, the subset of drivers who experienced situations where they rated at least half of their FCW alerts as useful tended to be more consistently positive with regard to their degree of advocacy. However, participants did express concern regarding possible reactions from other drivers if, based on an alert, they responded to something not typically viewed as a threat.

[25] The driving style/risk compensation sub-objective was proposed to address the possibility that driver behavior was affected in a way that was not consistent with the goals the ACAS system. At present, the proposed analysis of variables including headway distance and driver distraction require an additional effort.

Driver acceptance of ACC, as indicated by the advocacy survey measures, is best reflected in the dearth of negative Driver Acceptance Scale scores. Although drivers varied in the extent of their advocacy regarding ACC, responses were overall quite positive. A main concern expressed during focus groups and debriefings pertained to how other drivers might react to a vehicle exhibiting unexpected deceleration, acceleration, and/or activated brake lights in the midst of free flowing expressway traffic. Participants were concerned about how to warn other drivers about non-normative or unexpected vehicle actions, even to the point of suggesting placing a placard on the FOT vehicle's roof.

A head-to-head comparison of driver acceptance regarding FCW and ACC is inequitable and should be guarded against. ACC is best classified as an "incremental" innovation, building on the familiarity that most drivers now have with CCC, is used when convenient, and at the driver's discretion. However, FCW, as a "preventive" innovation, is less familiar, unable to be deactivated and, given the relative rarity of collisions it may mitigate, called on only infrequently. Rodgers (1995) noted that preventive innovations, such as FCW, are more difficult to introduce because the time scale required in order to see benefits is much longer as compared to innovations that are considered incremental.

5.6.2 Perceived Value

Drivers offered generally positive ratings pertaining to FCW safety and understandability. The more alerts drivers received, the less comfortable they felt performing additional tasks. Anecdotally, drivers who received imminent alerts while distracted appeared to recognize the benefits of such a system. With regard to ACC, measures of perceived value were consistently positive. Among the age groups, older drivers tended to be more positive in their attitudes concerning the predictability, distraction, and safety associated with using ACC. It is challenging to ask drivers if a system such as ACC will improve their safety because drivers identify themselves as safe drivers prior to acquiring enhancements such as ACC.

5.6.3 Ease Of Use

Drivers rated the ACAS implementation easy to use in terms of its settings and controls. They reacted positively to the HUD and its display of the FCW and ACC visual elements. Their suggestions to improve ACAS included the following: reducing the number of false alarms, simplifying the visual display and refining the color palette and icons, improving FCW's reliability (including during bad weather conditions), providing user-adjustable options, such as an on-off switch and adjustments by traffic state, and altering the imminent alert timing.

When drivers received FCW alerts that were not useful, considered false, or called their attention to obvious and expected actions of other vehicles, they tended to express less positive opinions. In particular, drivers did not like to receive what they viewed as "unnecessary" FCW crash-imminent alerts and were especially annoyed when they received alerts triggered by stationary objects on the side of the road or for no obvious reason. False imminent alerts were viewed as more annoying if they occurred repeatedly. Some FOT participants drove the same roads every day and expressed annoyance at receiving recurring false alerts from the same non-threatening objects. Middle-age and younger drivers were more likely to report this type of annoyance due to their work trips.

FCW false alerts deemed to have been triggered by benign inanimate sources tended to undermine the credibility of FCW. This outcome is consistent with research on trust in automation. Madhavan (2003) reported that if an automated aid makes errors on easy tasks, people are less willing to trust and rely on it than an aid that makes errors on difficult tasks and performs easy ones reliably. One driver used the "cry wolf" analogy to describe his reaction to repeated false alerts, while agreeing that, overall, FCW had safety benefits.

5.6.4 Ease of Learning

Although drivers rated FCW as easy to learn to use in a short amount of time, many did not appear to understand how it worked, as was evident from remarks made during focus groups and debriefings. For instance, when asked during the debriefing whether changing the sensitivity settings affected the timing of crash-imminent alerts, 41 percent of the drivers responded that manipulating the FCW sensitivity settings altered the imminent alert timing, which, in reality, was fixed.

Misunderstanding turned to frustration when drivers attempted to purposefully trigger an imminent FCW alert and were not able to do so. In the process, individuals sometimes pushed themselves to close the distance gap to the vehicle ahead, without realizing that relative velocity was also a factor. Consequently, some drivers were uncertain about exactly what activated their FCW alerts. They felt that the system alerted too late, because their ineffective attempts at testing FCW resulted in their vehicle ending up too close to the lead vehicle for their own comfort. The assumption made by some drivers, that FCW alerted based solely on distance to the vehicle ahead, may have been inadvertently and partially fostered by the system's visual representation of distance to the lead vehicle, a set of waves that some drivers referred to as "car lengths."

Nevertheless, many drivers volunteered that using FCW helped them to learn about their driving and reinforce good habits. Drivers realized that FCW was intended to mitigate driving risks that, on an individual basis, occur infrequently. As a result, when asked, drivers tended to identify feedback about their driving as a safety benefit.

5.6.5 Driving Performance

Drivers adjusted FCW controls fairly frequently, particularly when they first interacted with the system; however, the incidence of adjustments tapered off during the three weeks of ACAS-enabled driving, indicating a learning effect. Time of day appeared to be a factor, in that more frequent HUD adjustments were made during night driving.

Drivers evaluated themselves as more responsive to, and aware of, traffic when they used FCW. This may be attributed to the way FCW operates, as it explicitly called their attention to potential threats. However, drivers did not describe themselves as relying too much on FCW. Comments provided during focus groups and debriefings also supported the notion that drivers were not over-reliant, rather that their awareness of traffic threats increased when FCW was operating.

In conclusion, driver acceptance findings suggest a mixed response to the FCW system by FOT participants as a group. The data indicate that, when FCW alerted drivers to actual threats, their opinion of the FCW system was more positive. However, drivers did not experience many actual threats. The more tentative opinions may result from receiving false alerts that were deemed excessive and/or recurring. In general, drivers viewed ACC very positively, despite expressing concerns about its ungainly acceleration and braking, as well as some degree of uncertainty about brake light activation.

6. CONCLUSIONS

The ACAS FOT program was overall successful in building a production-intent rear-end crash avoidance system on-board a passenger vehicle. This system integrated state-of-the-art technologies that performed FCW and ACC functions. In addition, this program produced a reliable small fleet of ACAS-equipped vehicles that were used by lay people in an FOT as their own personal cars to experience ACAS functions under different naturalistic driving conditions. Given the scope of the program in terms of its duration and size of the vehicle fleet, the FOT was also successful in building a knowledge base about driver performance with and without ACAS assistance from 97 percent of the distance traveled during the FOT and about drivers' opinions of the ACAS. Based on FOT and system characterization test data, the independent evaluation was able to delineate the strengths and limitations of ACAS capability, gauge driver acceptance, and assess its safety impact. The FOT provided a first opportunity to obtain real world feedback from drivers about their tolerance of nuisance and false crash-imminent alerts. Moreover, both positive and negative safety consequences of ACAS use were highlighted. Indicators of positive safety impact outweighed those of negative safety impact. The independent evaluation was somewhat successful in projecting potential safety benefits of ACAS by combining FOT data with national crash statistics, which were constrained by short-term use of ACAS by relatively few subjects. Main results of the independent evaluation are reiterated below, followed by general comments reflecting on past and future FOTs of crash avoidance systems.

6.1 MAIN RESULTS

6.1.1 Exposure

A total of 66 subjects drove about 163,000 km during the FOT. Each subject had an instrumented vehicle for a period of four weeks: ACAS was disabled during the first week and later enabled for the following three weeks. About 97 percent of the total VDT or 158,000 km reflected valid trip data used in evaluation analyses:

- The ACAS-Disabled and ACAS-Enabled test periods comprised respectively 23 percent (36,000 km) and 77 percent (122,000 km) of the total valid VDT.
- CCC was engaged in 21 percent (7,000 km) of VDT in the ACAS-Disabled test period. On the other hand, ACC was engaged in 36 percent (44,000 km) of VDT in the ACAS-Enabled test period, thus, ACC use was about 1.8 times more than CCC. FCW was active in 53 percent (64,000 km) of VDT in the ACAS-Enabled test period.
- Older subjects drove the most distance in both test periods: 36 percent of VDT in ACAS-Disabled test period and 38 percent of VDT in ACAS-Enabled test period. Moreover, older subjects were the highest users of cruise control: 36 percent of their ACAS-Disabled VDT and 51 percent of their ACAS-Enabled VDT was in ACC. However, the largest ACC to CCC use ratio was observed at 2.6 for younger subjects.
- About 84 percent and 87 percent of VDT, respectively, in the ACAS-Disabled and ACAS-Enabled test periods were accumulated at vehicle speeds greater than or equal to 35 mph.

CCC use comprised 24 percent of the ACAS-Disabled VDT at that speed range, while ACC use accounted for 42 percent of the ACAS-Enabled VDT in the same speed range. CCC or ACC use was only 1 percent of the VDT at vehicle speeds below 35 mph.

- About 51 percent and 55 percent of VDT respectively in the ACAS-Disabled and ACAS-Enabled test periods were driven on freeways. CCC use comprised 33 percent of the ACAS-Disabled VDT on freeways, while ACC use accounted for 56 percent of the ACAS-Enabled VDT on freeways. On non-freeways, CCC and ACC comprised respectively 6 percent and 12 percent of VDT.
- Over 90 percent of the VDT was driven in clear weather during the FOT. CCC was used in 15 percent of the adverse weather VDT in the ACAS-Disabled test period, as opposed to 20 percent of this VDT by ACC in the ACAS-Enabled test period. FCW was active in 52 percent of the VDT in clear weather and arose to 68 percent of the VDT in adverse weather due to lower engagement rate of ACC.
- Over 73 percent of the VDT was driven in lighted conditions during the FOT. There was no noticeable change in CCC use rate between lighted and dark conditions (≈ 20%). There was a slight reduction in ACC use rate from 37 percent of VDT in lighted conditions to 32 percent of VDT in dark conditions. As a result, FCW active rate was slightly higher in dark conditions than in lighted conditions.
- About 67 percent of the VDT in the ACAS-Disabled test period was driven in low level of traffic, which was similar to the ACAS-Enabled test period (68%). CCC use rate dropped from 23 percent of the VDT in low traffic to 13 percent of the VDT in moderate traffic. On the other hand, ACC use rate fell from 40 percent to 30 percent of the VDT respectively in low and moderate traffic levels. Consequently, FCW active rate jumped from 51 percent to 60 percent of the VDT respectively in low and moderate traffic levels.
- The most sensitive FCW sensitivity setting, S6, was selected in 24 percent of the overall VDT in the ACAS-Enabled test period. Setting S3 followed at 22 percent of the VDT. The least sensitive setting, S1, was ranked third at 19 percent of the VDT. During the second half of the VDT in the ACAS-Enabled test period, S3 became the most widely selected setting and S6 dropped to second.
- The 2-second time gap was the most chosen ACC gap setting, accounting for 31 percent of the overall VDT driven with ACC, followed in descending order by 1.4- and 1-second gap settings. During the second half of the VDT in the ACAS-Enabled test period, the same order of gap settings remained except for a lower use rate of 2-second time gap. Finally, FOT subjects tended to use higher ACC gap settings on non-freeways than on freeways.

6.1.2 System Capability

The analysis of 8-second video episodes triggered by the auditory crash-imminent alerts revealed the following:

- Subjects received 6.2 crash-imminent alerts per 1,000 km traveled overall during the FOT. However, this alert rate was 21.8 crash-imminent alerts per 1,000 km traveled when subjects were driving at vehicle speeds between 25 and 35 mph.
- In-path targets triggered 3.5 crash-imminent alerts per 1,000 km traveled. The majority of these alerts, or 3.4 alerts per 1,000 Km, was attributed to moving targets. Stationary vehicles triggered 14 alerts or 2.6 percent of all in-path target alerts – 2 of these were declared by the

target selection algorithm as seen moving prior to stopping. About 0.4 crash-imminent alert per 1,000 km traveled was issued for moving in-path targets due to host vehicle changing lanes, turning, or passing behind an in-path moving vehicle. In contrast, about 1.5 moving in-path target alerts per 1,000 km traveled were caused by a lead vehicle changing lanes, turning, or making left turn across the path of the host vehicle.

- Out-of-path targets caused 2.7 crash-imminent alerts per 1,000 km traveled. The majority of these alerts, or 2.3 alerts per 1,000 km traveled, were due to stationary targets. About 75 percent of these stationary out-of-path alerts occurred at vehicle speeds over 35 mph.
- In response to crash-imminent alerts for in-path targets during the ACAS-Enabled test period, subjects did nothing or simply eased up on the throttle in close to 40 percent of the episodes. Subjects braked in about 55 percent of the episodes. About 55 percent of the subjects had an average reaction time of 0.5 seconds or less after an in-path target alert. This suggests that subjects were attentive or were about to respond to the situation ahead when they received the crash-imminent alerts.
- The driver appeared to be distracted, within 5 seconds before the crash-imminent alert, in 38 percent of all alert episodes based on an analysis of recorded facial images.
- Driver eyes were away from the road ahead for at least 1.5 seconds before the crash-imminent alert in 3 percent of all alert episodes.
- Based on the judgment of the independent evaluator, FOT subjects received about 1.8 “true” alerts per 10,000 km traveled for a potential impending rear-end collision.

The independent evaluator conducted a 7-hour system characterization test to supplement the FOT data, which yielded the following general results:

- The forward-looking sensor suite was late in detecting 17 percent of the in-path targets, intermittently detected 28 percent of the targets, and lost detection of 22 percent of the targets on curves with radius below 500 m. In contrast, target detection loss was about 8 percent of all in-path targets on curves with radius over 500 m. Also on these curves, late detection and intermittent detection rates were estimated respectively at 14 percent and 24 percent of all in-path targets. It should be noted that late detection (defined here by a speed-independent 100/70 m criterion) does not necessarily imply lateness in warning availability for these targets.
- The threat assessment algorithm, correctly, did not generate crash-imminent alerts for 98 percent of the stationary out-of-path targets and for 99.5 percent of driving situations where the lead vehicle is traveling on a curve in the adjacent lane. Also, the system did not generate crash-imminent alerts for 98 percent of the cases when the host vehicle passed another vehicle or changed lanes and when the lead vehicle turned ahead. Overhead bridges or signs were all rejected by the system during the characterization test.
- The median time delay for ACC to release the auto-brakes after the lead vehicle is no longer a threat (range rate ≥ 0) was about 2 seconds.

6.1.3 Safety Impact

The analysis of safety impact focused on ACAS as an integrated package of FCW and ACC, and did not attempt to separate ACC and FCW effects because the two functions were coupled in the FOT vehicle and will typically be bundled together in production vehicles. Separate analyses of FCW and ACC functions were conducted by UMTRI and GM (UMTRI and GM, 2005).

6.1.3.1 Driving Conflict Analysis

Impact of New Vehicle Familiarity and ACAS Experimentation

- Period 2 (second half of VDT with ACAS disabled) has slightly higher conflict exposure rates than Period 1 (first half of VDT with ACAS disabled); however, it was concluded that Periods 1 and 2 are sufficiently similar that they should be combined for analyses of driver exposure to conflicts. The slightly higher rates in Period 2 are attributed to increased familiarization with the ACAS vehicle resulting in less conservative driving behavior.
- Period 3 (first half of VDT with ACAS enabled) shows a consistent greater exposure to conflicts than Period 4 (second half of VDT with ACAS enabled) between all driver and conflict-level categories. These results strongly indicate that drivers' behavior changed between Periods 3 and 4. The change may be attributed to a combination of driver learning and experimentation with ACAS. Based on these results, Period 3 was not considered representative of long-term driving behavior and was not included in analyses of driver exposure to conflicts.

Impact of ACAS on Driver Exposure to Conflicts

- The effect of ACAS is to shift the distribution of conflict rates among all drivers to a lower average; e.g., no subjects with ACAS enabled have rates greater than 70 conflicts per 100 Km; whereas, 5 percent of subjects with ACAS disabled have rates greater than 70 conflicts per 100 Km.
- The results indicate that use of ACAS will reduce exposure to conflicts for drivers overall under the following conditions:
  - Light
  - Freeways
  - Clear weather
  - Moderate traffic
  - Speeds greater than or equal to 35 mph
- ACAS also appears to have some ability to reduce exposure to conflicts in conditions of dark, non-freeways, adverse weather, and low and heavy traffic levels; however, the results are not reliable.
- The results also suggest that that ACAS has an ability to reduce conflict exposure for a wide range of traffic levels; however, this ability might decline at higher traffic levels.
- At speeds less than 25 mph, ACAS is essentially inactive and has no impact on exposure to conflicts.

ACAS Effectiveness in Reducing Exposure to Conflicts Based on Aggregate Data

- The exposure effectiveness (EE) results indicate that ACAS is about 21 percent effective in reducing the exposure of drivers to rear-end pre-crash conflicts for all drivers and driving conditions. This overall exposure effectiveness of ACAS is consistent regardless of the conflict intensity level metric used.
- The EE of ACAS is positive for the different age groups. Using low-intensity conflicts as the metric for EE, the following results were obtained:
  - EE is highest among *female* (30%) and *older* (27%) drivers
  - EE is lowest among *male* (12%) drivers
  - EE increases with age group from *younger* (14%) to *middle-age* (23%) to *older* (27%) drivers
- The EE of ACAS is positive for the different driving conditions of ambient light, road type, weather, and traffic level for *all* drivers. Again, using low-intensity conflicts as the metric for EE for *all* drivers, the following results were obtained:
  - EE for light (24%) and dark (11%)
  - EE for freeways (25%) and non-freeways (7%)
  - EE for clear (21%) and adverse (19%) weather
  - EE for low (17%), moderate (19%), and heavy (12%) traffic levels
- The analysis of exposure to conflicts by vehicle speed revealed that the EE of ACAS was positive only for speeds at and above 35 mph (25%). The speed analysis concluded that the results for speeds less than 25 mph are not applicable to ACAS since the system essentially does not function at these speeds. It was also concluded that FCW has negligible EE for speeds between 25 mph and 35 mph. However, for speeds of 35 mph and above, ACC appears to have a substantial level of EE. Freeway driving seems to be the environment where ACAS has the highest level of EE.
- The following combinations of subject group and driving condition produced EE values, for all conflict intensity levels, that varied considerably from the general results:
  - *Younger* drivers have higher EE values for dark conditions (e.g., 20% for low-intensity conflicts).
  - *Older* drivers have lower EE values for freeway driving (e.g., 2% for low-intensity conflicts).
  - *Younger* drivers have lower, negative EE values for non-freeway driving (e.g., -10% for low-intensity conflicts).
  - *Older* and *younger* drivers have atypically low EE values for adverse conditions (e.g., 14% for *older* drivers and -19% for *younger* drivers for low-intensity conflicts).
  - *Middle-age* drivers have higher EE values for adverse conditions (e.g., 45% for low-intensity conflicts).
  - *Younger* drivers have atypically low, negative EE values for driving in heavy traffic (e.g., -15% for low-intensity conflicts).

  The above considerations suggest that the unusual results obtained for some subject groups and conditions might be explained, at least in part, by limitations in the data. The results for particular subject groups and conditions should, therefore, be interpreted with some caution.

ACAS Effectiveness in Reducing Exposure to Conflicts Based on Driver Average Statistics

- For all driving conditions, the highest EE is 14 percent for low-intensity conflicts and the lowest EE value is 8 percent for high-intensity near-crashes. There is no statistically significant difference in these values, however. These EE values, based on driver averages, are consistently lower than the corresponding population average value of about 21 percent.
- There is no consistency in the variation of EE by conflict intensity level for the various conditions investigated. For all the conditions considered, the EE values are positive and range between a minimum and maximum value by conflict intensity level as follows:
  - Light – min. 8 percent, high-intensity near-crashes; max. 14 percent, low-intensity conflicts
  - Freeways – min. 12 percent, low-intensity conflicts; max. 22 percent, high-intensity near-crashes
  - Clear – min. 11 percent, high-intensity near-crashes; max. 13 percent, low-intensity conflicts
  - Moderate traffic – min. 14 percent, low-intensity conflicts; max. 16 percent, high-intensity near-crashes
  - Speeds greater than or equal to 35 mph – min. 13 percent, high-intensity near-crashes; max. 16 percent, low-intensity conflicts

Exposure to Rear-End Pre-Crash Scenarios

- Based on aggregate data of all drivers, the breakdown of driving conflicts by specific scenarios was similar overall between the ACAS-Disabled and ACAS-Enabled (Period 4) test periods. Distributions of LVS, LVM, and LVD scenarios were observed to be similar between the two test periods. Moreover, driver/vehicle response to each of the three scenarios was similarly distributed across the two test periods and the two levels of conflict intensity. In addition, the ratio of near-crashes per conflict also remained the same between the two test periods at each of the two levels of conflict intensity.
- Driver exposure was investigated for 108 combinations of scenarios (4 conflict levels $\times$ 3 dynamic scenarios $\times$ 3 driver responses $\times$ 3 speed bins). Statistically significant difference of exposure between ACAS-Disabled and ACAS-Enabled test periods was found in only 7 of the 108 combinations. The remaining 101 combinations had no statistically significant difference or fewer than 8 subjects per combination. The reader is cautioned about the lack of robustness in the ACAS-Disabled versus ACAS-Enabled effects measured since only 7 out of the 108 tests performed were found to be statistically significant. These 7 effects might be spurious effects. In 6 of these 7 scenarios, ACAS was effective in reducing exposure to driving conflicts at travel speeds greater than or equal to 35 mph. About 54 percent of the VDT at these travel speeds during the ACAS-Enabled test period was driven with active FCW compared to 42 percent with ACC. On the other hand, ACAS was effective in reducing exposure to driving conflicts with statistical significance in only one scenario at travel speeds between 25 and 35 mph. FCW was active in 73 percent of the VDT at this speed range, as opposed to only 1 percent by ACC and 26 percent in manual control.

Response to Rear-End Pre-Crash Scenarios

Overall, driver response to driving conflicts was similar between ACAS-Disabled and ACAS-Enabled (Period 4) test periods with few exceptions.

- The analysis of response initiation using TTC (Range/Range Rate) for LVS and LVM scenarios, and TH (Range/Vehicle Speed) for the LVD scenario, revealed only 6 statistically significant ($p \leq 0.15$) differences in mean values between the two driving modes – 6 out of 108 combinations of scenarios (4 conflict levels × 3 dynamic scenarios × 3 driver responses × 3 speed bins). There were only two statistically significant ($p \leq 0.05$) differences in mean TTC values between the two driving modes in response to LVM scenarios at speeds below 35 mph. The reader is again cautioned about the lack of robustness in the ACAS-Disabled versus ACAS-Enabled effects measured since very few cases out of many tests performed were found to be statistically significant. These might be spurious effects. The examination of TTC for the LVD scenario, taking into account the deceleration level of the lead vehicle, identified statistically significant differences ($p < 0.05$) between the means of the two test periods at vehicle speeds greater than or equal to 35 mph. However, this difference was only 0.1 seconds or less in each of the four conflict-intensity levels.
- The analysis of response intensity measures identified few cases where differences were found between ACAS-Disabled and ACAS-Enabled (Period 4) test periods. These differences however were very small. There were only three statistically significant ($p \leq 0.05$) differences in mean values of minimum TTC between the two test periods – three out of 72 combinations (4 conflict levels × 3 dynamic scenarios × 3 driver responses × 2 speed bins). Moreover, there were 7 statistically significant ($p \leq 0.05$) differences in mean values of peak and average deceleration between the two test periods – 7 out of 144 combinations (4 conflict levels × 3 dynamic scenarios × 3 driver responses × 2 speed bins × 2 measures).

Safety Benefits Estimation

ACAS, as an integrated system of FCW and ACC functions, has the potential to prevent about 6 to 15 percent of all rear-end crashes depending on the source of crash data used for safety benefits estimation. This system effectiveness ranges between 3 and 26 percent according to 95 percent confidence bounds. By averaging estimates from the four sources of crash data, ACAS might prevent about 10 percent of all rear-end crashes with variability between 3 and 17 percent based on 95 percent confidence bounds. As a result, ACAS might avoid between approximately 133,000 and 687,000 rear-end crashes in the United States annually. About 17 percent of these benefits based on travel speed rear-end crash data are accrued from response to driving conflicts at vehicle speeds below 25 mph, 20 percent of these benefits are attributed to less exposure to driving conflicts at vehicle speeds between 25 and 35 mph, and the remaining 63 percent of these benefits are also attributed to less exposure to driving conflicts at speeds greater than or equal to 35 mph. On the other hand, 9 percent of the benefits based on speed limit rear-end crash data are due to vehicle speeds between 25 and 35 mph while the remaining 91 percent are found at speeds greater than or equal to 35 mph. It should be noted that FCW was active in only 4 percent of the VDT below 25 mph. At speeds between 25 and 35 mph, FCW and ACC accounted respectively for 73 percent and 1 percent of all VDT at this speed range. FCW and ACC accounted respectively for 54 percent and 42 percent of all VDT at speeds greater than or equal to 35 mph. These projections of safety benefits are conservative estimates and a "best guess" given the nature of data collected during this FOT. There were no crashes in this FOT, and subjects generally experienced few severe near-crashes.

6.1.3.2 Severe Near-Crash Analysis

- ACAS has the potential to reduce the number of severe near-crashes per 1,000 km traveled by 10 percent and 20 percent respectively for low-and high-intensity levels based on aggregate FOT data from all subjects. FCW sensitivity settings did not affect the frequency rate of severe near-crashes. Similarly, ACC gap settings did not have an impact on the frequency rate of low-intensity severe near-crashes. However, 1-second gap setting was prevalent in high-intensity severe near-crashes. This result must be taken with caution since there were very few high-intensity severe near-crashes with ACC during the FOT.
- The observation of video episodes triggered by crash-imminent alerts identified 24 events where ACAS assisted the driver in potentially preventing a crash, near-crash, or heavy braking. For 11 events, the driver was clearly distracted and unaware of the events ahead. ACAS alerted the drivers of the lead vehicle braking (in one case the lead vehicle was stopped) and the driver responded to the alert by braking to avoid a crash. For 13 events, the driver appeared to be looking at the road ahead; however, the driver failed to respond to the event prior to being warned by ACAS. In 11 of these 13 cases, the lead vehicle braked and the driver responded by braking only after being warned by ACAS. In one event, the lead vehicle was stopped and in another case the driver's response to the ACAS warning was to brake and steer. For all 24 cases, the drivers' responses to ACAS warnings were relatively severe with a mean braking rate of about 4.9 m/s^2 (about 0.5 g).

6.1.3.3 Driver Impact Analysis

No unintended negative consequences were observed by examining travel speed, time headway, lane position, distraction, and eyes-off-road. These results were based on a short-term exposure with ACAS. The analysis of driver adaptation and risk compensation would require longer exposure periods than afforded by this FOT.

6.1.4 Driver Acceptance

Driver acceptance findings suggest a mixed response to the FCW system by FOT participants as a group. The data indicate that, when FCW alerted drivers to actual threats, their opinion of the FCW system was more positive. However, drivers did not experience many actual threats. The more tentative opinions may result from receiving false alerts that were deemed excessive and/or recurring. In general, drivers viewed ACC very positively, despite expressing concerns about its ungainly acceleration and braking, as well as some degree of uncertainty about brake light activation to alert vehicles behind.

The results from the analysis of driver acceptance were mostly based on the subjective opinions of FOT participants with regard to overall acceptance of ACAS and its system components: FCW, to a greater extent, and ACC. The assessment of driver acceptance was structured on five objectives as highlighted below.

6.1.4.1 Advocacy

- The analysis of the advocacy survey data suggested that driver attitudes, overall, regarding acceptance of the ACC system were positive and that those regarding FCW were somewhat less so. However, it is important to consider that there was often variability in responses that was masked by summary statistics and borne out in analyses investigating age group differences.
- Anywhere from 14 percent-36 percent of younger and middle-age drivers expressed negative opinions regarding their intent to purchase FCW. Older drivers were more likely to consider purchasing FCW, on average, than younger drivers. However, it is relevant to note that older drivers made significantly greater use of the ACC system, which served to reduce the number of imminent alerts received, and in turn may have affected attitudes.
- Drivers' reported experiences with FCW alerts appeared to be associated with attitudes regarding the system, as expressed in focus groups and during debriefings. For instance, imminent FCW alerts that served to refocus the driver on the road, or alerted him/her to "actual" perceived threats, tended to garner positive regard for the system. Additionally, the subset of drivers who experienced situations where they rated at least half of their FCW alerts as useful tended to be more consistently positive with regard to their degree of advocacy. However, participants did express concern regarding possible reactions from other drivers if, based on an alert, they responded to something not typically viewed as a threat.
- Driver acceptance of ACC, as indicated by the advocacy survey measures, is best reflected in the dearth of negative Driver Acceptance Scale scores. Although drivers varied in the extent of their advocacy regarding ACC, responses were overall quite positive. A main concern expressed during focus groups and debriefings pertained to how other drivers might react to a vehicle exhibiting unexpected deceleration, acceleration, and/or activated brake lights in the midst of free flowing expressway traffic. Participants were concerned about how to warn other drivers about non-normative or unexpected vehicle actions, even to the point of suggesting placing a placard on the FOT vehicle's roof.
- A head-to-head comparison of driver acceptance regarding FCW and ACC is inequitable and should be guarded against. ACC is best classified as an "incremental" innovation, building on the familiarity that most drivers now have with CCC, is used when convenient, and at the driver's discretion. However, FCW, as a "preventive" innovation, is less familiar, unable to be deactivated and, given the relative rarity of collisions it may mitigate, called on only infrequently. Rodgers (1995) noted that preventive innovations, such as FCW, are more difficult to introduce because the time scale required in order to see benefits is much longer as compared to innovations that are considered incremental.

6.1.4.2 Perceived Value

- Drivers offered generally positive ratings pertaining to FCW safety and understandability. The more alerts drivers received, the less comfortable they felt performing additional tasks. Anecdotally, drivers who received imminent alerts while distracted appeared to recognize the benefits of such a system.
- With regard to ACC, measures of perceived value were consistently positive. Among the age groups, older drivers tended to be more positive in their attitudes concerning the

predictability, distraction, and safety associated with using ACC. It is challenging to ask drivers if a system such as ACC will improve their safety because drivers identify themselves as safe drivers prior to acquiring enhancements such as ACC.

6.1.4.3 Ease of Use

- Drivers rated the ACAS implementation easy to use in terms of its settings and controls. They reacted positively to the HUD and its display of the FCW and ACC visual elements. Their suggestions to improve ACAS included the following: reducing the number of false alarms, simplifying the visual display and refining the color palette and icons, improving FCW's reliability (including during bad weather conditions), providing user-adjustable options, such as an on-off switch and adjustments by traffic state, and altering the imminent alert timing.
- When drivers received FCW alerts that were not useful, considered false, or called their attention to obvious and expected actions of other vehicles, they tended to express less positive opinions. In particular, drivers did not like nuisance FCW crash-imminent alerts and were especially annoyed if triggered by stationary objects on the side of the road or for no obvious reason. False imminent alerts were viewed as more annoying if they occurred repeatedly. Some FOT participants drove the same roads every day and expressed annoyance at receiving recurring false alerts from the same non-threatening objects. Middle-age and younger drivers were more likely to report this type of annoyance due to their work trips.
- FCW false alerts deemed to have been triggered by benign inanimate sources tended to undermine the credibility of FCW. This outcome is consistent with research on trust in automation. Madhavan (2003) reported that if an automated aid makes errors on easy tasks, people are less willing to trust and rely on it than an aid that makes errors on difficult tasks and performs easy ones reliably. One driver used the "cry wolf" analogy to describe his reaction to repeated false alerts, while agreeing that, overall, FCW had safety benefits.

6.1.4.4 Ease of Learning

- Although drivers rated FCW as easy to learn to use in a short amount of time, some did not appear to understand how it worked, as was evident from remarks made during focus groups and debriefings. For instance, when asked during the debriefing whether changing the sensitivity settings affected the timing of crash-imminent alerts, 41 percent of the drivers responded that manipulating the FCW sensitivity settings altered the crash-imminent alert timing, which, in reality, was fixed.
- Misunderstanding turned to frustration when drivers attempted to purposefully trigger an imminent FCW alert and were not able to do so. In the process, individuals sometimes pushed themselves to close the distance gap to the vehicle ahead, without realizing that relative velocity was also a factor. Consequently, some drivers were uncertain about exactly what activated their FCW alerts. They felt that the system alerted too late, because their ineffective attempts at testing FCW resulted in their vehicle ending up too close to the lead vehicle for their own comfort. The assumption made by some drivers, that FCW alerted based solely on distance to the vehicle ahead, may have been inadvertently and partially fostered by the system's visual representation of distance to the lead vehicle, a set of waves

that some drivers referred to as "car lengths." Nevertheless, many drivers volunteered that using FCW helped them to learn about their driving and reinforce good habits. Drivers realized that FCW was intended to mitigate driving risks that, on an individual basis, occur infrequently.

6.1.4.5 Driving Performance

- Drivers adjusted FCW controls fairly frequently, particularly when they first interacted with the system; however, the incidence of adjustments tapered off during the three weeks of the ACAS-Enabled test period, indicating a learning effect. Time of day appeared to be a factor, in that more frequent HUD adjustments were made during night driving.
- Drivers evaluated themselves as more responsive to, and aware of, traffic when they used FCW. This may be attributed to the way FCW operates, as it explicitly called their attention to potential threats. However, drivers did not describe themselves as relying too much on FCW. Comments provided during focus groups and debriefings also supported the notion that drivers were not over-reliant, rather that their awareness of traffic threats increased when FCW was operating.

6.2 GENERAL COMMENTS

General comments are made about the ACAS state-of-the-art status, FOT design, supplementary tests, learning period and long-term effects of ACAS, and analysis of safety benefits based on results and observations by the independent evaluation.

6.2.1 System Design

The FCW function of ACAS incorporates state-of-the-art sensor technologies for short-term deployment plans (1 – 2 years). However, improved signal processing and threat assessment algorithms would enhance FCW alert efficacy by recognizing slower lead vehicles transitioning from the path of the host vehicle to out of its path. This event generated numerous unnecessary crash-imminent alerts during the FOT, and even forced the ACC to automatically brake in response to lead vehicles exiting the freeway. Stationary out-of-path targets were mostly the source of false crash-imminent alerts. The GM Consortium identified some remedies that seemed to be worthy of consideration in dealing with this particular problem, including the disregard of the closest in-path stationary (CIPS) target flag by the target selection algorithm. The remedy is for the threat assessment algorithm to rely completely on the closest in-path moving (CIPV) target flag that accounts only for moving vehicles and for stopped vehicles tracked by the radar to be moving prior to stopping. This approach would increase system credibility and driver acceptance since false alarms to these stationary (never before seen moving) objects would be removed. The examination of video episodes revealed a few cases where CIPS-tagged vehicles triggered the crash-imminent alerts, mainly at intersections. Thus, a concern is raised regarding the elimination of the CIPS flag from the threat assessment algorithm.

The analysis of crash-imminent alerts also showed that increasing the threshold operating speed of FCW over 25 mph would not make any significant impact on false and nuisance alerts (> 50%

reduction). To boost driver acceptance of FCW at the expense of some limited safety benefits, it is recognized that a tradeoff must be made between alert rates and the operating envelope and sensitivity of FCW. The ACAS incorporated many subsystems to identify the path of the host vehicle, and track and select targets at long ranges in the path of the host vehicle. One of these subsystems is GPS/GIS mapping to help identify the path of the host vehicle and make in-path target selection. It appears that this feature had little impact on crash-imminent alerts as was evident from the system characterization test that was conducted in the Boston metropolitan area. The map information was not available there and the alert rate did not seem to differ from the rates observed in Michigan by FOT subjects with available map data. Given the cost of such a feature, the ACAS could perform without it unless, of course, this feature is also a part of a navigation device or a curve speed warning system. Moreover, it is recommended that human factors tests be conducted to obtain user feedback on the usability of some of the HUD icons presented to FOT subjects by the ACAS. This recommendation is based on qualitative comments made by FOT subjects during debriefings and focus group meetings. It should be noted that only the cautionary and crash-imminent alert icons of FCW were tested prior to building the pilot vehicle for the FOT. Survey and subjective data from FOT subjects and system characterization test data suggest that even better acceptance of ACC would be achieved with improved automatic acceleration and deceleration characteristics. The results of the independent evaluation suggest marginal acceptance of FCW and better acceptance of ACC as well as some positive safety indicators that warrant deployment at least at low-level market penetration.

Additional research may be necessary to reduce the rates of false and nuisance alerts of FCW and to enhance the timing of crash-imminent alerts for mid-term deployment plans (2 – 5 years). Proceeding with further FCW enhancement activities may depend on successful results (driver satisfaction, units sold, and positive safety impact) from short-term deployment and good market penetration levels. The recognition of the driver state would improve FCW alert timing, ranging from low complexity to identify the location of driver face (facing forward or sideways), medium complexity to track the eyes of the driver, to high complexity to measure the cognitive load of the driver. This research could build on current efforts undertaken in the SAVE-IT program (Witt et al., April 2004). Another FCW improvement might be achieved with the use of digital image processing of the forward scene to discern the objects that the radar is tracking. This might reduce the rates of crash-imminent alerts due to stationary out-of-path targets.

Vehicle to vehicle communication is suggested to improve the forward-looking sensing capability of FCW for long-term deployment plans (> 5 years). This research would build upon prior work in vehicle safety communications (Crash Avoidance Metrics Partnership, May 2004). This enhancement would call upon lead vehicles to transmit information about their state to following vehicles, given wider deployment of FCW in the vehicle fleet. The transmission of relevant information about the lead vehicle such as its dynamic state (stopped in traffic, moving at constant speed, decelerating, or accelerating), brake initiation, and value of its acceleration/ deceleration might improve the timing of crash-imminent alerts, thus reducing the rates of "too late" alerts (increasing crash prevention potential) as well as "too early" alerts (decreasing nuisance alert rate). It should be noted that this current ACAS estimates the value of lead vehicle acceleration/deceleration in support of the timing algorithm. Proceeding with such system improvement activity might depend on significant market penetration rates of FCW in the vehicle fleet during the next 5 to 10 years.

6.2.2 FOT Design

The FOT should involve as many subjects as possible given the limited number of instrumented or equipped vehicles and FOT duration. The use of more subjects (greater than 66 participants) might improve the estimates of distributions for the different measures of performance and might increase exposure to the various driving conditions. The engagement of 120 subjects would be feasible if each subject had an instrumented vehicle for a test period of three weeks. The FOT scope would then amount to 360 car-weeks. This scope is less than the ACAS FOT that totaled 369 car-weeks from testing the three versions of ACAS – Algorithm A= 15 subjects × 4 weeks, Algorithm B= 15 subjects × 3 weeks, and Algorithm C= 66 subjects × 4 weeks. The three-week test period would be sufficient based on the conflict results of the ACAS FOT, using the defined measures of low-and high-intensity conflict and near-crashes. One week would be dedicated to baseline data collection and two weeks would be allocated to driving with enabled crash countermeasure systems. One week with system enabled would be devoted to subjects learning and becoming familiar with the system. To limit the experimentation and learning period of the system to less than one week, it is recommended that subjects be given training for a time period slightly longer than in the ACAS FOT (extended 2 to 4 hours of driving accompanied by a researcher). Driver performance with the system would be observed in the second week of the system-enabled period. The analysis would then compare driver performance without the system in the first baseline week to driver performance with the system in the third week. In contrast, increased exposure (e.g., having some FOT subjects experience the system for a prolonged period of time, such as 6-8 weeks) would serve to increase the number of close calls and raise the likelihood of the driver experiencing a crash-imminent alert perceived as “highly valuable.” This alternative would significantly decrease the number of FOT subjects (≈ 40) given the scope of this type of FOTs, unless more resources were dedicated to expanding the FOT. Moreover, it is uncertain whether the prolonged exposure time (≤ 8 weeks) would result in more close calls.

Based on exposure results of the ACAS FOT, future FOT subject recruits should be high-mileage drivers since the test period is relatively short given the cost of instrumented vehicles. The more the mileage accumulated the more is the exposure to driving conflicts, which affects the analysis of safety impact. This recommendation, however, would reduce the generalizability of the findings since it would exclude a portion of the general public who drives fewer miles, such as the older population. This trade off should be further examined. To ensure that they accumulate as much mileage as possible given the value of the car-week allocated, subjects should be tracked and pulled out of the FOT if they did not use the equipped vehicle. It is recognized that this action would add a cost to the logistics of running the FOT. Subjects should remain in the three age groups representing the younger driver between 20 and 30 years old, the middle-age drivers between 40 and 50 years old, and the older between 60 and 70 years old. It would also be helpful to recruit FOT subjects who usually have travel patterns under driving conditions that are targeted by the crash countermeasure systems. For instance, rear-end crash countermeasures address conditions of moderate to heavy traffic and more following vehicle situations while, on the other hand, lane departure warning systems target drivers who are most likely tired (nighttime conditions) or inattentive on long trips typically with a low level of traffic.

In addition, subjects "at risk" should be recruited based on information derived from crash data or studies about drivers of higher involvement in crashes targeted by the countermeasures (e.g., younger drivers with many traffic violations).

It is important that crash countermeasure functions dealing with similar dynamic scenarios be treated in separate vehicles in the FOT. It was difficult to isolate the effects of ACC from FCW in the ACAS FOT since these two functions were integrated by design.

6.2.3 Supplementary Tests

Additional tests are recommended to supplement the data collected from the FOT. Due to the limitations of data used in the analysis of safety benefits, a test track or driving simulator experiment would be needed to gauge the response of subjects to severe driving conflicts or near-crashes with and without assistance by the crash countermeasures. It should be noted that differences were observed in maneuver onset and peak conflict behavior during last-second barking/steering maneuvers between the National Advanced Driving Simulator (NADS) and closed-course test track tests (Curry et al., 2005). This type of experiment would generate data about the swiftness of reaction and intensity of response to these severe events, which feed into the safety benefits estimation equation. This was a weakness in the ACAS FOT because the subjects rarely encountered events of severe nature under similar initial conditions. This experiment could be a part of the design and development cycle to improve system performance. To avoid a false start of the FOT that led subsequently to three phases of testing in the ACAS FOT, it is recommended that a small FOT be conducted prior to the regular FOT with few subjects in a similar test period so as to try out all the data collection instruments and logistics. This would be a dress rehearsal for the FOT. The results could also be used to modify the scope of the planned FOT, make changes to objective and subjective data collection, and make minor changes to the system as needed and thus used as another part of the design and development cycle of the system. In addition, the independent evaluation should plan on longer duration of the system characterization test to collect data under different driving conditions such as in rain or snow or different traffic conditions.

6.2.4 Long-Term Effects

The analysis of unintended consequences in this FOT was limited to short-term exposure with the system. Short-term test periods (few weeks) do not yield comprehensive information on driver adaptation with the system, thus risk compensation behavior would not be easy to detect. Results of the safety assessment don't convey in any way the long-term, positive, or negative, safety effects of ACAS. Perhaps few FOT subjects could be selected to drive a test vehicle for a longer time period to assess long-term effects of system use. Longer exposure periods (months-years) could be accommodated if the subjects' own vehicles were equipped with less expensive crash countermeasure and data acquisition systems, which would of course yield better data to examine driver adaptation and potential safety benefits. A higher degree of system acceptance might be achieved if drivers were able to experience the full capability of the crash countermeasure system in a near-crash event. The low acceptance rate of FCW was due perhaps to many subjects not experiencing true alerts to hazardous or imminent rear-end crash events during the ACAS FOT. Longer exposure with the system might improve FCW acceptance.

FOT subjects became familiar very quickly with the operation of a new vehicle (2002 Buick LeSabre in the ACAS FOT) based on the number of conflicts or near-crashes encountered per distance traveled. However, a past study indicated that drivers might learn quickly to operate a new vehicle in normal driving situations but might take longer time to appreciate its capability in intense evasive maneuvers (Perel, 1983). Thus, it is recommended that subjects experience heavy braking or steering maneuvers during the training stage of the FOT so as to get acclimated with the capability and performance of the new vehicle.

6.2.5 Safety Benefits Analyses

To gain a better understanding of the potential safety benefits that can be accrued from ACAS use, it is recommended that the FCW threat assessment algorithm be applied to real world rear-end crashes already recorded in a naturalistic driving study (Neale et al., 2002). The ACAS issues crash-imminent alerts that were deemed sometimes as “too late” by some FOT subjects. This is mostly done by design to minimize the rate of nuisance alerts. The application of the algorithm to rear-end crash data would help to estimate how many of these rear-end crashes the ACAS may have prevented. The intent is to explore whether or not the ACAS algorithm would have issued an imminent alert in time that could have helped the subjects avoid the rear-end collisions or other collisions preceded by a rear-end pre-crash scenario.

Based on the results of data analysis to assess the safety impact of ACAS, it is recommended that improved filtering processes be applied to identify driving conflicts and near-crashes, and filter out low-risk conflicts. The analysis of the ACAS FOT numerical data limited the conflict duration to at least 1 second to capture meaningful driving events of the host vehicle closing in on a lead vehicle. Perhaps, longer time of minimum duration would have filtered out events in which the lead vehicle was cutting in or out of the host vehicle’s path. Moreover, counting a driving conflict in the ACAS FOT once the peak deceleration surpassed the 0.1g threshold resulted in many driving conflicts and near-crashes where the driver responded with very low average braking levels. low-risk conflicts with very low deceleration levels dilute the response with and without ACAS assistance, which affects the comparison between the baseline and treatment conditions. In addition, including too many conflicts of low-risk nature adds to the complexity of the analysis. An additional filter might assign a certain time duration in which the peak deceleration must remain over 0.1g. The analysis of severe near-crashes imposed the criteria of minimum TTC less than or equal to 3 seconds and peak deceleration over 0.3g. This filter, however, yielded a number of events that was very small to conduct any statistical analysis. The evaluation of the ACAS FOT used low-and high-intensity levels that were assigned to conflicts and near-crashes. Based on the results of using both levels, it is recommended that the high-intensity level be used even though most statistically significant results were observed at the low-intensity level. Hopefully, upcoming FOTs would employ more subjects who would drive longer distances and thus increasing exposure to driving conflicts.

Visual filtering step could be used as well to filter out low-risk conflicts from numerical FOT data. This would add more labor effort to sort conflicts out. In addition, continuous recording of the forward scene would be needed at a higher frame rates of at least 2 Hz or 2 images every second instead of 1 image every second in the ACAS FOT (other than triggered events). This would add to the amount of stored data. Finally, this evaluation used Monte Carlo simulations to estimate the probability of a crash given an encounter with a specific driving conflict. Use of direct mathematical techniques to estimate the probability of a crash is recommended such as the application of statistical distributions from extreme value theory or crash prevention boundary techniques.

7. REFERENCES

Becker, S., Bork, M., Dorisen, H. T., Geduld, G., Hofmann, O., Naab, K., et al. (1995). Summary of Experiences with Autonomous Intelligent Cruise Control (AICC). Part 2: Results and Conclusions. World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems.

Cole, B., and Hughes, P. (1984). A Field Trial of Attention and Search Conspicuity. *Human Factors, 26*(3), 299-313.

Colgin, R.C. (1999). Automotive Collision Avoidance System Field Operational Test. Technical proposal submitted by GM and Delphi to NHTSA.

Crash Avoidance Metrics Partnership, Vehicle Safety Communications Consortium (2004). Task 3 - Identify Intelligent Vehicle Safety Applications Enabled by DSRC. Vehicle Safety Communications project, NHTSA Cooperative Agreement, No. DTFH61-01-X-0001.

Curry, R.C., Greenberg, J.A., and Kiefer, R.J. (2005). *NADS versus CAMP Closed-Course Comparison Examining "Last Second" Braking and Steering Maneuvers Under Various Kinematic Conditions*. Performed by Crash Avoidance Metrics Partnership (CAMP), DOT HS 809 925, Contract DTFH61-01-X-00014, National Highway Traffic Safety Administration, Washington, DC.

Davis, F. D., Bagozzi, R. P., and Warshaw, P.R. (1989). User Acceptance of Computer Technology: A Comparison of Two Theoretical Models. *Management Science*, 35(8), 982-1003.

Davis, F. D. J. (1985). A Technology Acceptance Model for Empirically Testing New End-User Information Systems: Theory and Results. Unpublished Ph.D. in Management, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Delphi-Delco Electronic Systems (2000). *Automotive Collision Avoidance Systems (ACAS) Program*. Final Report, DOT HS 809 080, National Highway Traffic Safety Administration, Washington, DC.

Dingus, T. A., Jahns, S. K., Horowitz, A. D., and Knipling, R. (1998). Human Factors Design Issues for Crash Avoidance Systems. In W. Barfield and T. A. Dingus (Eds.), *Human Factors in Intelligent Transportation Systems* (pp. 55-93). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Fancher, P., Ervin, R., Sayer, J., Hagan, M., Bogard, S., Bareket, Z., Mefford, M., and Haugen, J. (1998). *Intelligent Cruise Control Field Operational Test*. Vol. I, DOT HS 808 849, National Highway Traffic Safety Administration, Washington, DC.

General Motors Corporation (2005). *Automotive Collision Avoidance System Field Operational Test (ACAS FOT) – Final Program Report*. DOT HS 809 886, National Highway Traffic Safety Administration, Washington, DC.

Henderson, R.D (1987). *Driver Performance Data Book.* DOT HS 807 121, National Highway Traffic Safety Administration, Washington, DC.

Intelligent Transportation Systems Joint Program Office (2000). Intelligent Transportation Systems (ITS) Projects Book. Federal Highway Administration, United States Department of Transportation, page 371, Washington, D.C.

Juster, T. F. (1966). Consumer Buying Intention and Purchase Probability: An Experiment In Survey Design. *Journal of the American Statistical Association*, 61, 658-696.

Kantowitz, B., Lee, J., Becker, C., Bittner, A., Kantowitz, S., Hanowski, R., et al. (1996). *Development of Human Factors Guidelines for ATIS and CVO: Exploring Driver Acceptance of In-Vehicle Information Systems*. FHWA-RD-96-143, Federal Highway Administration, Washington, DC.

Kiefer, R., LeBlanc, D., Palmer, M., Salinger, J., Deering, R., and M. Shulman (1999). *Development and Validation of Functional Definitions and Evaluation Procedures for Collision Warning/Avoidance Systems*. DOT HS 808 964, National Highway Traffic Safety Administration, Washington, DC.

Kiefer, R.J., Cassar, M.T., Flannagan, C.A., LeBlanc, D.J., Palmer, M.D., Deering, R.K., and M.A. Shulman (2003). *Forward Collision Warning Requirements Project Task 1 Final Report: Refining the CAMP Crash Alert Timing Approach by Examining 'Last-Second' Braking and Lane-Change Maneuvers Under Various Kinematic Conditions*. DOT HS 809 574, National Highway Traffic Safety Administration, Washington, DC.

Koopmann, J.A., and Najm, W.G. (2003). *Identification of Traffic States from Onboard Vehicle Sensors*. SAE 2003 World Congress, Paper No. 2003-01-0535, Detroit, MI.

Koziol, J., Inman, V., Carter, M., Hitz, J., Najm, W., Chen, S., Lam, A., Penic, M., Jensen, M., Baker, M., Robinson, M., and Goodspeed, C. (1999). *Evaluation of the Intelligent Cruise Control System, Volume I - Study Results*. DOT-VNTSC-NHTSA-98-3, DOT HS 808 969, National Highway Traffic Safety Administration, Washington, DC.

Madhavan, P., Wiegmann, D. A., and Lacson, F. C. (2003). Automation Failures on Tasks Easily Performed by Operators Undermines Trust in Automated Aids. Paper presented at the Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting.

Morwitz, V. G., and Schmittlein, D. (1992). Using Segmentation To Improve Sales Forecasts Based On Purchase Intent: Which 'Intenders' Actually Buy? *Journal of Marketing Research* (29), 391-405.

Najm, W.G., Lam, A.H., and Koopmann, J.A. (2003). Data Processing of Rear-End Crash Avoidance System Field Operational Test. HS16, Volpe National Transportation Systems Center, Cambridge, MA.

Najm, W.G. Alternative Methods for Safety Benefits Estimation (2003). Project Memorandum, HS16, Volpe National Transportation Systems Center, Cambridge, MA.

Najm, W.G., Sen, B., Smith, J.D., and Campbell, B.N. (2003). *Analysis of Light Vehicle Crashes and Pre-Crash Scenarios Based on the 2000 General Estimates System*. DOT VNTSC NHTSA 02 04, DOT HS 809 573, National Highway Traffic Safety Administration, Washington, DC.

Najm, W. G., Stearns, M. D., and Boyle, L. N. (2001). Detailed Plan for an Independent Evaluation of the Automotive Collision Avoidance System Field Operational Test. Project Memorandum, DOT-VMTSC-HS116-PM-01-09, Volpe National Transportation Systems Center, Cambridge, MA.

Najm, W.G., D.L. Smith, and A.H. Lam (2002). Modeling Driver Response to Rear-End Pre-Crash Scenarios. Project Memorandum, HS-316, DOT-VNTSC-NHTSA-02-10, Volpe National Transportation Systems Center, Cambridge, MA.

Najm, W.G., and D.L. Smith (2004). Modeling Driver Response to Lead Vehicle Decelerating. Paper No. 04AE-26, SAE 2004 World Expo, Detroit, MI.

National Highway Traffic Safety Administration (1997). *Report to Congress on the National Highway Traffic Safety Administration ITS Program-Program Progress During 1992-1996 and Strategic Plan for 1997-2002*. National Highway Traffic Safety Administration, Washington, DC.

Neale, V.L., Klauer, S.G., Knipling, R.R., Dingus, T.A., Holbrook, G.T., and Petersen, A. (2002). *The 100-Car Naturalistic Driving Study, Phase 1 – Experimental Design*. Interim Report, DOT HS 808 536, National Highway Traffic Safety Administration, Washington, DC.

OECD (Organization for Economic Cooperation and Development). (1990). *Behavioural Adaptations to Changes in the Road Transport System*. Paris: Organization for Economic Cooperation and Development.

Okabayashi, S., Sakata, M., Furukawa, M., and Hatada, T. (1989). How Head-up Display Affects Recognition of Objects in Foreground in Automobile Use. Paper presented at the Current Developments in Optical Engineering and Commercial Optics, Proceedings of the International Society for Optical Engineering.

Olson, P.L., Cleveland, D.E., Fancher, P.S., Kostyniuk, L.P., and Schneider, L.W. (1984). *Parameters Affecting Stopping Sight Distance*. National Cooperative Highway Research Program, Report No. 270, Transportation Research Board, Washington, DC.

Perel, M. (1983). *Vehicle Familiarity and Safety*. DOT HS 806 509, National Highway Traffic Safety Administration, Washington, DC.

Reynolds, M.T. (1996). *Test and Evaluation of Complex Systems*. John Wiley & Sons.

Rogers, E. M. (1995). *Diffusion of Innovations* (4th ed.). New York: Free Press.

Smiley, A. (2000). Auto Safety and Human Adaptation. *Issues in Science and Technology. Online, http://www.nap.edu/issues/17.2/smiley.htm*(Winter).

Smith, D.L., W.G. Najm, and R.A. Glassco (2002). Feasibility of Driver Judgment as Basis for a Crash Avoidance Database. TRB 2002 Annual Meeting, No. 02-3695, Transportation Research Record No. 1784, Washington, DC.

Smith, D.L., W.G. Najm, and A.H. Lam (2003). Analysis of Braking and Steering Performance in Car-Following Scenarios. Paper No. 2003-01-0283, SAE 2003 World Expo, Detroit, MI.

Sojourner, R. J., and Antin, J. F. (1990). The Effects of a Simulated Head-up Display Speedometer on Perceptual Task Performance. *Human Factors, 32*, 329-240.

Stevens, R.T. (1986). *Operational Test & Evaluation: A Systems Engineering Process*. Krieger Publishing Company.

Taoka, G.T. (1989). Brake Reaction Times of Unalerted Drivers. *ITE Journal*.

United States Census Bureau (2000). from http://factfinder.census.gov/home/saff/main.html?_lang=en

University of Michigan Transportation Research Institute and General Motors (2005). *Automotive Collision Avoidance System Field Operational Test – Methodology and Results*. DOT HS 809 900, National Highway Traffic Safety Administration, Washington, DC.

Urban, G. L., and Hauser, J. R. (1993). *Design and Marketing of New Products* (2nd ed.). Englewood Cliffs, NJ: Prentice Hall.

van der Laan, J. D., Heino, A., and de Waard, D. (1997). A Simple Procedure for the Assessment of Acceptance of Advanced Transport Telematics. *Transportation Research C, 5*(1), 1-10.

Weinberger, M., Winner, Hermann , and Heiner B. (2001). Adaptive Cruise Control Field Operational Test-The Learning Phase. *JSAE Review, 22*(JSAE20014502), 487-494.

Witt, G.J., Zhang, H., and Smith, M. (2004). Phase 1 Research Summary and Phase 2a Planning Document. SAfety VEhicle(s) Using Adaptive Interface Technology (SAVE-IT), Volpe National Transportation Systems Center, Cambridge, MA

8. APPENDICES

APPENDIX A. System Characterization Test

A system characterization test was conducted as part of the independent evaluation using an ACAS-equipped vehicle similar to vehicles used in the FOT. The purpose of this test was to supplement FOT data with additional information to characterize the capability of the system. Data collection was performed over several weeks in the fall of 2003 in the Boston metropolitan area. The University of Michigan Transportation Research Institute (UMTRI), FOT conductor, provided the independent evaluator with a special key to alter the data acquisition system onboard the test vehicle from regular FOT data collection mode to a special mode that records the forward scene video continuously at 10 Hz rate and does not store images of the driver face. This allowed the independent evaluator to analyze the forward scene images afterwards to measure the ability of the forward-looking sensor suite to detect and track in-path targets as well as to reject out-of-path targets. The test vehicle was also equipped with a rear-facing camera to record the activities of following vehicles so as to observe their response to ACC autobraking and acceleration.

This test was executed on a wide variety of roadway configurations and environmental conditions for a total distance of 392 km and total time of 6 hours and 48 minutes. Tables A-1 and A-2 present the breakdown of km and time traveled respectively by driving mode, roadway type, traffic state, and atmospheric condition. Testing was not conducted within crosshatched areas because ACC would not function on urban and suburban routes due to low speed and frequent stops, or because it was assumed that night driving on freeway routes would not alter results from day driving. Cells with gray fill refer to incomplete testing due to the lack of rain while the test vehicle was in Boston. Figures A-1, A-2, and A-3 highlight the maps of the test routes respectively for urban, freeway, and suburban roadways. Roadway type was selected to represent typical roadways of the Boston region, which may challenge the ACAS forward-looking sensor suite to correctly track in-path targets and reject out-of-path targets. Urban roadways constituted one to three lanes, frequent stoplights, parked cars, and speed limits of 35 mph or less. Freeways were either typical Interstate multi-lane freeways with two or more lanes and speed limit of 65 mph, or two-lane urban freeways with frequent sharp curves and speed limit of either 40 or 50 mph. Suburban roadways comprised one or two lane roadways with frequent curves, elevation changes, speed limits of 25-35 mph, and varying levels of population density.

Data analysis was conducted using a multi-media data display tool that was developed by the independent evaluator to examine video and numerical FOT episodes triggered by crash-imminent alerts. In this case, the video and associated numerical data were viewed on a continuous basis rather than alert episodes only. Observations were recorded in a MS Access database, which noted details such as environmental conditions, presence of a lead vehicle, roadway curvature, and target tracking. This continuous video analysis allowed the independent evaluator to observe ACAS exposure to challenging situations.

Table A-1. Breakdown of Distance Traveled During System Characterization Test

	FCW				ACC	
	Day Clear	Day Rain	Night Clear	Night Rain	Day Clear	Day Rain
Urban	8.0%	5.7%	4.7%			
Freeway	20.0%	12.3%			(Low) 7.1%	
					(Moderate) 27.0%	
					(Heavy) 2.6%	
Suburb	6.4%		6.2%			

(checkered) = Tests not conducted

(gray) = Incomplete tests due to weather

(xxx) = Traffic state

Total distance = 392 Km

Table A-2. Breakdown of Time Traveled During System Characterization Test

	FCW				ACC	
	Day Clear	Day Rain	Night Clear	Night Rain	Day Clear	Day Rain
Urban	18.2%	12.6%	9.3%			
Freeway	14.2%	7.5%			(Low) 3.5%	
					(Moderate) 15.8%	
					(Heavy) 2.3%	
Suburb	7.8%		8.7%			

(checkered) = Tests not conducted

(gray) = Incomplete tests due to weather

(xxx) = Traffic state

Total time = 6 hours and 48 minutes

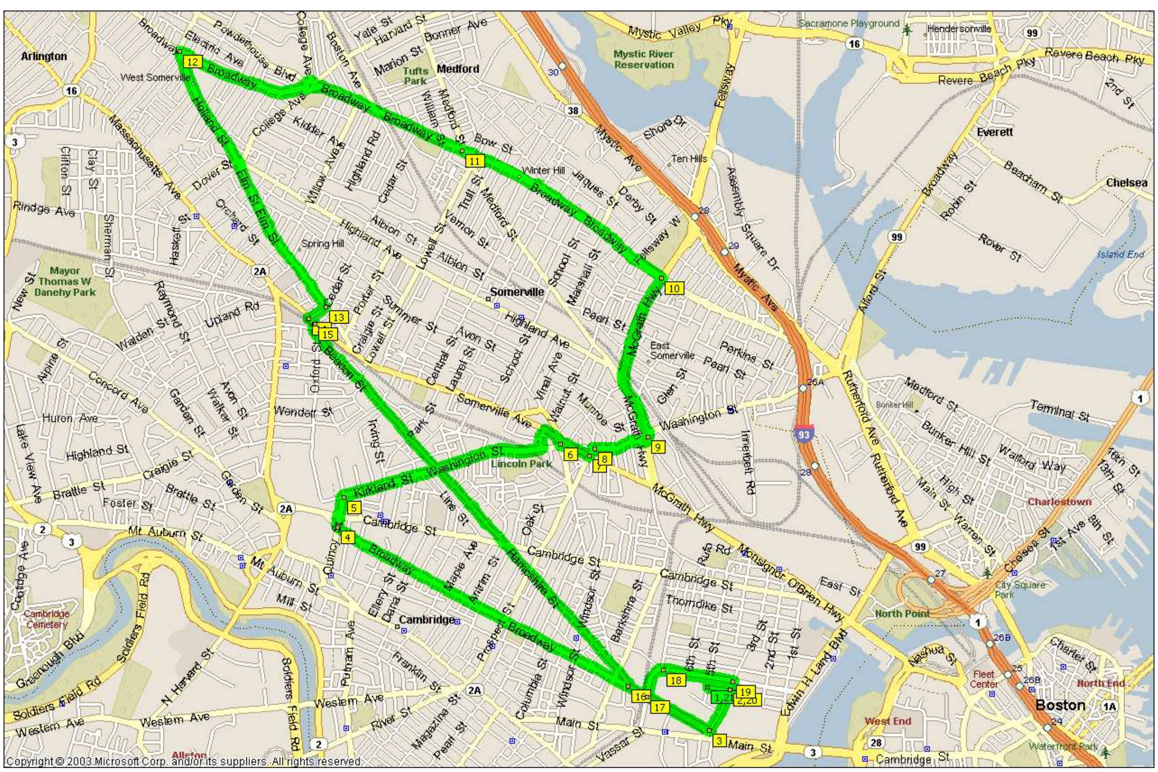


Figure A-1. Urban Route Map of System Characterization Test

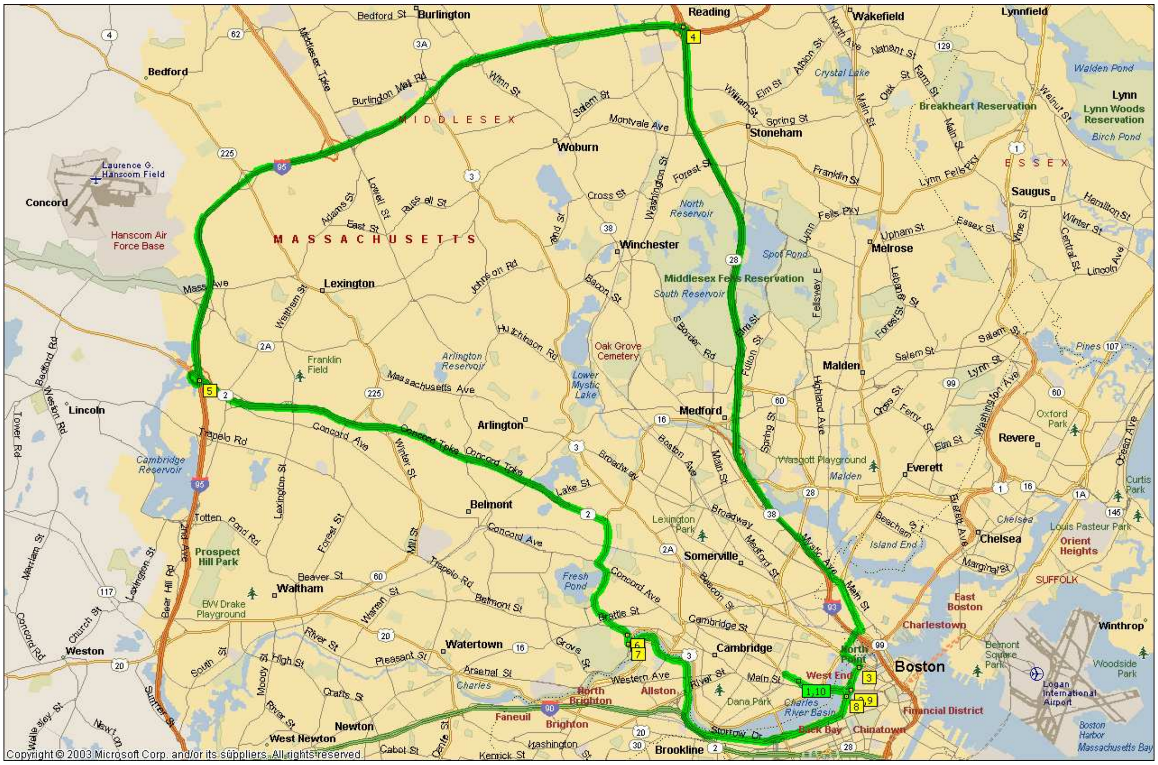


Figure A-2. Freeway Map of System Characterization Test

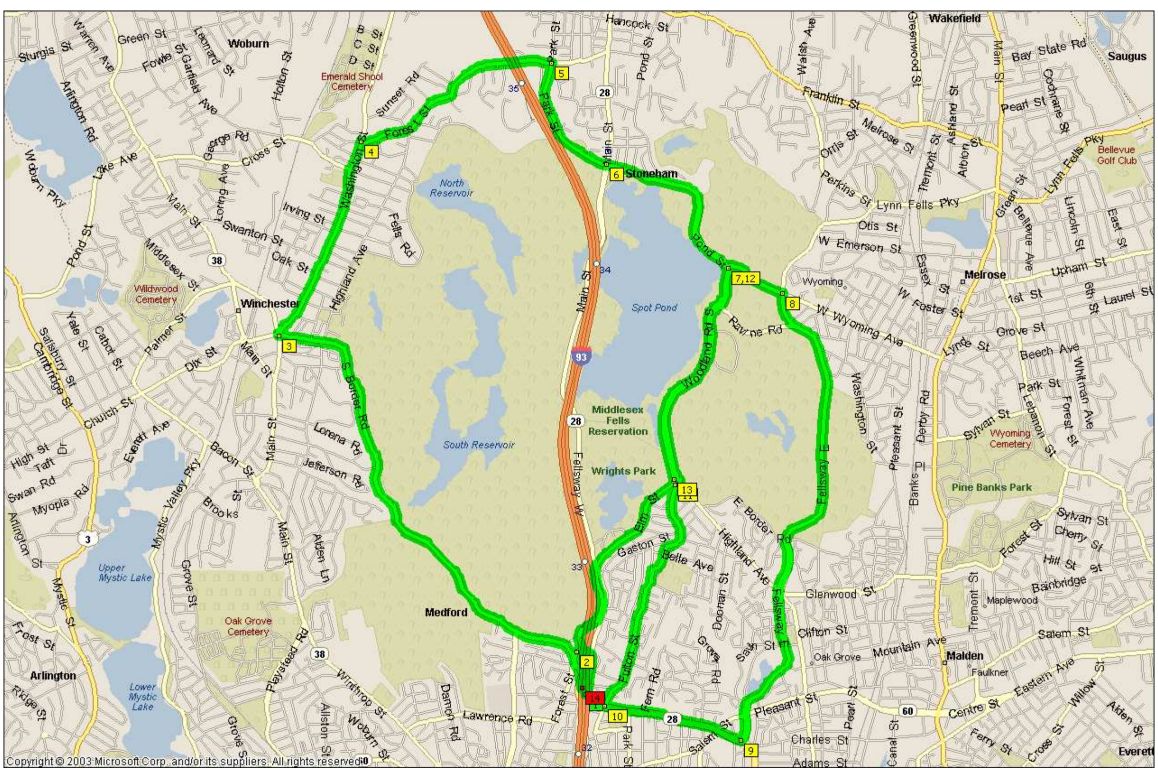


Figure A-3. Suburban Route Map of System Characterization Test

APPENDIX B. Data Logger and Coding Instructions of Video Episodes

Variables and Codes

- *Driver ID*
- *Trip No*
- *Episode StartTime*
- *Episode EndTime*
- *System*
  - 0 MAN
  - 1 CCC
  - 2 FCW
  - 3 ACC+FCW
- *AlertTime*
- *TargetMotion*
  - 0 stationary
  - 1 moving
- *TransSpeed*
- *AxFiltered*
- *CIPTRange*
- *CIPTRangeRate*
- *CIPTAcceleration*
- *TargetPathVideo*
  - 0 in-path
  - 1 out-of-path
- *TargetTypeVideo*
  - 0 vehicle
  - 1 sign
  - 2 mailbox
  - 3 pole
  - 4 bridge/overhead sign
  - 5 guardrail
  - 6 Jersey barrier
  - 7 fire hydrant
  - 8 other
- *TargetLocVideo*
  - 0 straight
  - 1 in curve
  - 2 curve entry
  - 3 curve exit
- *HostLocVideo*
  - 0 straight
  - 1 in curve
  - 2 curve entry
  - 3 curve exit
- *LeadVehManVideo*

0 going straight
1 changing lanes
2 turning
3 on curve
4 LTAP
5 other
6 none

- *LeadVehStateVideo*
  0 none
  1 stopped
  2 constant speed
  3 decelerating
  4 accelerating
  5 undefined
  6 LDV to stop
  7 LDV to C.L.S.
- *TimeLVBrakeVideo*
- *IOLVLCTime*
- *LVChangingLane*
  0 no
  1 IP to OP
  2 OP to IP
  3 OP to IP to OP
- *HostVehManVideo*
  0 going straight
  1 changing lanes
  2 turning
  3 on curve
  4 passing
- *IO Host LC Time*
- *Driver Response before Alert*
  0 none
  1 braking
  2 steering
  3 braking and steering
  4 off throttle only
- *Driver Response before Alert Time*
- *Driver Response After Alert*
  0 none
  1 braking
  2 steering
  3 braking and steering
  4 off throttle only
- *Driver Response After Alert Time*
- *Event*
  0 no

1 yes

- *Driver Eyes Off Road*
  0 no
  1 yes
  2 unknown
- *Driver Annoyed*
  0 no
  1 yes
  2 unknown
- *DistractedVideo*
  0 no
  1 dialing phone
  2 talking/listening to phone
  3 singing/whistling
  4 grooming
  5 adjusting controls
  6 scratching face
  7 yawning
  8 drinking/eating/smoking
  9 talking to passenger
  10 reading
  11 searching interior
  12 scanning back adjacent lanes
  13 scanning rear-view mirror
  14 looking to the side/outside car
  15 reaching for items
  16 other
  17 unknown
- E*yewearVideo*
  0 none
  1 sunglasses
  2 prescription glasses
- *JunctionRelVideo*
  0 no
  1 intersection
  2 driveway
  3 ramp
- *TCDVideo*
  0 none
  1 signal
  2 stop sign
  3 other sign
- *Obs. Speed*
- *Lane_CatVideo*
  0 1 lane
  1 2-3 lanes

2 ≥4 lanes

- *DividerVideo*
  0 no
  1 yes
- *RampVideo*
  0 no
  1 yes
- *LOSVideo*
  0 undefined
  1 light
  2 medium
  3 heavy
- *RoadTypeVideo*
  0 nonfreeway
  1 freeway
- *LightingVideo*
  0 day
  1 night
- *AtmosphereVideo*
  0 clear
  1 rain
  2 snow
- *SurfaceVideo*
  0 dry
  1 wet
  2 snowy
- *Comments*: Analyst writes out observations not included in coded variables.
- *Submitted by*: Analyst name.
- *Date*: Date when video episode is analyzed.

Coding Instructions

Italicized text = field from the data logger
Bold text = field from the Volpe Video Viewer

Episode Information

1. Enter *Driver ID* and *Trip No* from Overlay information Displayed on bottom right of forward video
2. Move episode to beginning, enter *Episode start time* from the **Timestamp** field or the first row of the time column in the **Trip Data Table**
3. Watch the episode. Once complete enter the *Episode End Time.*
4. *System* is based on which of the various systems is available and used at the time of the alert. Move the video again to the beginning of the episode and look for the yellow text on the left of the DVI indicating if the system is operating under **FCW**, **ACC**, or **CCC**. If no yellow text appears then the system is operating under manual, "man", driving mode.

Alert

5. Move the video to the time when the GM alert occurs, indicated by either the first instance of the splat icon on the DVI or the first 100 in the **FcwAlertLev** Column of the **Trip Data Table**. (approximately record 51) Enter the *Alert Time* (GM). If the alert reaches 100 falls to lower level and then rises to 100 again examine the video to ensure both alerts were caused by the same target and situation. If it was a different target or the lead vehicle state or maneuver is different the alerts must be analyzed as distinct alerts. The additional 100 level arts, which are distinct from the first alert, should be analyzed in a new record.
6. Next play the video again. Observe which target causes the alert. Red = **FCWTargetId** (FCW system target), Blue = **CIPS** (stationary) if different than **FCWTargetId**, Green = **CIPV** (movable) if different than **FCWTargetId**. In most cases the alert should be issued based on the FCW system (Red) target. Examine the video closely to ensure the Red (**FCWTargetId**) target causes the alert because discrepancies are possible. Choose either stationary, a non moving object (sign, guardrail, parked car, etc.), or moving (non-stationary vehicle) for *Target Motion* (GM).

- Steps 7-12: Values at the time when the GM alert occurs *(Alert Time)*
  7. Enter speed from the DVI into *Trans Speed* (GM)
  8. Enter the value from the **Ax Filtered** column of the **Trip Data Table** into *Ax Filtered* (GM)
  - Steps 9-11: Values are based on the target which causes the alert and are located in the **Radar Targets Table**
    9. *CIPT Range* (GM) = **Range**
    10. *CIPT Range Rate* (GM) = **Rdot**
    11. *CIPT Acceleration* (GM) = **Acceleration**
  12. *Target Path Video* (GM) identifies if the target is in-path or out-of-path from the forward video. In-path targets are those which are currently in the same lane as the host vehicle. A target vehicle which is either entering or exiting the lane should be recorded as in-path until the vehicle is entirely outside the lane.

Detailed Episode Information

13. Next enter the *Target Type Video* based on the observed target which causes the alert. If the target is not a choice from the drop down menu choose "other" and type a description of the target into the *Comments* box. If the target cannot be determined choose "other" and type "Undetermined target type" in the *Comments* box.
14. *Target loc video* is the location of the target. "curve entry " = a target located in the transition from straight roadway to curve, "curve exit" = a target located in the transition from curved roadway to straight.
15. *Host loc video* is the location of the host vehicle. Instructions are the same as Step 22 except for the host vehicle.

- Steps 16-20 only should only be done for episodes of *target motion* = "moving". All values are based on when the alert issues.
  16. Movement of the lead vehicle is recorded in *Lead veh man vid.* "going straight" = traveling on a straight roadway, "on curve" = lead vehicle at any part of curve including transitions (curve entry/exit), "changing lanes" = lead vehicle executing a lane change

(lane change begins when the lead vehicle begins crossing the lane marking or entering a new lane and ends when the vehicle is entirely in the new lane), "turning" = lead vehicle turning from or entering the host vehicle roadway or driveway (only true once the lead begins the turning maneuver), "LTAP" = Left Turn Across Path, when a lead vehicle approaches from the opposite direction and turns left across the path of the host vehicle

17. *lead veh state video* records the longitudinal movement of the vehicle. "none" = no vehicle, "stopped" = not moving, "constant" = steady movement, "decelerating" = brake lights illuminated but not certain about the type of deceleration, "LVD to stop" = Lead Vehicle Decelerate to a stop, "LVD to C.L.S." = Lead Vehicle Decelerate to Constant Lower Speed, "accelerating" = when the lead vehicle is noticeably accelerating (ex. after a traffic light), "undefined" = uncertain about the lead vehicle state or the state is transitioning to another state.
18. *time lv brake video* = the first video frame when lead vehicle brake lights illuminate (only fill in this field if the lead vehicle brakes)
19. *iolvlc* = the time when the lead vehicle starts/ends a lane change. (this includes lane change, turning, or any other maneuver where the lead vehicle changes lanes) For OP to IP lane changes the time is recorded when the lead vehicle begins to enter the lane of the host vehicle. The time recorded for IP to OP and OP to IP to OP lane changes is when the lead vehicle completely exits the lane of the host vehicle.
20. *lead veh lane change* = the movement of the lead vehicle. (this includes lane change, turning, or any other maneuver where the lead vehicle changes lanes) "none" = no lane change, "IP to OP" = lead vehicle changes from the host vehicle lane (in-path) to an adjacent lane (out-of-path), "OP to IP" = lead vehicle changes from an adjacent lane (out-of-path) to the host vehicle lane (in-path). Choose OP to IP to OP for movements where the lead vehicle crosses the host vehicles path.

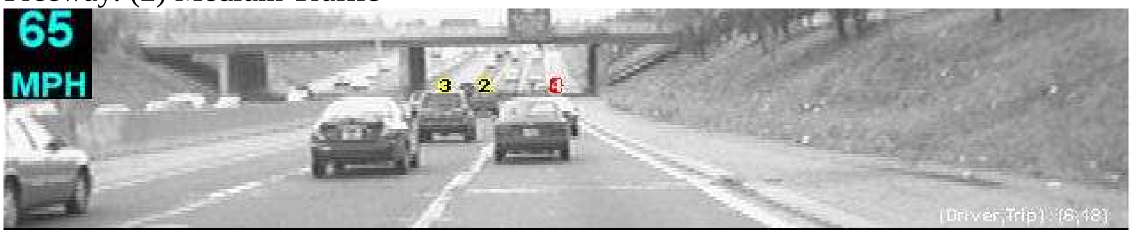
21. Movement of the host vehicle is recorded in *host veh man vid.* "going straight" = only traveling on a straight roadway. "on curve" = vehicle at any part of curve including transitions (curve entry/exit). "changing lanes" = host vehicle executing a lane change (lane change begins when the host vehicle begins crossing the lane marking or entering a new lane and ends when the vehicle is entirely in the new lane) "turning" = host vehicle turning from or entering another roadway or driveway (only true once the host begins the turning maneuver), "passing" = when the host vehicle changes lanes to pass a slower vehicle.
22. *io host lc time* = the time when the host vehicle starts/ends a lane change. The same rules apply as in Step 28. (only fill in the field if the host vehicle changes lane)
23. *driver response before alert* = the driver response to the conflict situation. This is the driver response to the conflict situation that causes the alert. (The response can occur even during the first week when alerts are silent) "none" = no driver action, "braking" = if the **brake** text appears in yellow on the DVI, "steering" = if the driver changes heading within the lane, changes lanes, or passes a slower (Range rate $\leq$ -2.5m/s) or braking (brake lights on) lead vehicle, "braking and steering" = if the driver both brakes and steers, "off throttle only" = when the driver changes the throttle opening significantly (more than a 50% change from the time when the alert was issued)
24. *driver before response time* = The time when the driver begins their response to the situation.
25. *driver response after alert* = the driver response to the alert. (The response can occur even during the first week when alerts are silent) If the response is obviously coincidental (ex. braking for an upcoming stop sign) choose "none" but note reason for response in comments.

“none” = no driver action or the response is a continuation of the response before the alert, “braking” = if the **brake** text appears in yellow on the DVI, “steering” = if the driver changes heading within the lane or changes lanes, “braking and steering” = if the driver both brakes and steers, “off throttle only” = when the driver changes the throttle opening significantly (more than a 50% change from the time when the alert was issued)

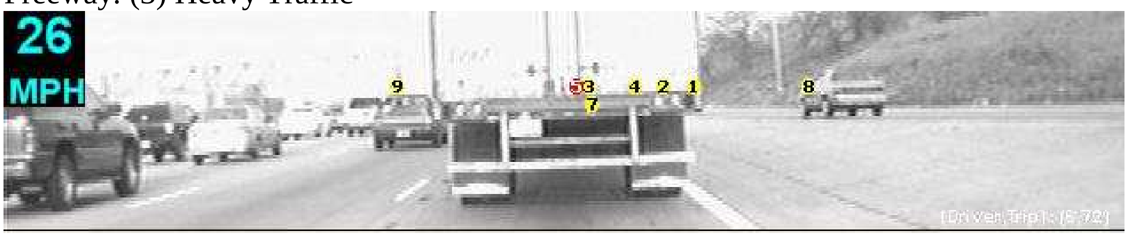
26. *driver after response time* = The time when the driver begins their response to the alert.
27. *event* = Severe episodes that should be marked “yes” for further review or analysis. This includes any near collision or instances where the driver took drastic action. [Y]es” also includes episodes where the alert produced unintended consequences such as swerving into an adjacent lane and cause a collision or near collision with an vehicle in the adjacent lane.
28. *drivers eyes off road* = The location of the drivers eyes for the 5 seconds previous to and during the alert. If the driver appeared to be looking at locations other than the forward view for a particular instance for 15 samples or more choose “yes,” otherwise “no.” “[U]nknown” includes situations where it is unclear if the driver was looking at the forward scene or elsewhere or where the driver’s eyes are hidden by sunglasses or otherwise obscured.
29. *driver annoyed* = The reaction of the driver to the alert. If the driver has an obvious reaction of annoyance, frustration, or comment select “yes.” If the driver appears surprised or has no obvious reaction select “no”. If unsure how to categorize the drivers reaction choose “unknown.”
30. *distracted video* = choose the specific distraction applicable. If more than 1 distraction exists chose the distraction with the greatest risk for collision and list the other distractions in comments.
31. Record the driver eyewear if any in *eyewear video*.
32. *junction rel v* records if the alert is in the vicinity of a junction. If the alert occurs at a junction or one is passed before the end of the episode choose the appropriate junction type.
33. If the alert is junction related mark the traffic control device of the roadway the host vehicle is traveling on in *tcd video.*
34. *obs. speed* = observed speed from the forward video. If speed limit sign is visible during the episode enter the posted speed limit. If not leave the field empty.
35. *lane cat video* = the number of lanes in the direction of travel of the host vehicle when the alert occurs.
36. *divider video* = yes if the roadway is separated from the opposite direction by a median, guardrail, or other divider, no otherwise.
37. *ramp video* = yes if the alert occurs while the host vehicle is on a ramp
38. *los video* = level of service or measure of congestion of the roadway. This measure is based on a combination of vehicle speed for the roadway type and how crowded the roadway is with other vehicles. (See images below for levels of LOS for different roadways.)
39. *roadtype video* records if the host vehicle is on a freeway or non-freeway. Freeways are divided roadway with speed limits of 55 mph or greater, all other roadways are non-freeways.
40. *lighting video* is a measure of the environment ambient light. “[D]ay” = bright light conditions, “night” = dark or low light (ex. dawn, dusk)
41. *atmosphere video* records the precipitation from the atmosphere.
42. *surface video* records the roadway surface.

Freeway: (1) Light Traffic

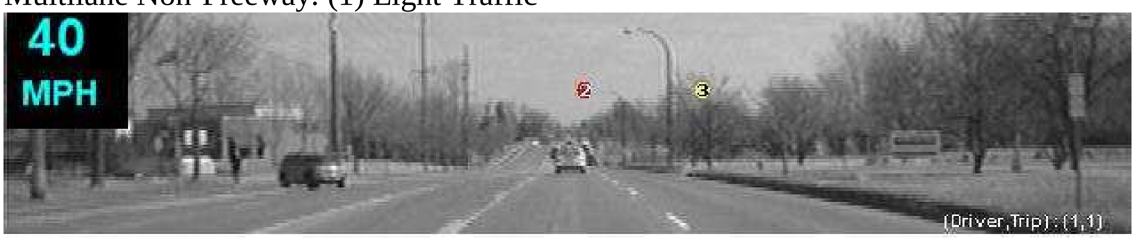
Freeway: (2) Medium Traffic



Freeway: (3) Heavy Traffic



Multilane Non-Freeway: (1) Light Traffic



Multilane Non-Freeway: (2) Medium Traffic

Multilane Non-Freeway: (3) Heavy Traffic

Single Lane Non-Freeway: (1) Light Traffic

Single Lane Non-Freeway: (2) Medium Traffic

Single Lane Non-Freeway: (3) Heavy Traffic

APPENDIX C. Classification of Driving Conflicts and Near-Crashes

Conflicts and near-crashes for the ACAS evaluation were defined based on an analysis of the Crash Avoidance Metrics Partnership (CAMP) data as follows:

- *Conflicts*: CAMP scenarios where drivers were instructed to brake or steer at the last-second at a *comfortable* acceleration level.
- *Near crashes*: CAMP scenarios where drivers were instructed to brake or steer at the last-second at a *hard* acceleration level. near crashes are severe conflicts and are, thus, subsets of all conflicts.

Two levels of intensity were also assigned to the driving conflicts and near-crashes using TTC-range rate thresholds derived from the CAMP data as follows:

- *Low intensity*: Quantified by TTC versus range rate diagrams derived from CAMP's 50 percentile data for LVS, LVM, LVA scenarios, and CAMP's 85 percentile data for the LVD scenario.
- *High intensity*: Quantified by TTC versus range rate diagrams derived from CAMP's 95 percentile data for LVS, LVM, LVA, and LVD scenarios.

For more details about the classification of driving conflicts and near-crashes, the reader is referred to the following publications:

Smith, D.L., W.G. Najm, and R.A. Glassco, "*Feasibility of Driver Judgment as Basis for a Crash Avoidance Database*". TRB 2002 Annual Meeting, No. 02-3695, Transportation Research Record No. 1784, Washington, DC, January 2002.

Najm,W.G., D.L. Smith, and A.H. Lam, "*Modeling Driver Response to Rear-End Pre-Crash Scenarios*". Project Memorandum, PPA # HS-316, DOT-VNTSC-NHTSA-02-10, Volpe National Transportation Systems Center, Cambridge, MA, November 2002.

Smith, D.L., W.G. Najm, and A.H. Lam, *Analysis of Braking and Steering Performance in Car-Following Scenarios*. Paper No. 2003-01-0283, SAE 2003 World Expo, Detroit, MI, March 2003.

Najm, W.G. and D.L. Smith, "*Modeling Driver Response to Lead Vehicle Decelerating*". Paper No. 04AE-26, SAE 2004 World Expo, Detroit, MI, March 2004.

Lead Vehicle Stopped

Figures C-1 and C-2 illustrate the kinematic boundaries that define driving conflicts and near-crashes for lead vehicle stopped with brake response respectively at low-and high-intensity levels. On the other hand, Figures C-3 and C-4 display the kinematic boundaries that define driving conflicts and near-crashes for lead vehicle stopped with steer response respectively at low-and high-intensity levels.

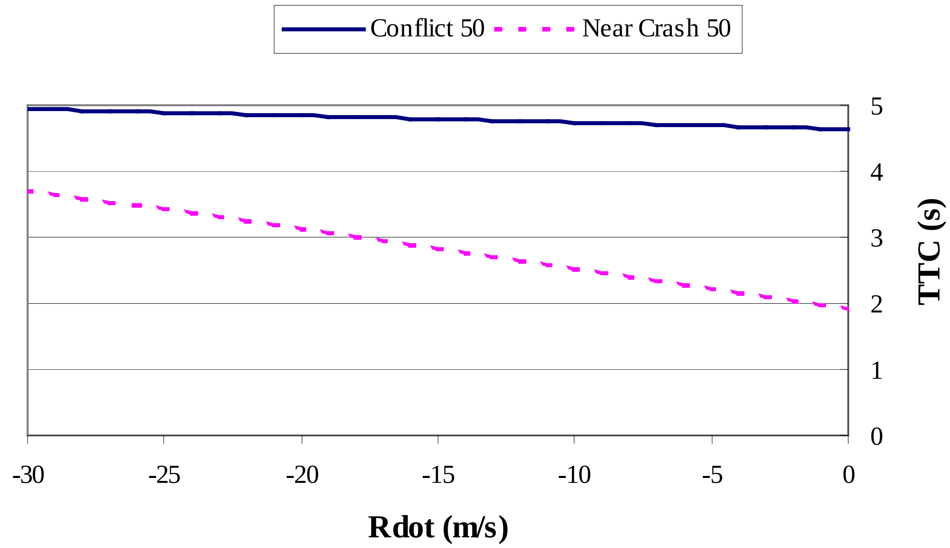


Figure C-1. Low-Intensity Driving Conflict and Near-Crash Boundaries – Lead Vehicle Stopped with Brake Response

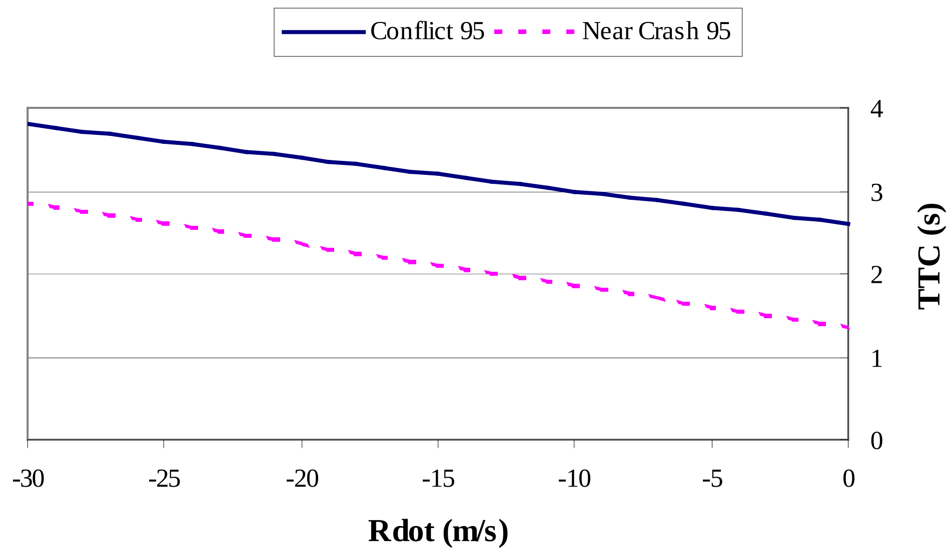


Figure C-2. High-Intensity Driving Conflict and Near-Crash Boundaries – Lead Vehicle Stopped With Brake Response

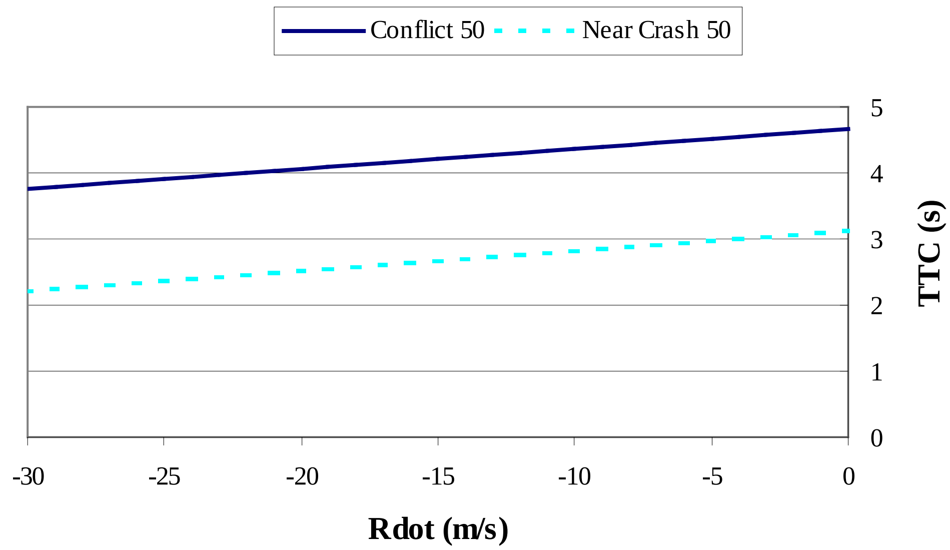


Figure C-3. Low-Intensity Driving Conflict and Near-Crash Boundaries – Lead Vehicle Stopped With Steer Response

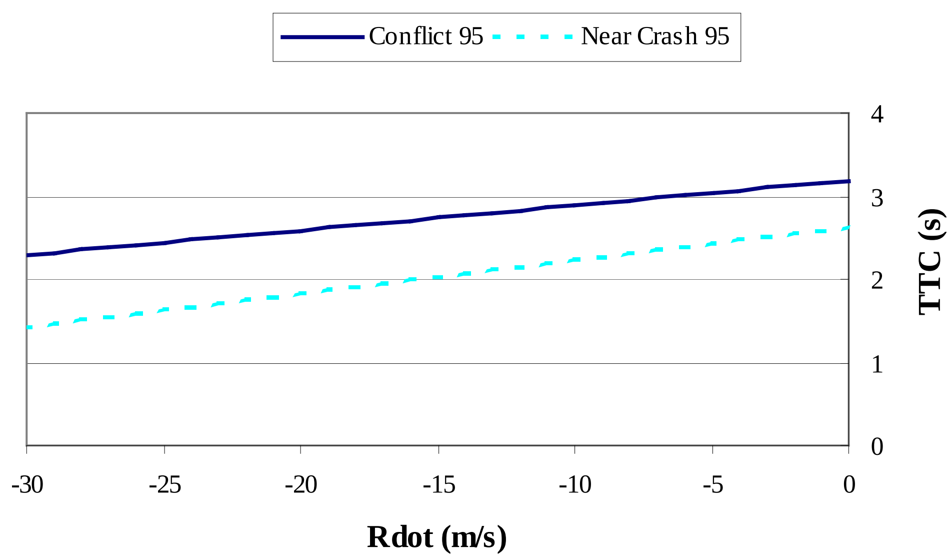


Figure C-4. High-Intensity Driving Conflict and Near-Crash Boundaries – Lead Vehicle Stopped With Steer Response

Lead Vehicle Moving at Slower Constant Speed

Figures C-5 and C-6 illustrate the kinematic boundaries that define driving conflicts and near-crashes for lead vehicle moving at slower speed with brake response respectively at low-and high-intensity levels. On the other hand, Figures C-7 and C-8 display the kinematic boundaries that define driving conflicts and near-crashes for lead vehicle moving at slower speed with steer response respectively at low-and high-intensity levels.

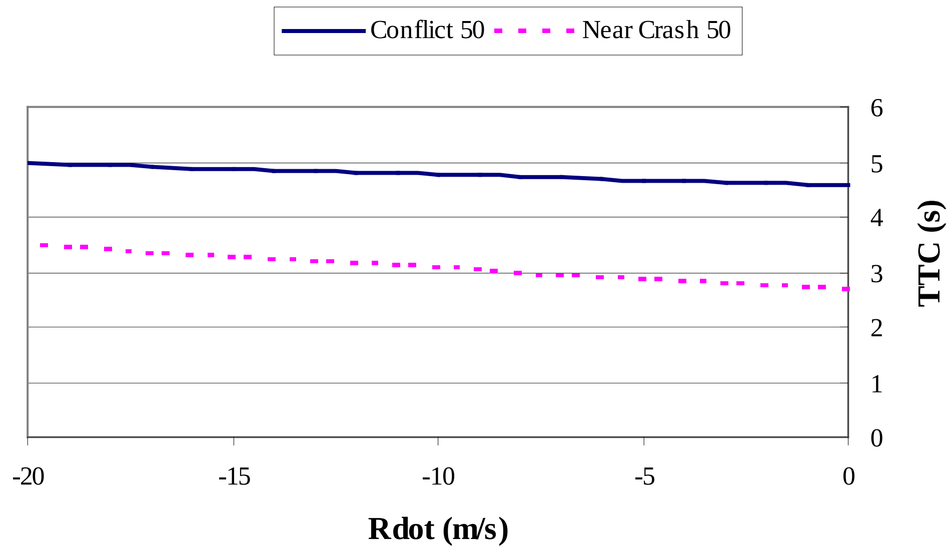


Figure C-5. Low-Intensity Driving Conflict and Near-Crash Boundaries – Lead Vehicle Moving at Slower Constant Speed With Brake Response

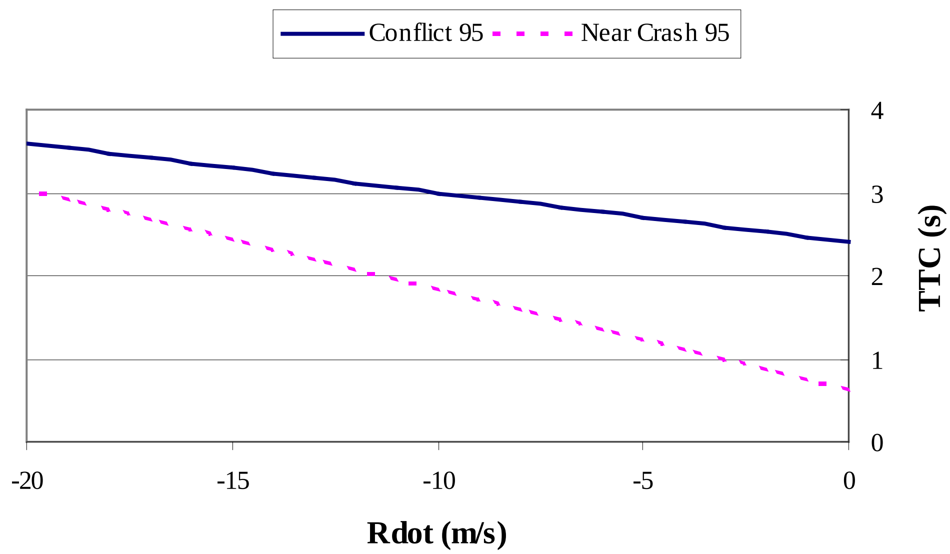


Figure C-6. High-Intensity Driving Conflict and Near-Crash Boundaries – Lead Vehicle Moving at Slower Constant Speed With Brake Response

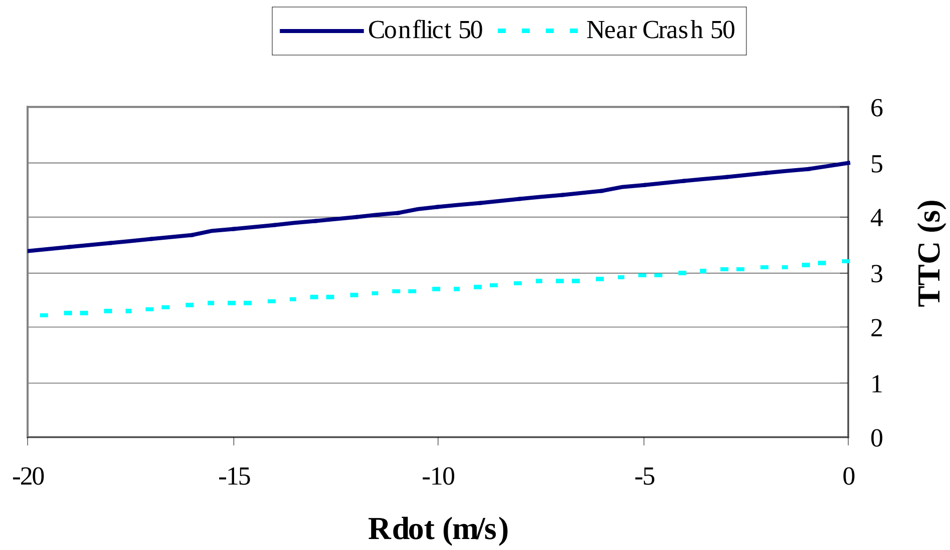


Figure C-7. Low-Intensity Driving Conflict and Near-Crash Boundaries – Lead Vehicle Moving at Slower Constant Speed With Steer Response

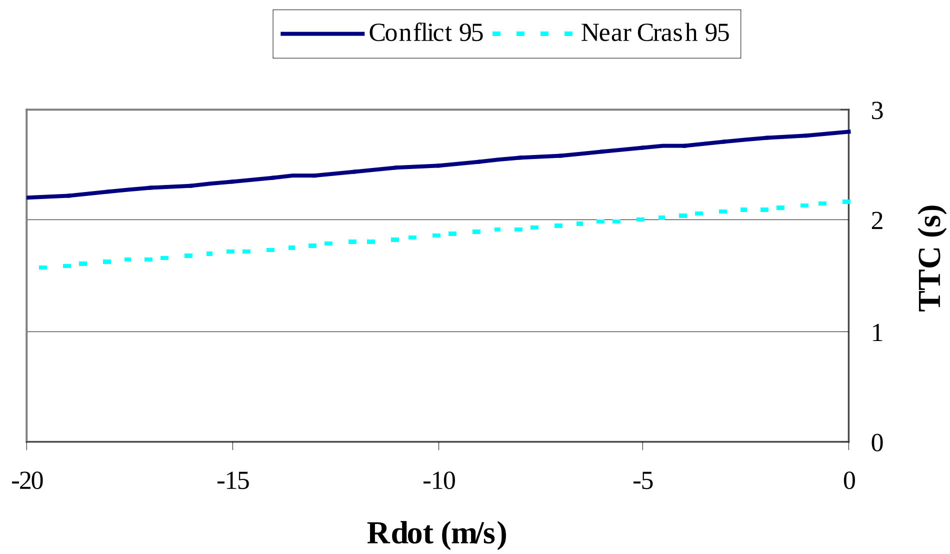


Figure C-8. High-Intensity Driving Conflict and Near-Crash Boundaries – Lead Vehicle Moving at Slower Constant Speed With Steer Response

Lead Vehicle Decelerating

Figures C-9 and C-10 illustrate the kinematic boundaries that define driving conflicts and near-crashes for lead vehicle decelerating with brake response respectively at low-and high-intensity levels. On the other hand, Figures C-11 and C-12 display the kinematic boundaries that define driving conflicts and near-crashes for lead vehicle decelerating with steer response respectively at low-and high-intensity levels.

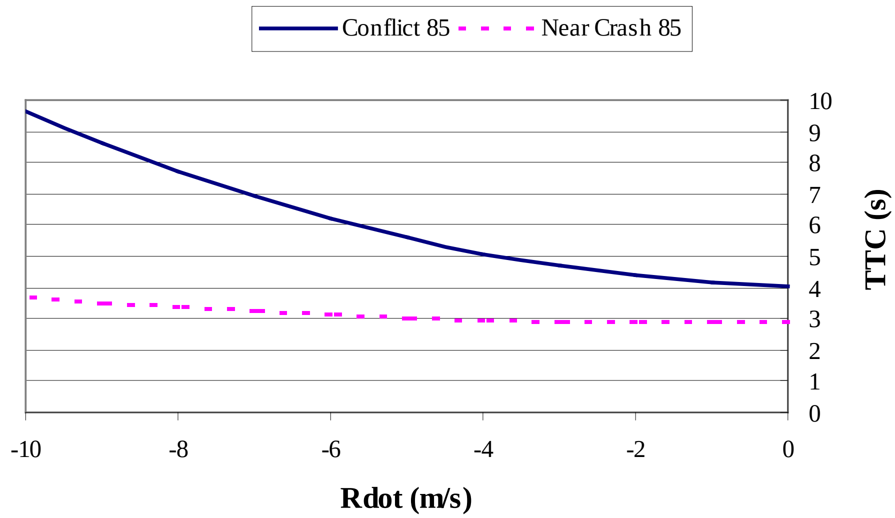


Figure C-9. Low-Intensity Driving Conflict and Near-Crash Boundaries – Lead Vehicle Decelerating With Brake Response

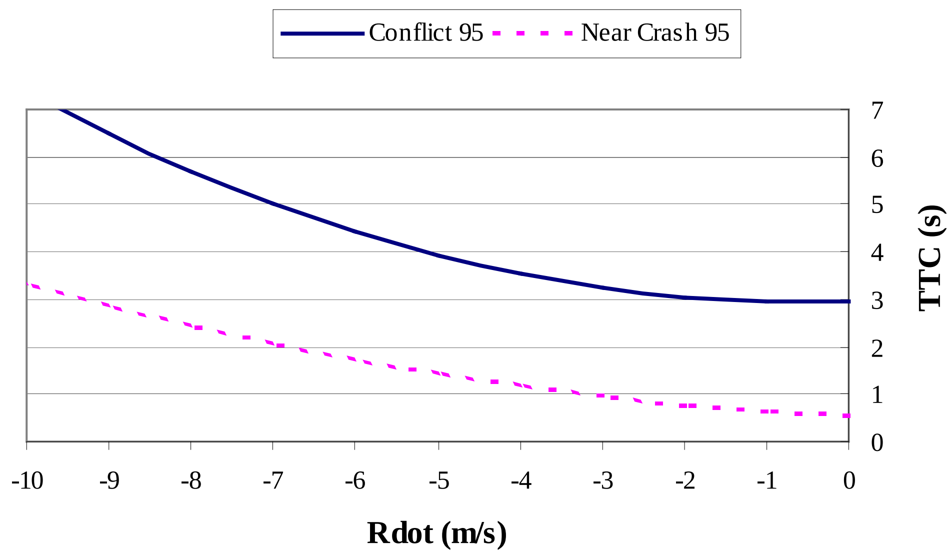


Figure C-10. High-Intensity Driving Conflict and Near-Crash Boundaries – Lead Vehicle Decelerating With Brake Response

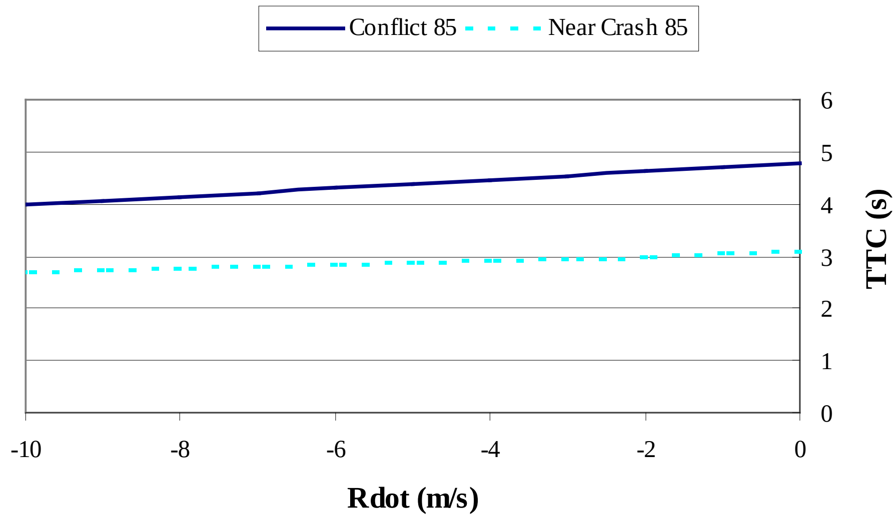


Figure C-11. Low-Intensity Driving Conflict and Near-Crash Boundaries – Lead Vehicle Decelerating With Steer Response

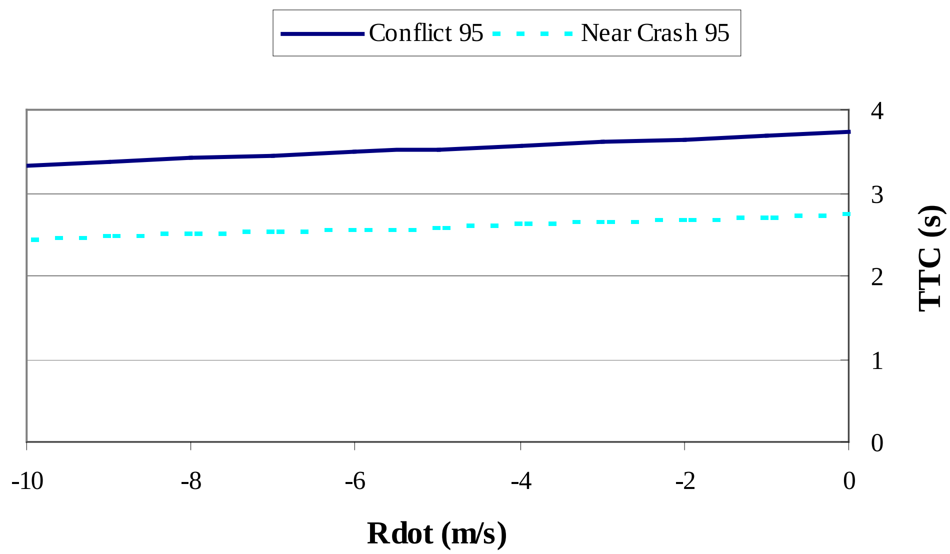


Figure C-12. High-Intensity Driving Conflict and Near-Crash Boundaries – Lead Vehicle Decelerating With Steer Response

Lead Vehicle Accelerating

Apply LVM boundaries if $(Rdot^2 - 2 \times a_L \times R) > 0$ and $TTC \leq 5$ sec

$$TTC = \frac{-Rdot + \sqrt{Rdot^2 - 2 \times a_L \times R}}{a_L}$$

APPENDIX D. Distribution of Conflict and Near-Crash Rates by ACAS Status, Subject Groups, and Driving Conditions

DISTRIBUTION OF CONFLICTS FOR ALL CONDITIONS AND ALL SUBJECTS, ACAS DISABLED AND ACAS ENABLED

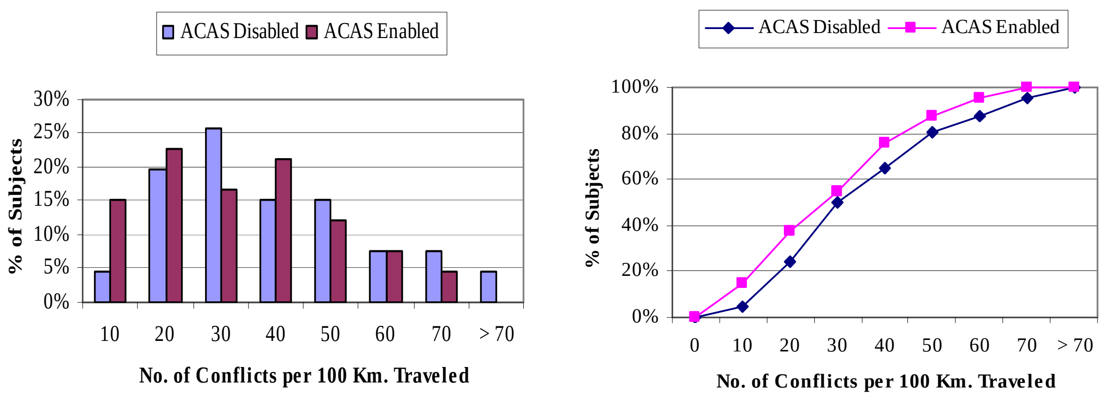


Figure D-1. Distribution of Low-Intensity Conflicts, All Conditions, All Subjects, ACAS-Disabled versus ACAS-Enabled

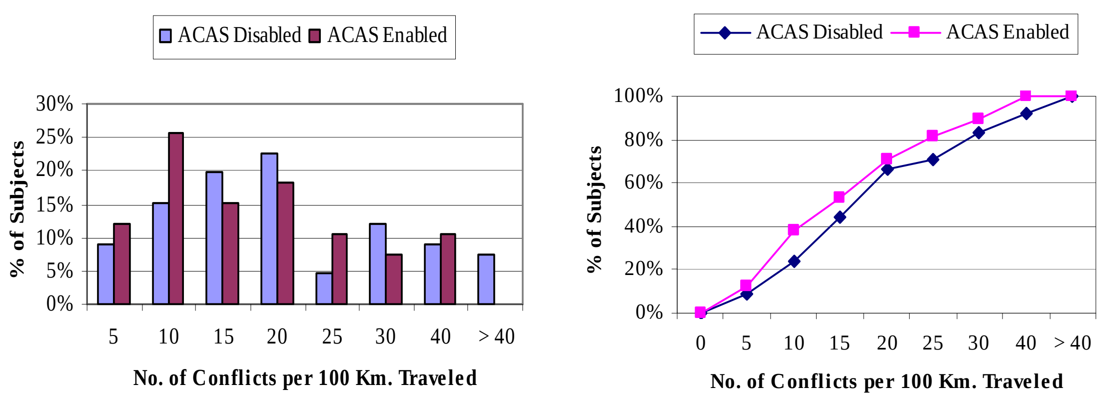


Figure D-2. Distribution of High-Intensity Conflicts, All Conditions, All Subjects, ACAS-Disabled versus ACAS-Enabled

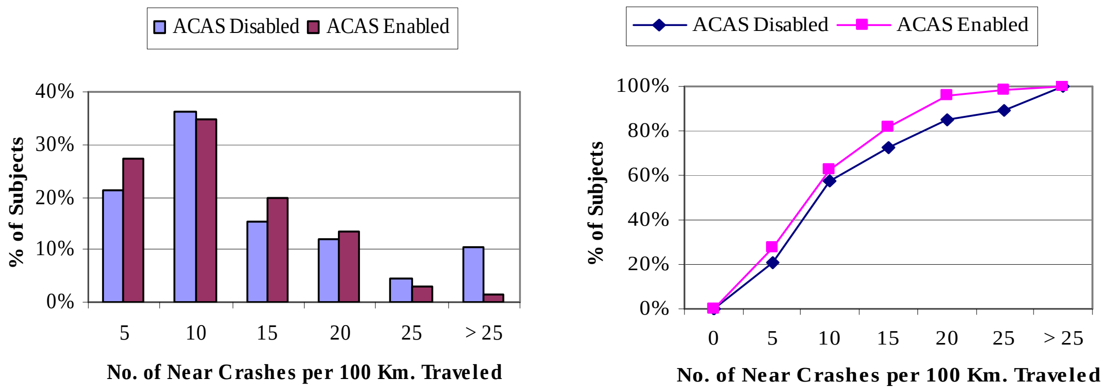


Figure D-3. Distribution of Low-Intensity Near-Crashes, All Conditions, All Subjects, ACAS-Disabled versus ACAS-Enabled

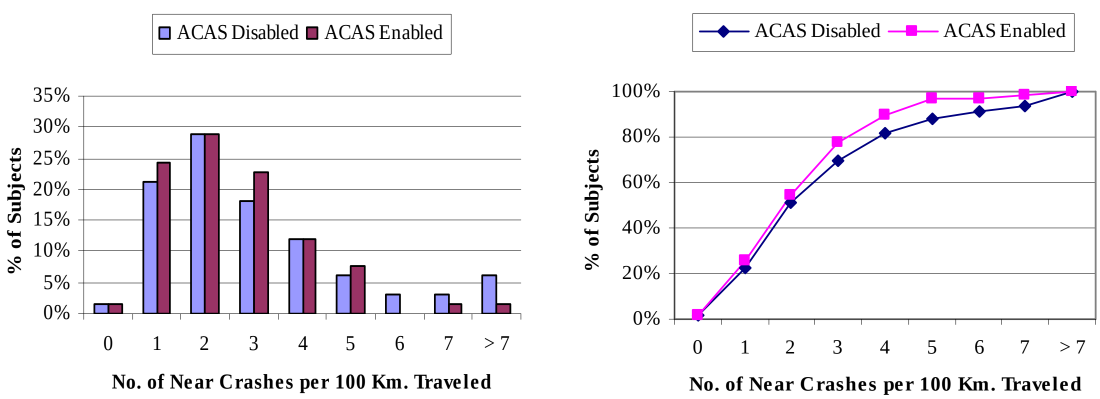


Figure D-4. Distribution of High-Intensity Near-Crashes, All Conditions, All Subjects, ACAS-Disabled versus ACAS-Enabled

DISTRIBUTION OF CONFLICTS BY SUBJECT GROUP, ACAS DISABLED AND ACAS ENABLED

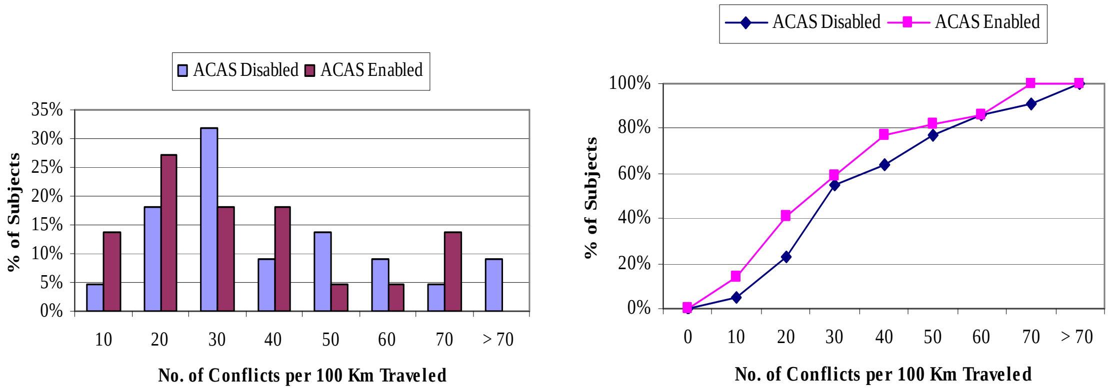


Figure D-5. Distribution of Low-Intensity Conflicts for Younger Drivers, ACAS-Disabled versus ACAS-Enabled

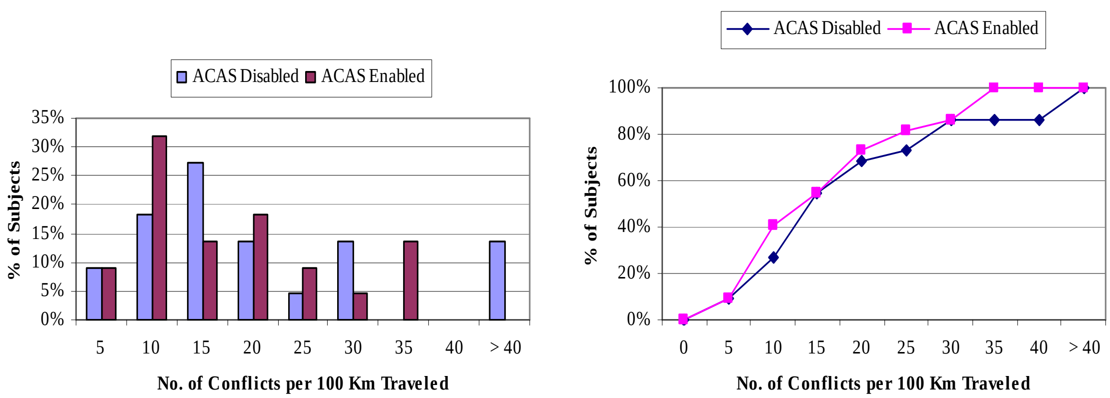


Figure D-6. Distribution of High-Intensity Conflicts for Younger Drivers, ACAS-Disabled versus ACAS-Enabled

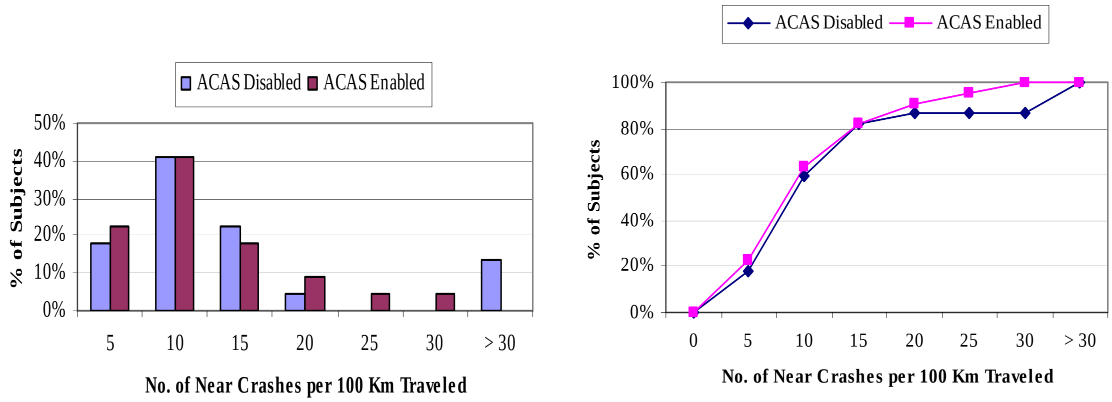


Figure D-7. Distribution of Low-Intensity Near-Crashes for Younger Drivers, ACAS-Disabled vs. ACAS-Enabled

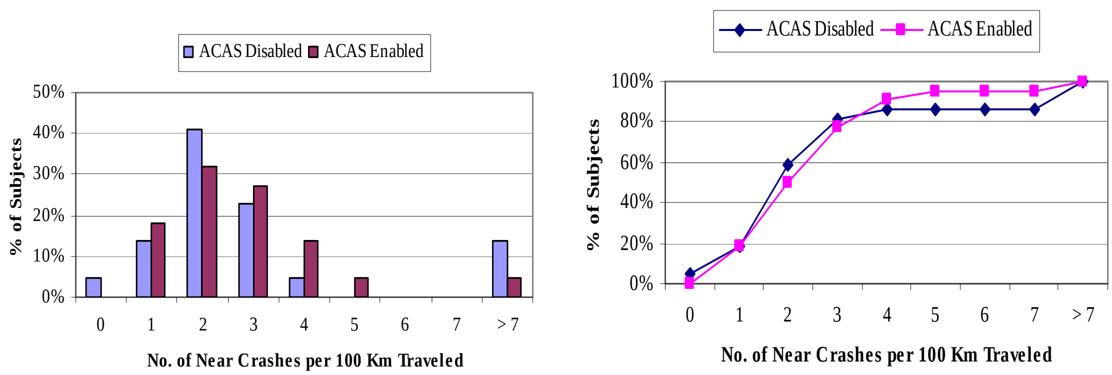


Figure D-8. Distribution of High-Intensity Near-Crashes for Younger Drivers, ACAS-Disabled vs. ACAS-Enabled

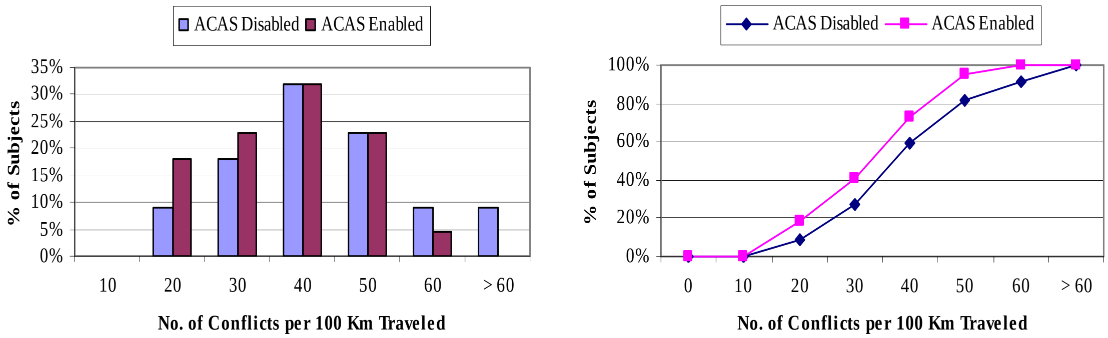


Figure D-9. Distribution of Low-Intensity Conflicts for Middle-Age Drivers, ACAS-Disabled versus ACAS-Enabled

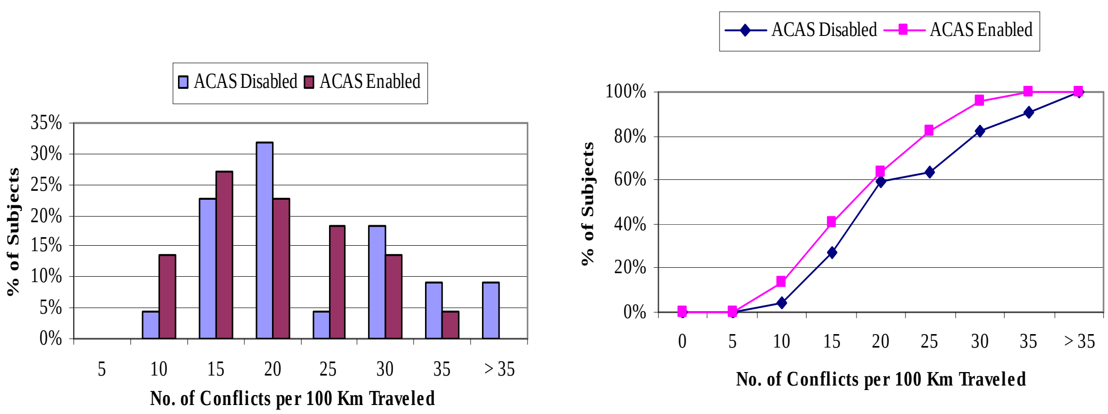
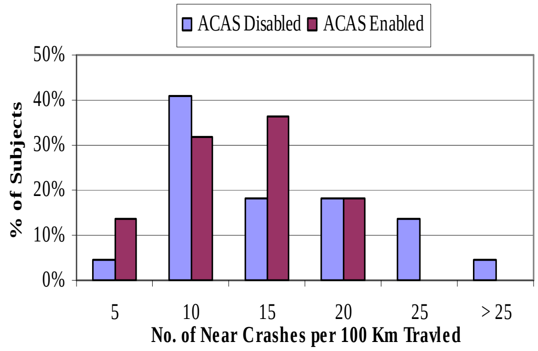


Figure D-10. Distribution of High-Intensity Conflicts for Middle-Age Drivers, ACAS-Disabled versus ACAS-Enabled



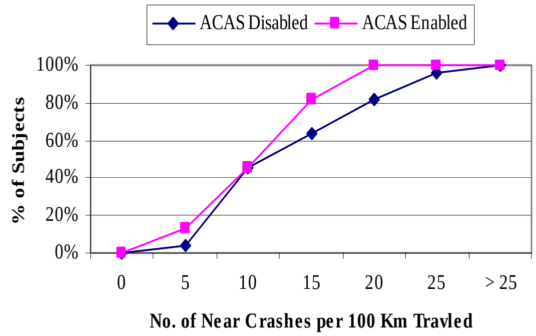
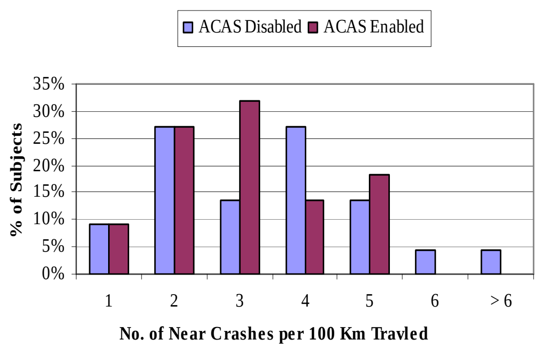


Figure D-11. Distribution of Low-Intensity Near-Crashes for Middle-Age Drivers, ACAS-Disabled versus ACAS-Enabled



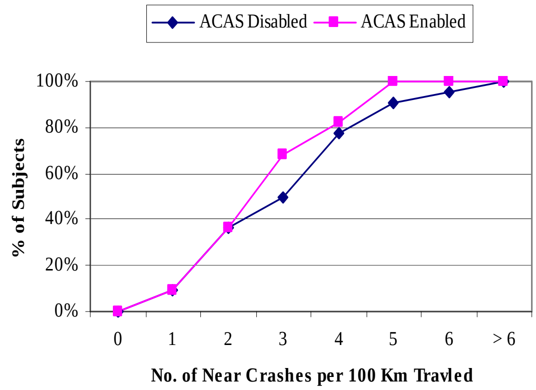


Figure D-12. Distribution of High-Intensity Near-Crashes for Middle-Age Drivers, ACAS-Disabled versus ACAS-Enabled

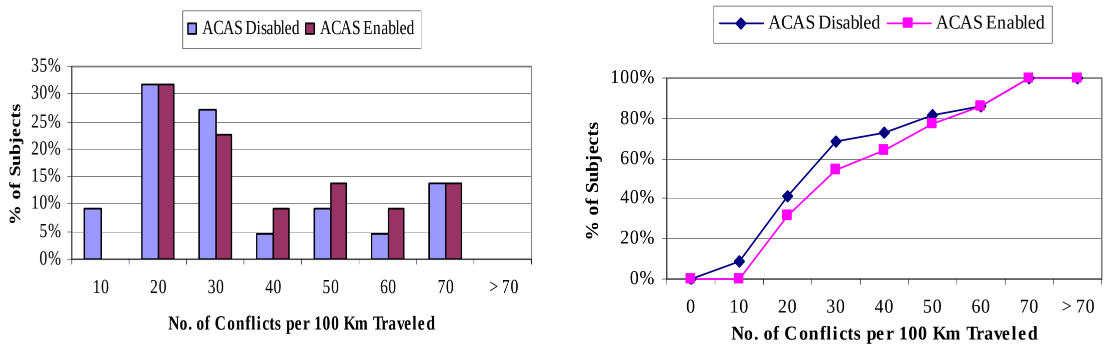


Figure D-13. Distribution of Low-Intensity Conflicts for Older Drivers, ACAS-Disabled versus ACAS-Enabled

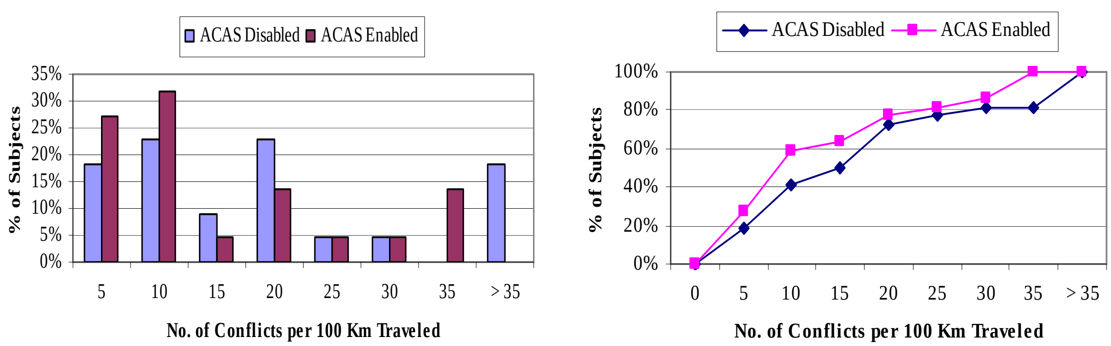
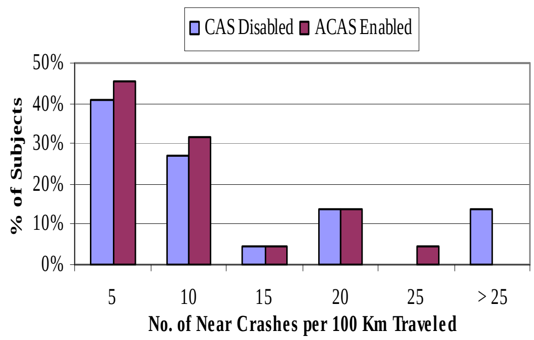


Figure D-14. Distribution of High-Intensity Conflicts for Older Drivers, ACAS-Disabled versus ACAS-Enabled



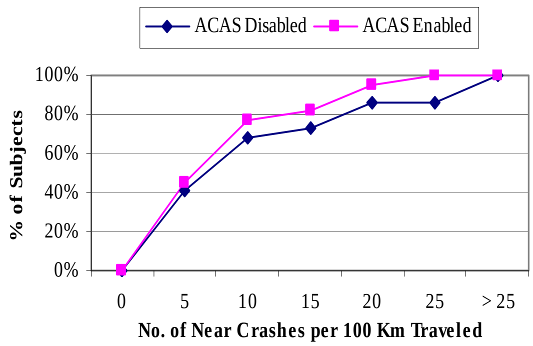
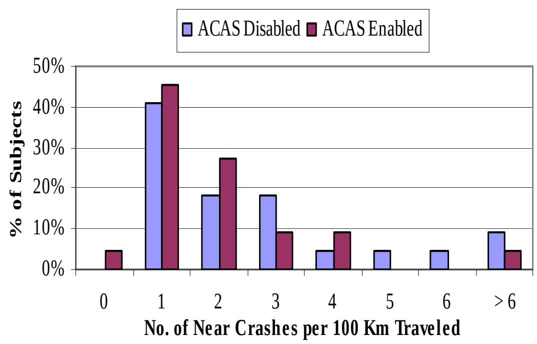


Figure D-15. Distribution of Low-Intensity Near-Crashes for Older Drivers, ACAS-Disabled versus ACAS-Enabled



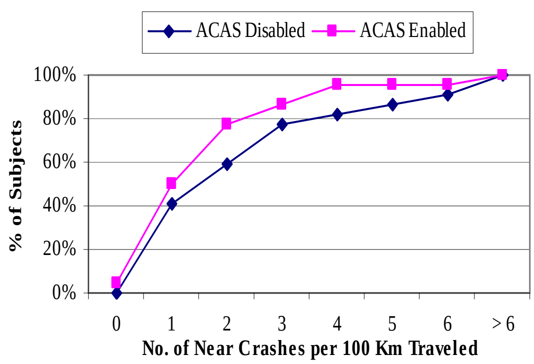


Figure D-16. Distribution of High-Intensity Near-Crashes for Older Drivers, ACAS-Disabled versus ACAS-Enabled

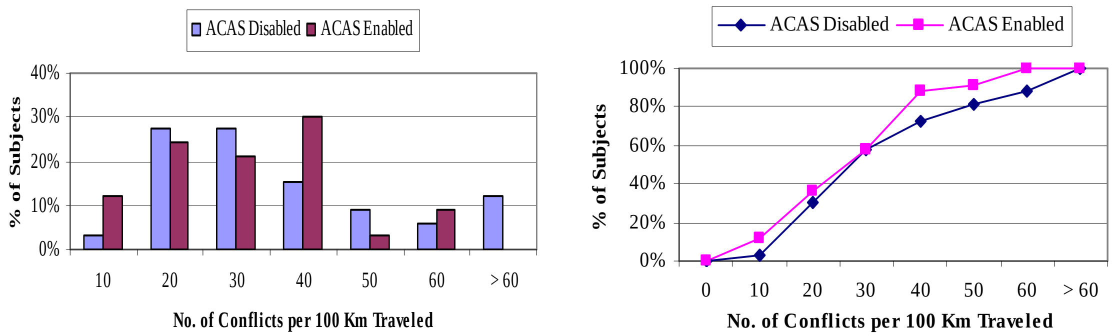


Figure D-17. Distribution of Low-Intensity Conflicts for Male Drivers, ACAS-Disabled versus ACAS-Enabled

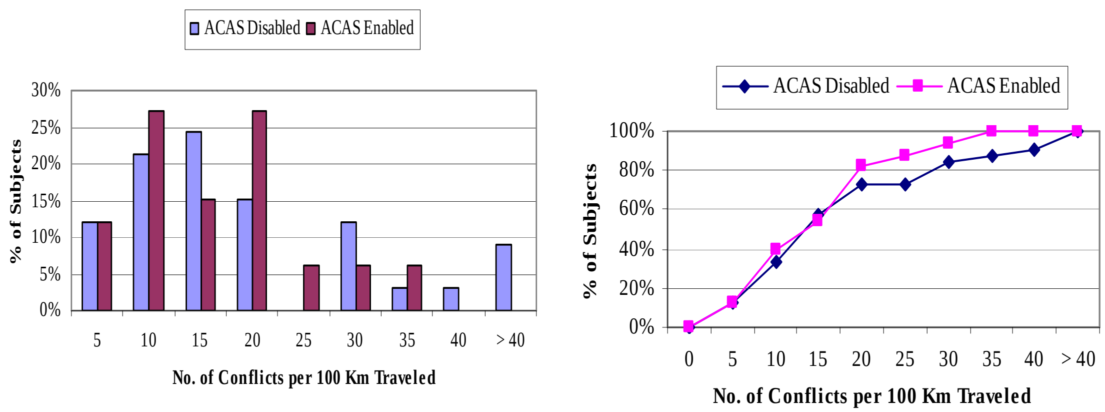


Figure D-18. Distribution of High-Intensity Conflicts for Male Drivers, ACAS-Disabled versus ACAS-Enabled

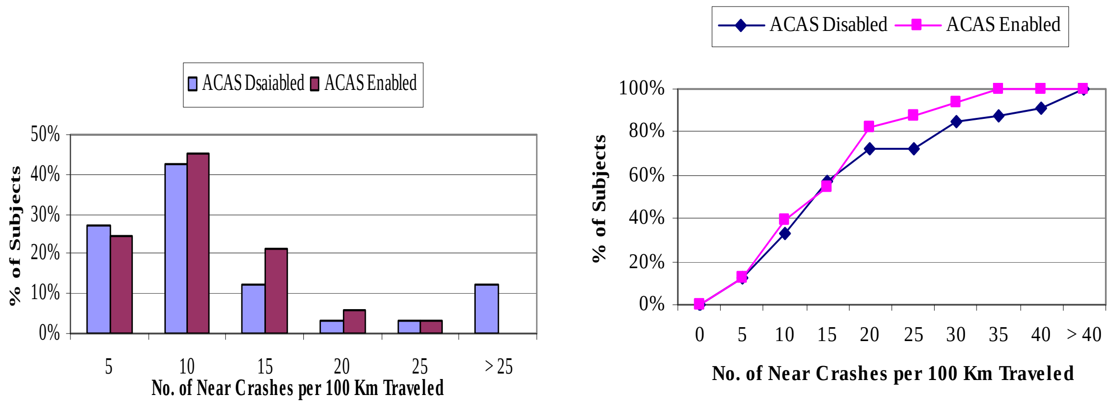


Figure D-19. Distribution of Low-Intensity Near-Crashes for Male Drivers, ACAS-Disabled versus ACAS-Enabled

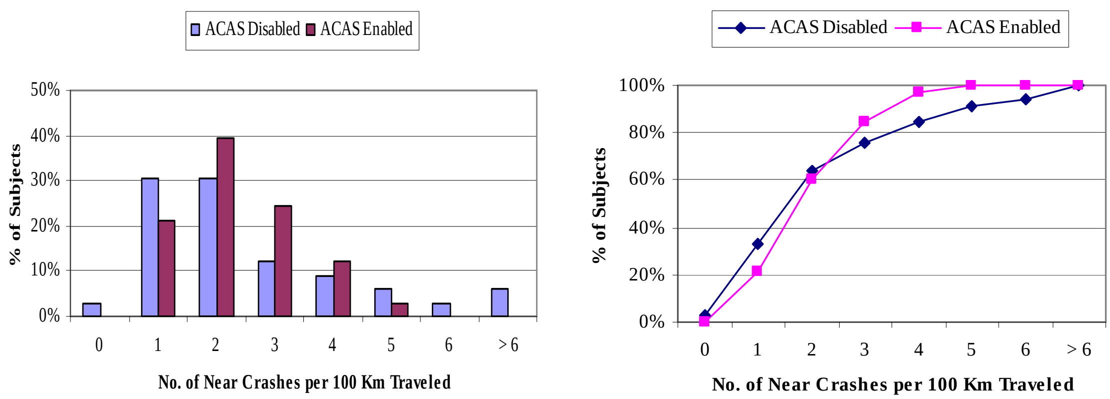


Figure D-20. Distribution of High-Intensity Near-Crashes for Male Drivers, ACAS-Disabled versus ACAS-Enabled

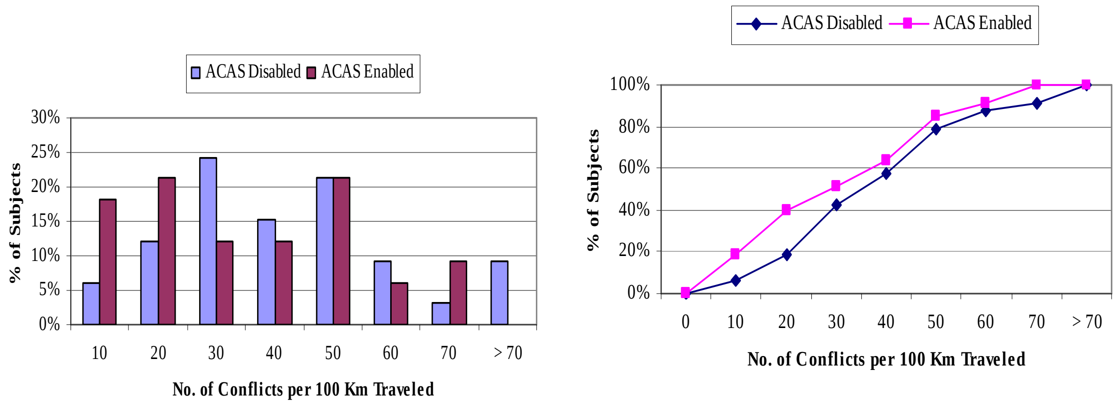


Figure D-21. Distribution of Low-Intensity Conflicts for Female Drivers, ACAS-Disabled versus ACAS-Enabled

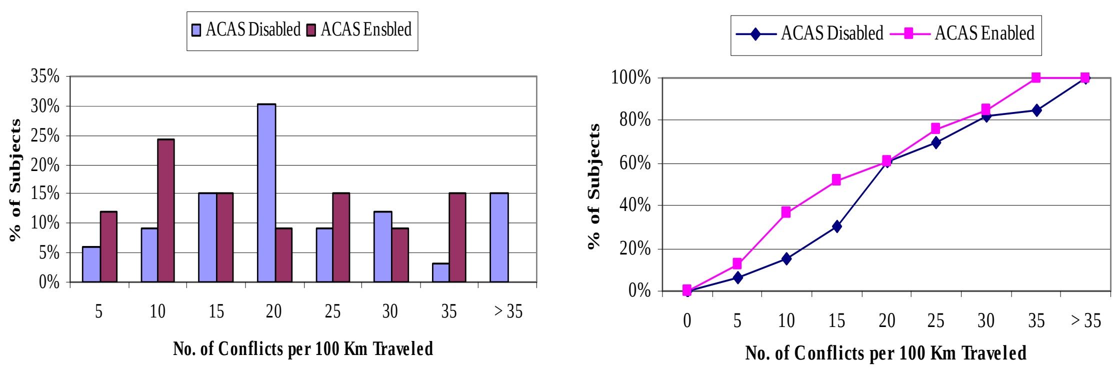


Figure D-22. Distribution of High-Intensity Conflicts for Female Drivers, ACAS-Disabled versus ACAS-Enabled

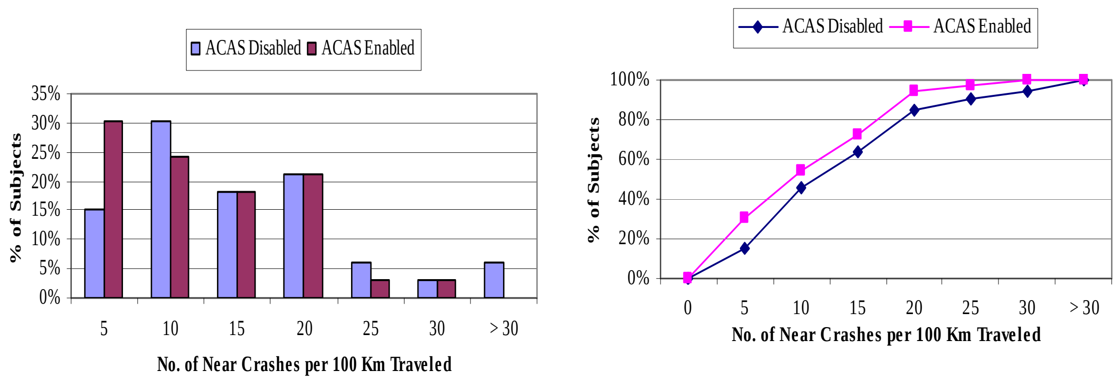


Figure D-23. Distribution of Low-Intensity Near-Crashes for Female Drivers, ACAS-Disabled versus ACAS-Enabled

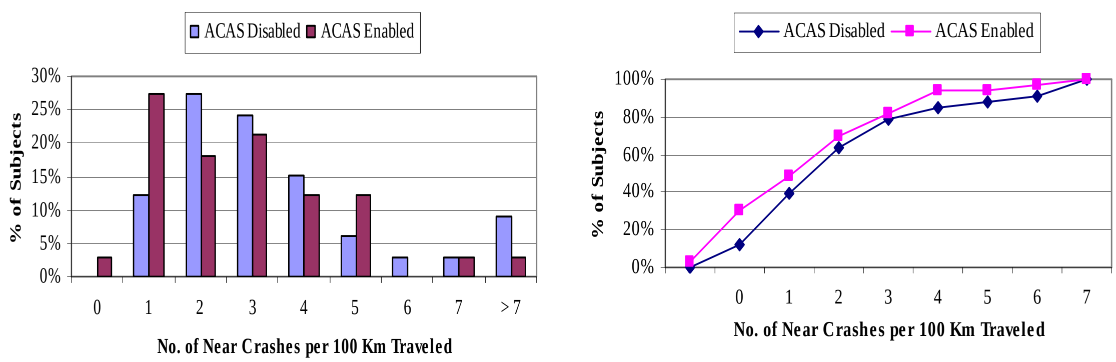


Figure D-24. Distribution of High-Intensity Near-Crashes for Female Drivers, ACAS-Disabled versus ACAS-Enabled

DISTRIBUTION OF CONFLICTS BY DRIVING CONDITIONS AND ALL SUBJECTS, ACAS DISABLED AND ACAS ENABLED

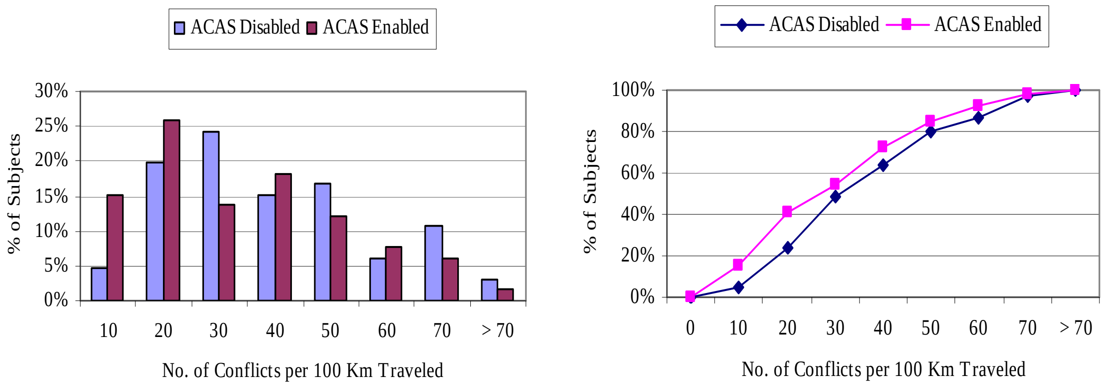


Figure D-25. Distribution of Low-Intensity Conflicts in Clear weather, ACAS-Disabled versus ACAS-Enabled

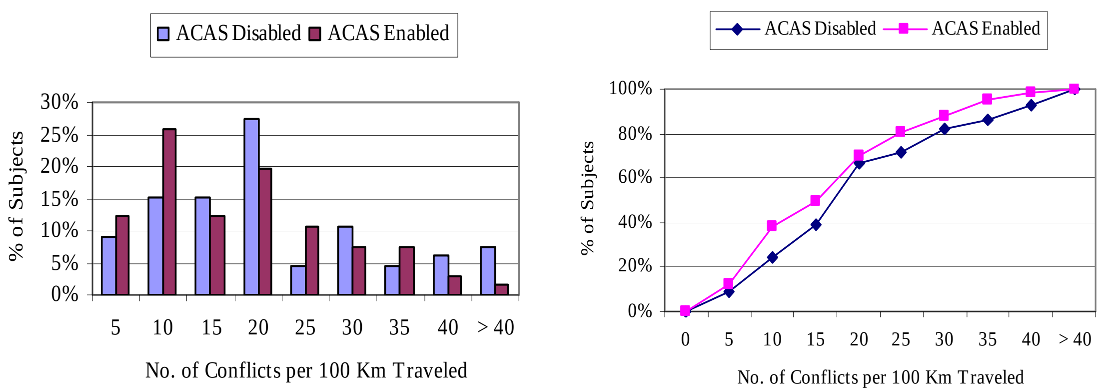
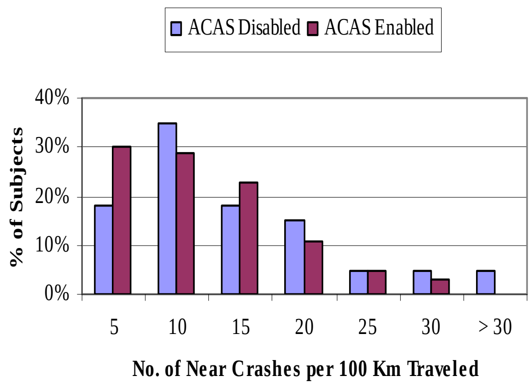


Figure D-26. Distribution of High-Intensity Conflicts in Clear Weather, ACAS-Disabled versus ACAS-Enabled



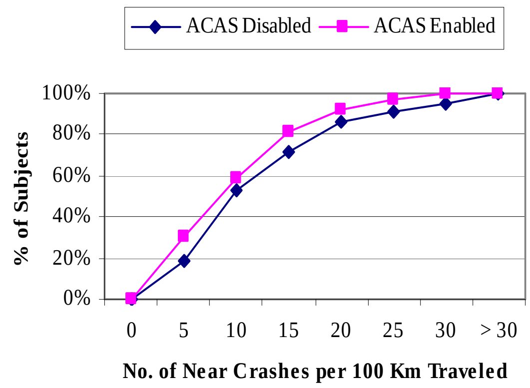
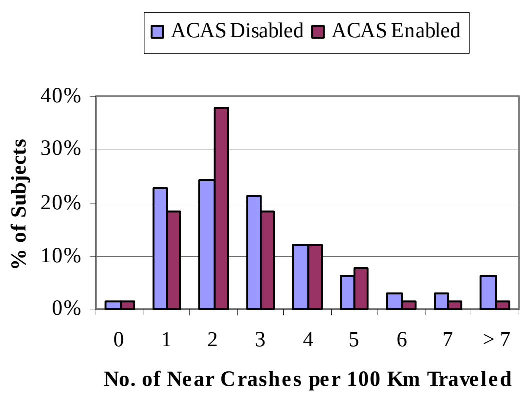


Figure D-27. Distribution of Low-Intensity Near-Crashes in Clear Weather, ACAS-Disabled versus ACAS-Enabled



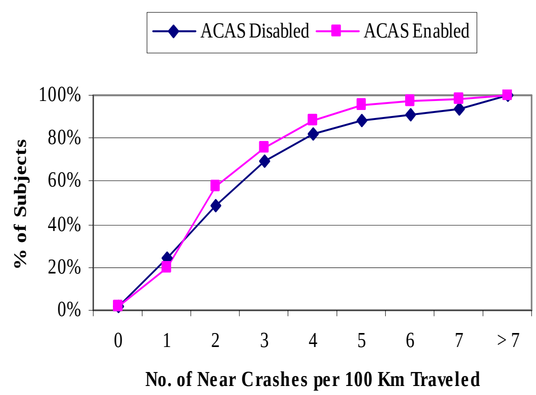
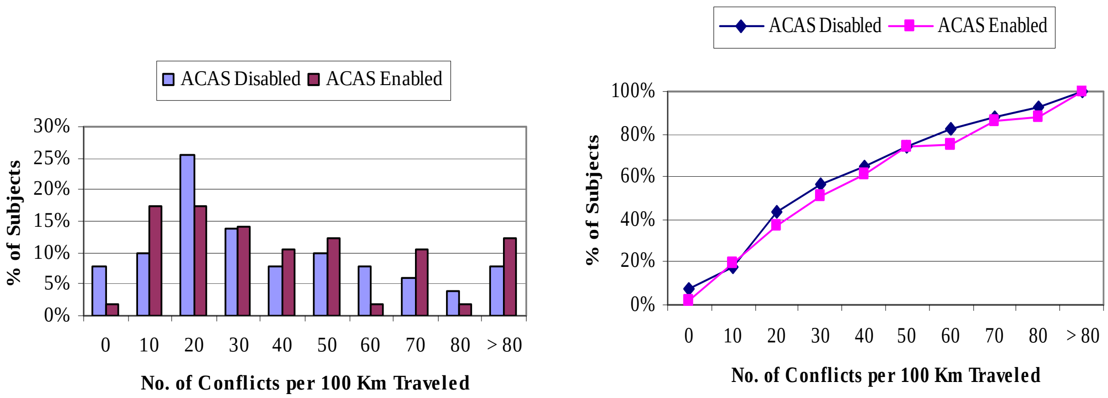
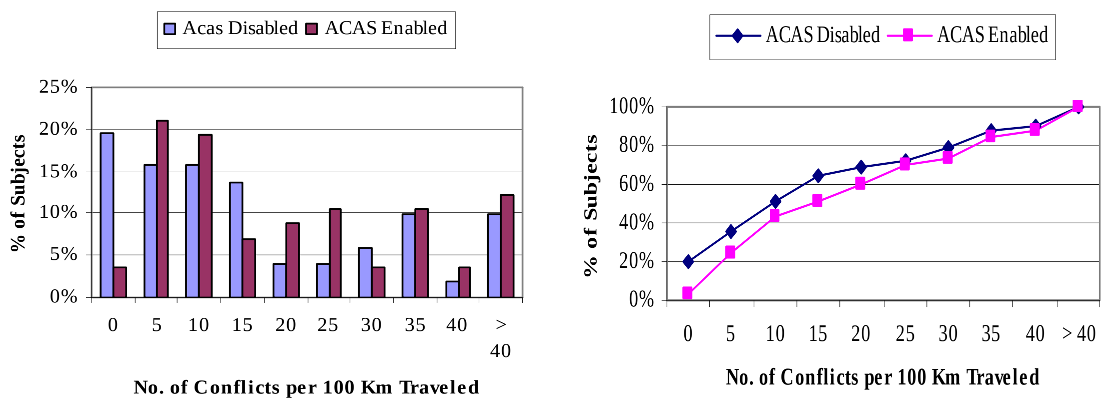


Figure D-28. Distribution of High-Intensity Near-Crashes in Clear Weather, ACAS-Disabled versus ACAS-Enabled



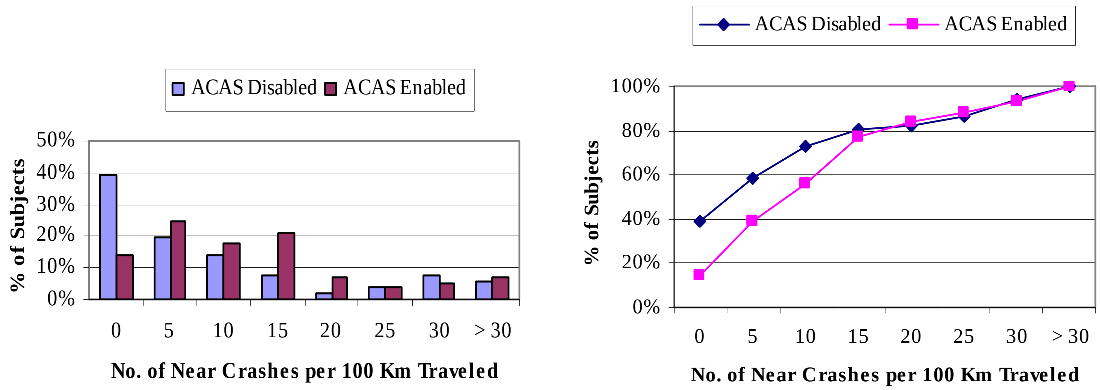
Note: ACAS-Disabled = 51 Subjects, ACAS-Enabled = 57 Subjects, for adverse weather

Figure D-29. Distribution of Low-Intensity Conflicts in Adverse Weather, ACAS-Disabled versus ACAS-Enabled



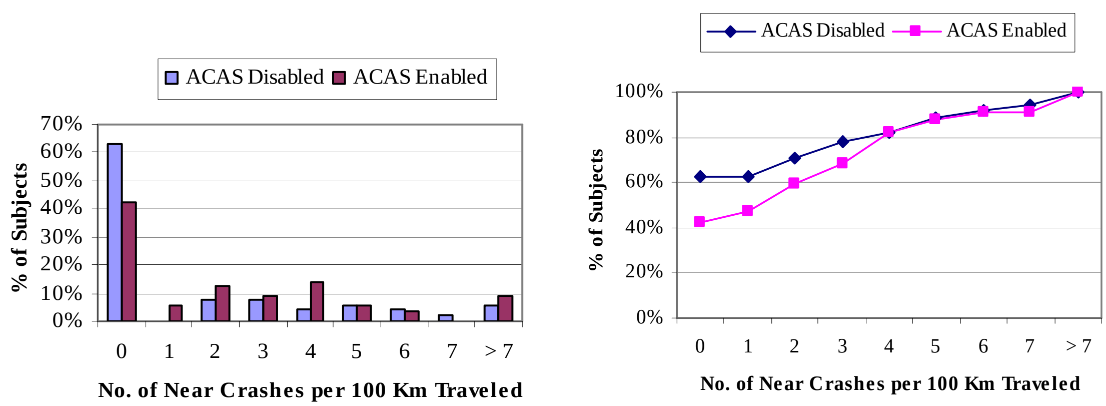
Note: ACAS-Disabled = 51 Subjects, ACAS-Enabled = 57 Subjects, for adverse weather

Figure D-30. Distribution of High-Intensity Conflicts in Adverse Weather, ACAS-Disabled versus ACAS-Enabled



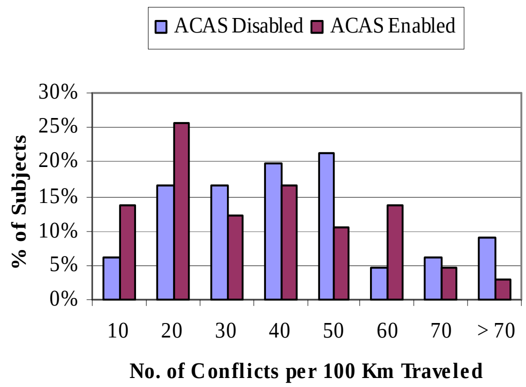
Note: ACAS-Disabled = 51 Subjects, ACAS-Enabled = 57 Subjects, for adverse weather

Figure D-31. Distribution of Low-Intensity Near-Crashes in Adverse Weather, ACAS-Disabled versus ACAS-Enabled



Note: ACAS-Disabled = 51 Subjects, ACAS-Enabled = 57 Subjects, for adverse weather

Figure D-32. Distribution of High-Intensity Near-Crashes in Adverse Weather, ACAS-Disabled versus ACAS-Enabled



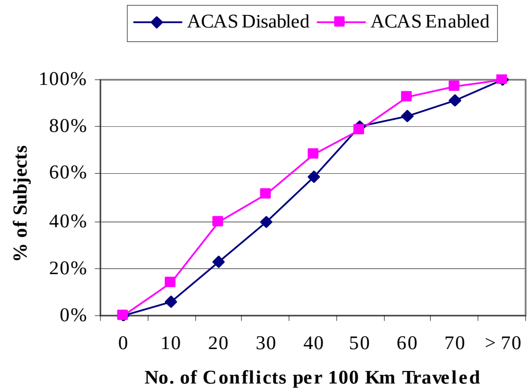
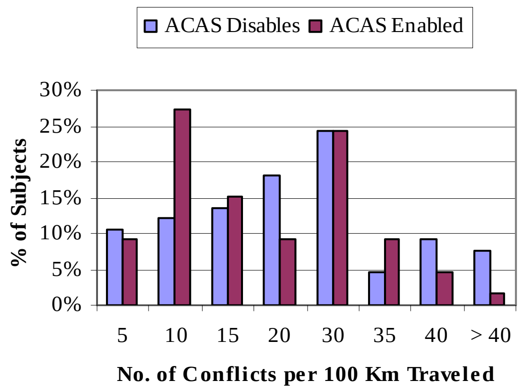


Figure D-33. Distribution of Low-Intensity Conflicts in Light Conditions, ACAS-Disabled versus ACAS-Enabled



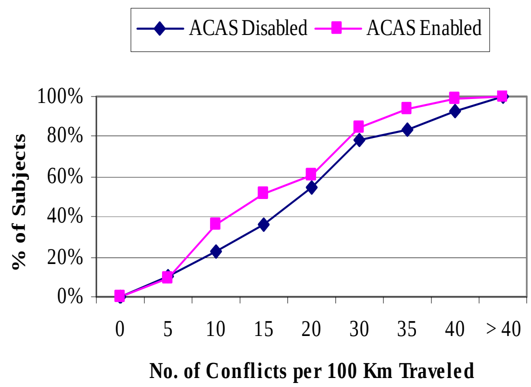


Figure D-34. Distribution of High-Intensity Conflicts in Light Conditions, ACAS-Disabled versus ACAS-Enabled

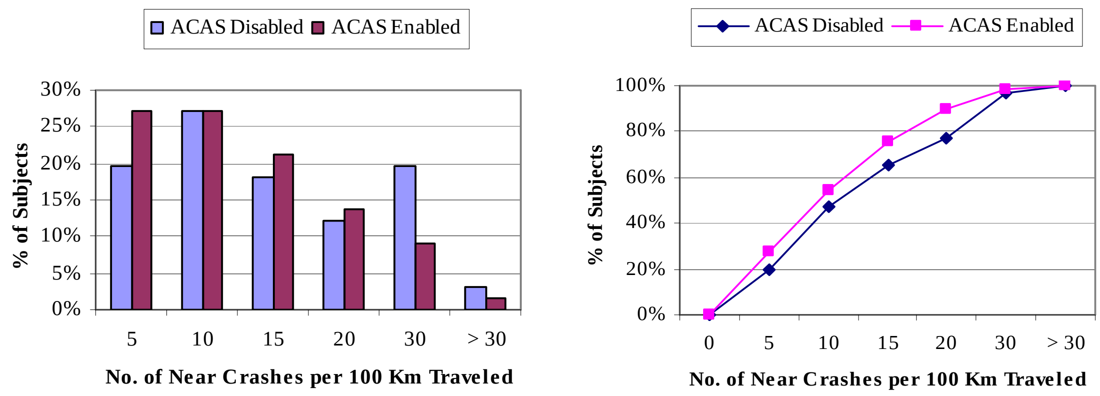


Figure D-35. Distribution of Low-Intensity Near-Crashes in Light Conditions, ACAS-Disabled versus ACAS-Enabled

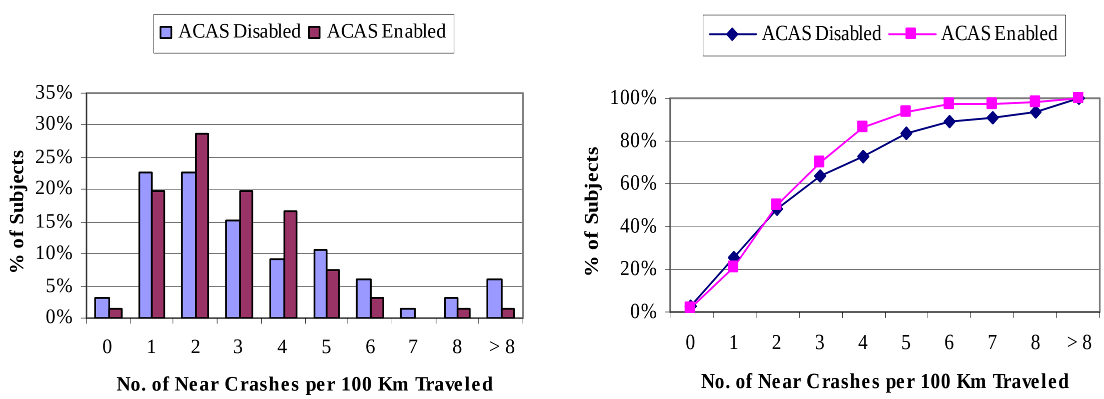
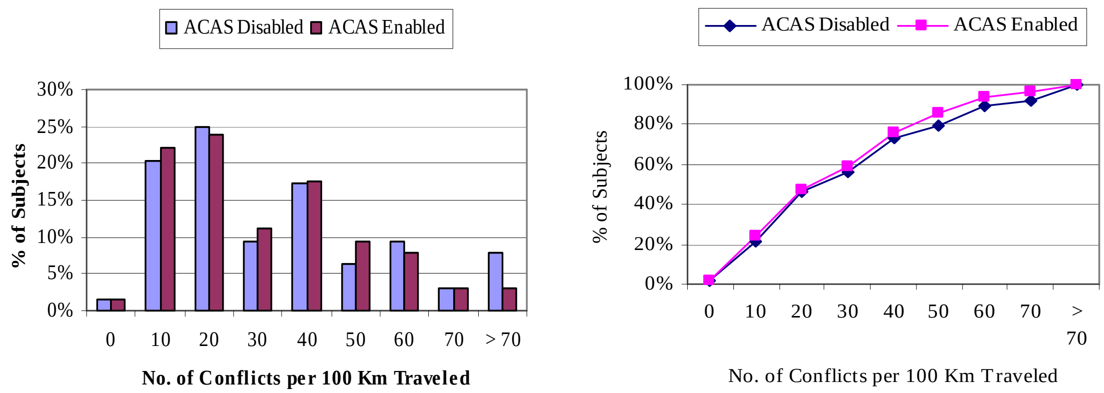
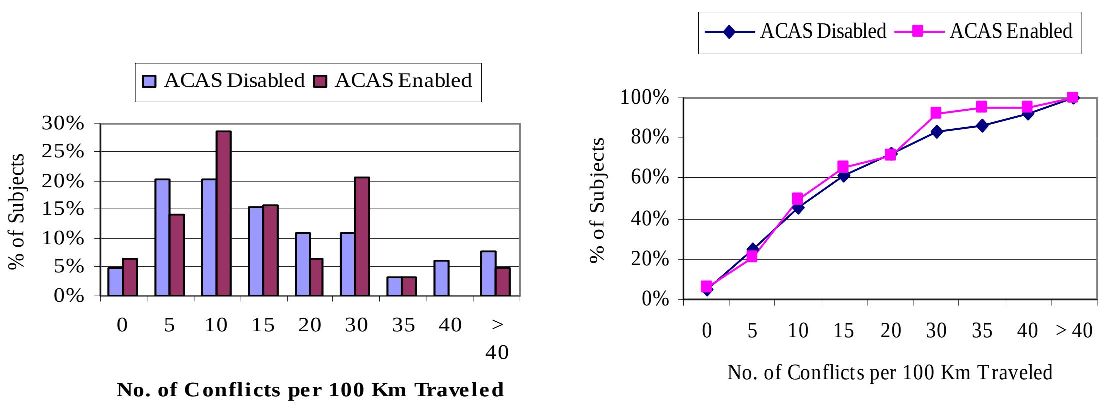


Figure D-36. Distribution of High-Intensity Near-Crashes in Light Conditions, ACAS-Disabled versus ACAS-Enabled



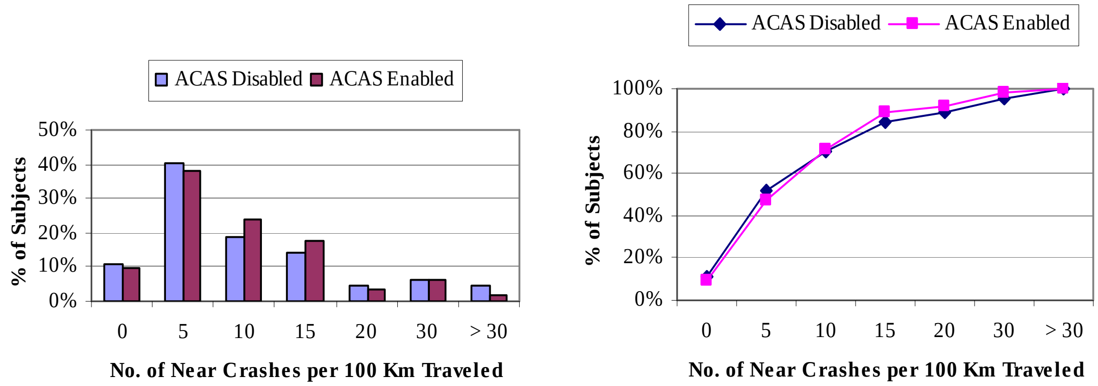
Note: ACAS-Disabled = 64 Subjects, ACAS-Enabled = 63 Subjects, for dark conditions

Figure D-37. Distribution of Low-Intensity Conflicts in Dark Conditions, ACAS-Disabled versus ACAS-Enabled



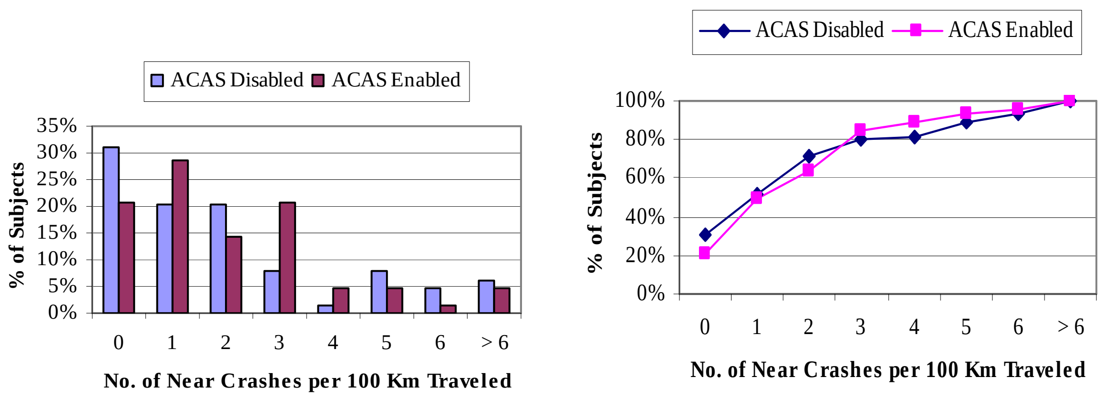
Note: ACAS-Disabled = 64 Subjects, ACAS-Enabled = 63 Subjects, for dark conditions

Figure D-38. Distribution of High-Intensity Conflicts in Dark Conditions, ACAS-Disabled versus ACAS-Enabled



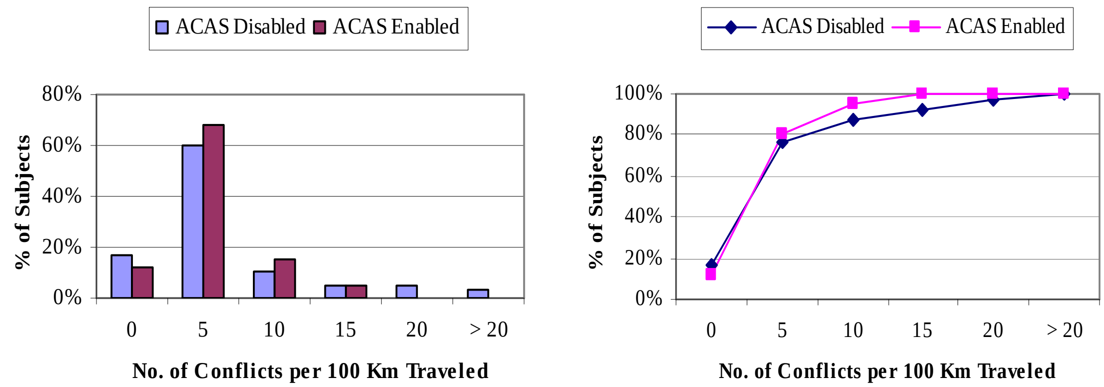
Note: ACAS-Disabled = 64 Subjects, ACAS-Enabled = 63 Subjects, for dark conditions

Figure D-39. Distribution of Low-Intensity Near-Crashes in Dark Conditions, ACAS-Disabled versus ACAS-Enabled



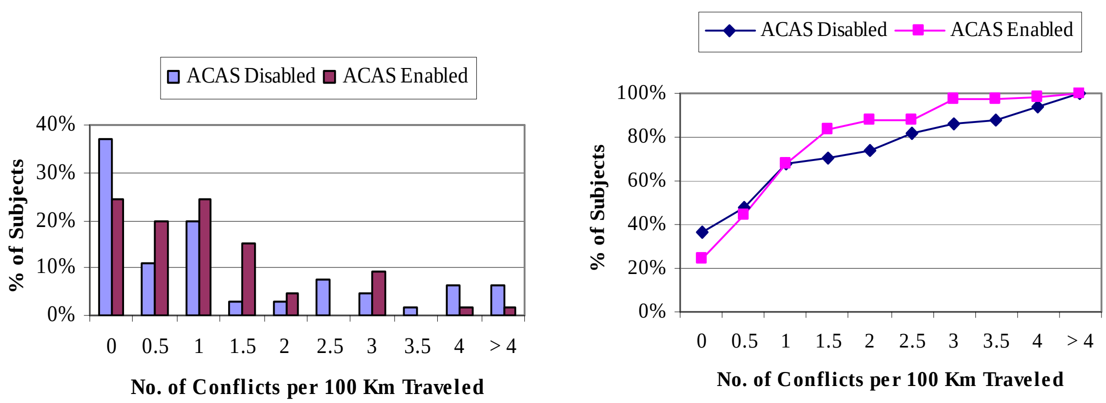
Note: ACAS-Disabled = 64 Subjects, ACAS-Enabled = 63 Subjects, for dark conditions

Figure D-40. Distribution of High Intensity Near-Crashes in Dark Conditions, ACAS-Disabled versus ACAS-Enabled



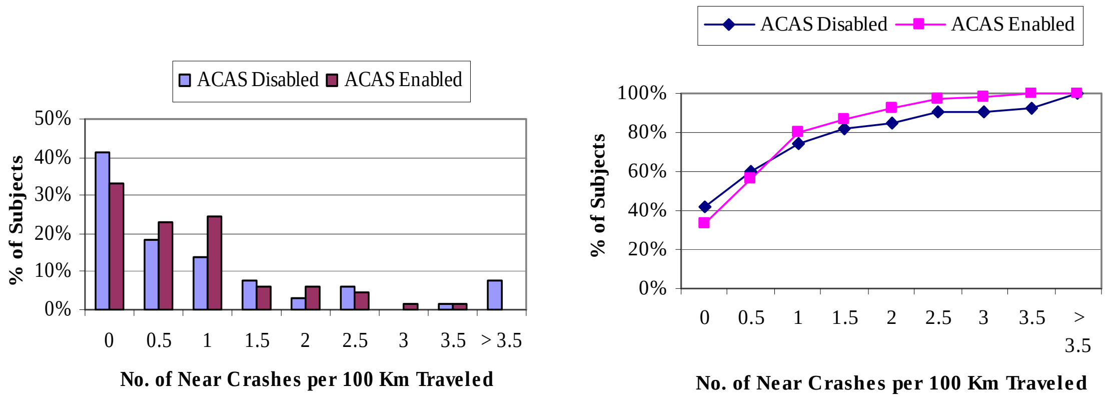
Note: ACAS-Disabled = 65 Subjects, ACAS-Enabled = 66 Subjects, on freeway

Figure D-41. Distribution of Low-Intensity Conflicts on Freeway, ACAS-Disabled versus ACAS-Enabled



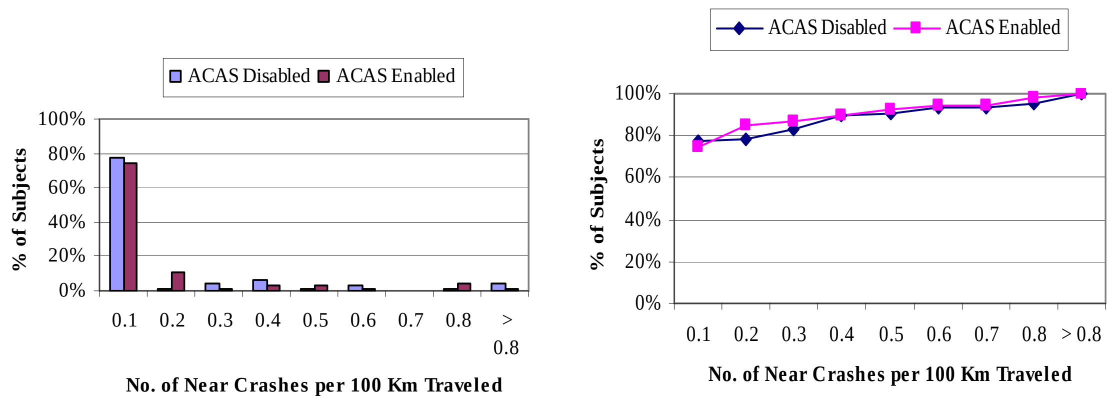
Note: ACAS-Disabled = 65 Subjects, ACAS-Enabled = 66 Subjects, on freeway

Figure D-42. Distribution of High-Intensity Conflicts on Freeway, ACAS-Disabled versus ACAS-Enabled



Note: ACAS-Disabled = 65 Subjects, ACAS-Enabled = 66 Subjects, on freeway

Figure D-43. Distribution of Low-Intensity Near-Crashes on Freeway, ACAS-Disabled versus ACAS-Enabled



Note: ACAS-Disabled = 65 Subjects, ACAS-Enabled = 66 Subjects, on freeway

Figure D-44. Distribution of High-Intensity Near-Crashes on Freeway, ACAS-Disabled versus ACAS-Enabled

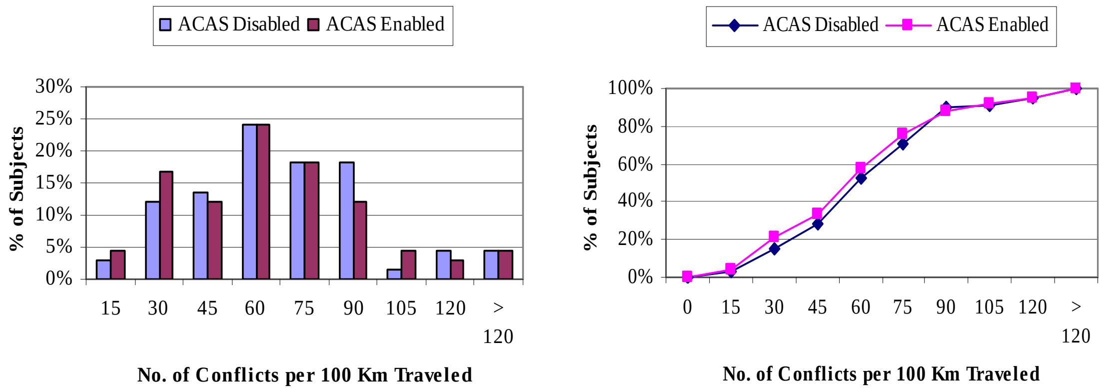


Figure D-45. Distribution of Low-Intensity Conflicts on Non-Freeway, ACAS-Disabled versus ACAS-Enabled

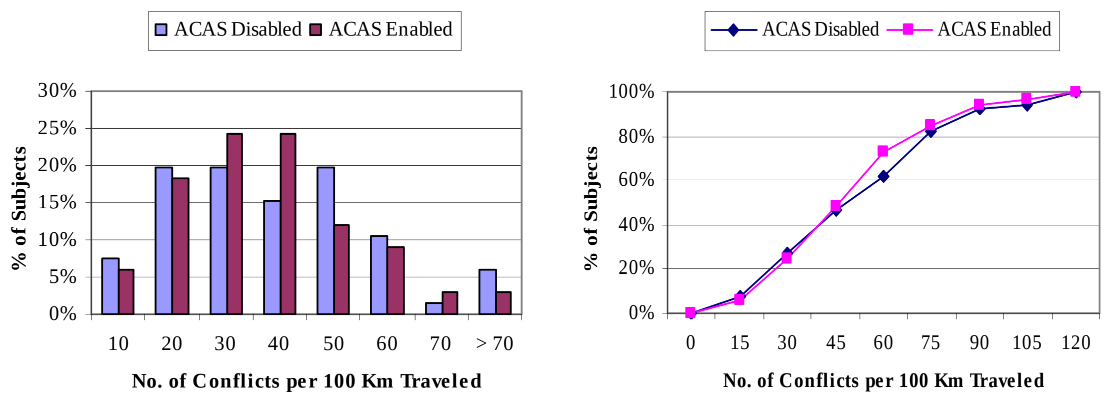


Figure D-46. Distribution of High-Intensity Conflicts on Non-Freeway, ACAS-Disabled versus ACAS-Enabled

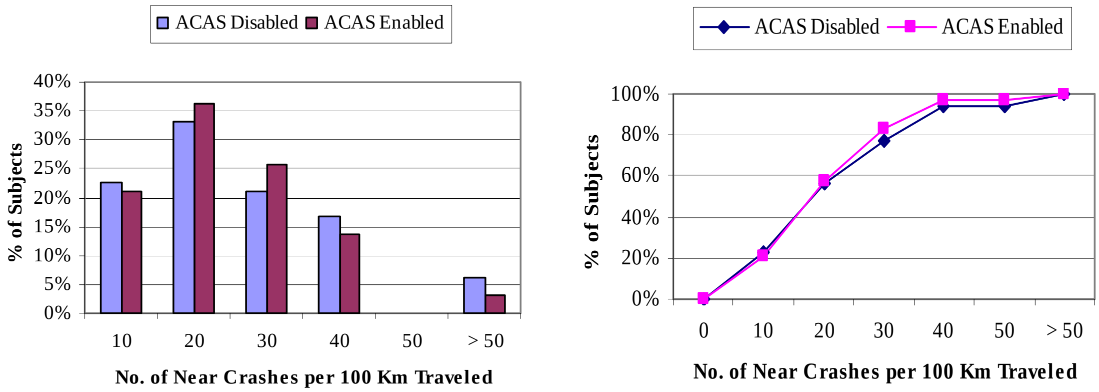


Figure D-47. Distribution of Low-Intensity Near-Crashes on Non-Freeway, ACAS-Disabled versus ACAS-Enabled

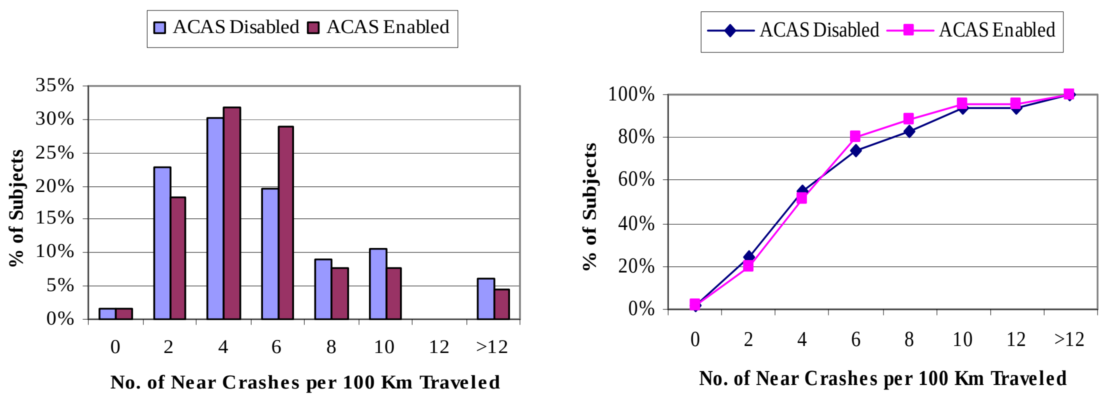
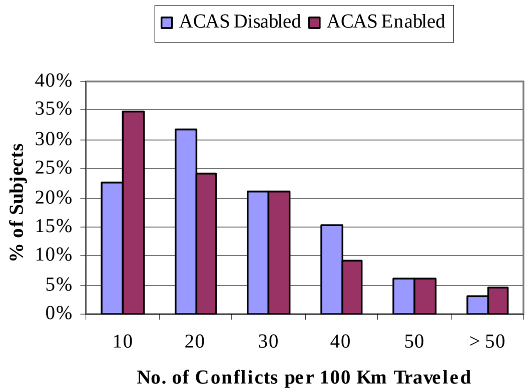


Figure D-48. Distribution of High-Intensity Near-Crashes on Non-Freeway, ACAS-Disabled versus ACAS-Enabled



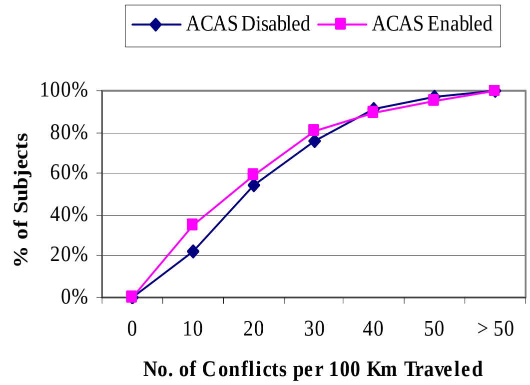
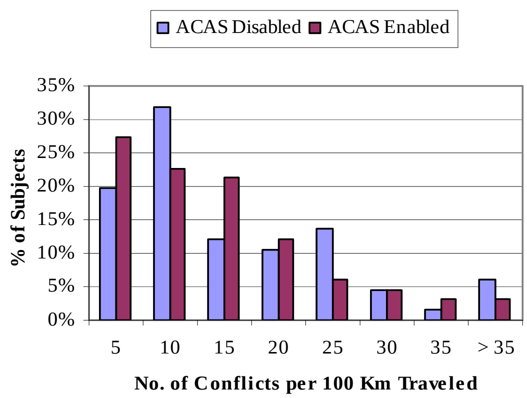


Figure D-49. Distribution of Low-Intensity Conflicts in Light LOS, ACAS-Disabled versus ACAS-Enabled



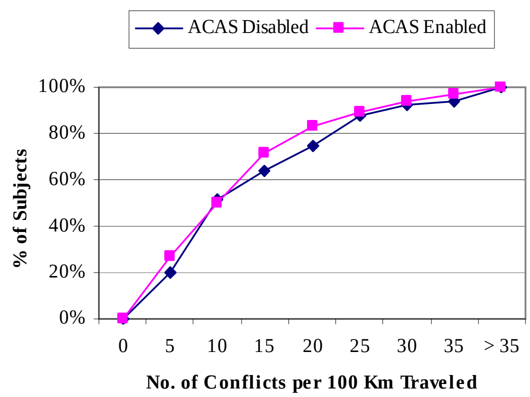


Figure D-50. Distribution of High-Intensity Conflicts in Light LOS, ACAS-Disabled versus ACAS-Enabled

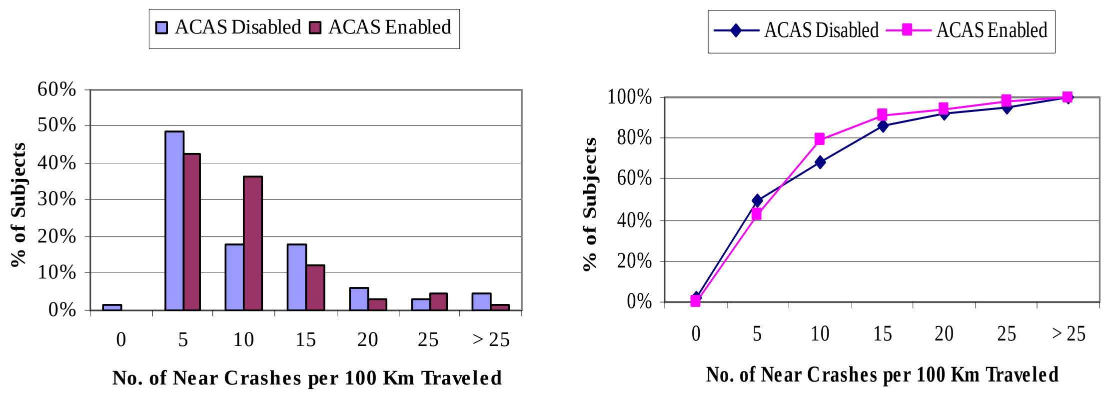


Figure D-51. Distribution of Low-Intensity Near-Crashes in Light LOS, ACAS-Disabled versus ACAS-Enabled

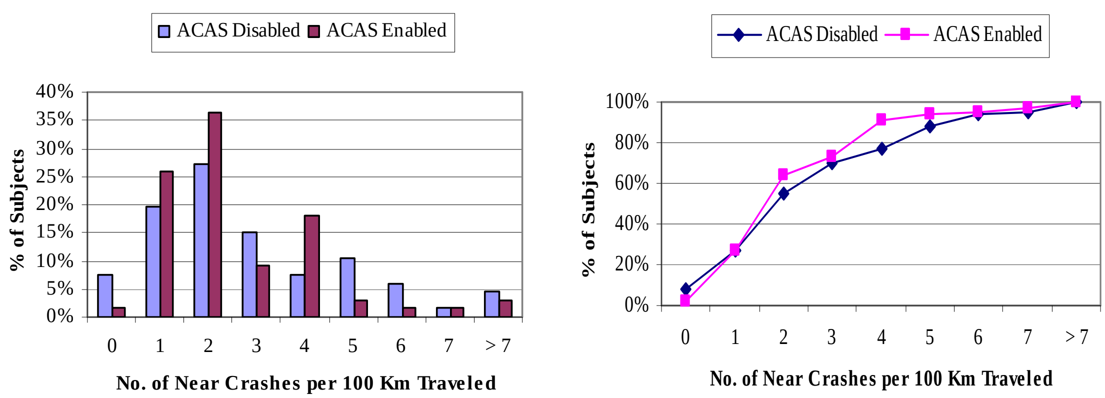


Figure D-52. Distribution of High-Intensity near Crashes in Light LOS, ACAS-Disabled versus ACAS-Enabled

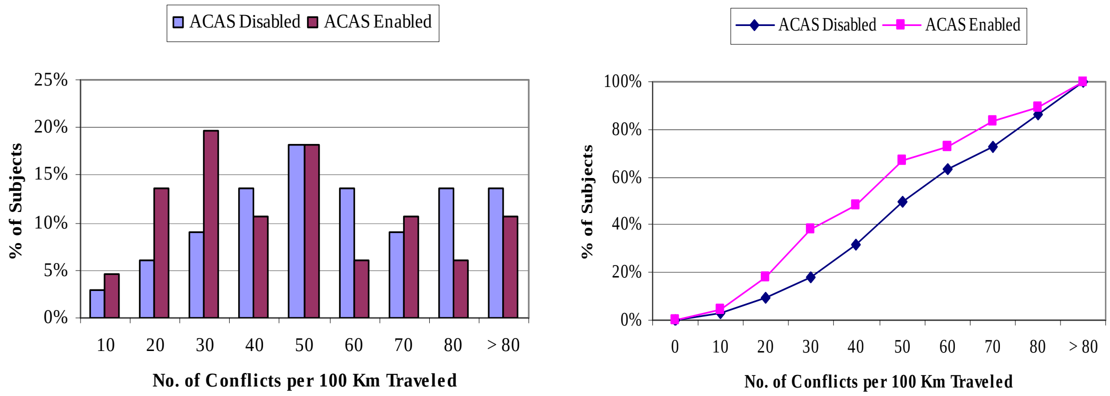


Figure D-53. Distribution of Low-Intensity Conflicts in Moderate LOS, ACAS-Disabled versus ACAS-Enabled

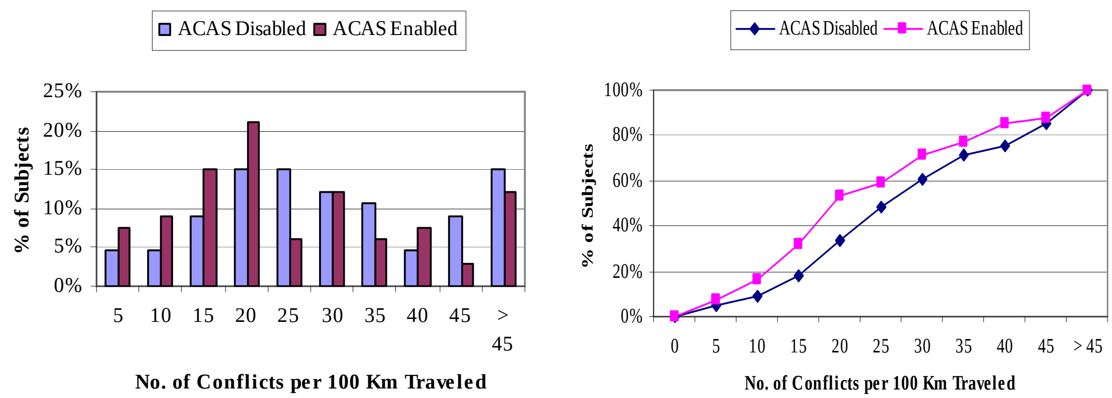
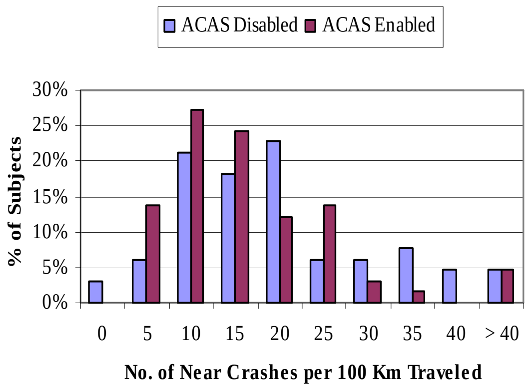


Figure D-54. Distribution of High-Intensity Conflicts in Moderate LOS, ACAS-Disabled versus ACAS-Enabled



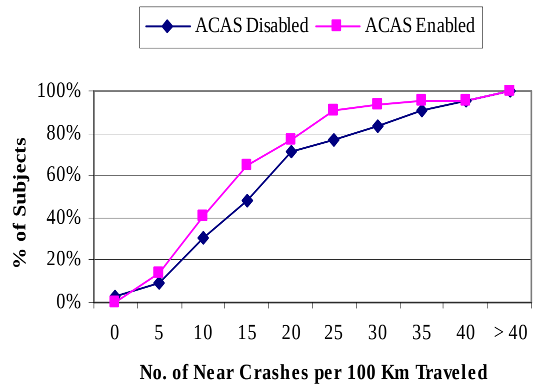
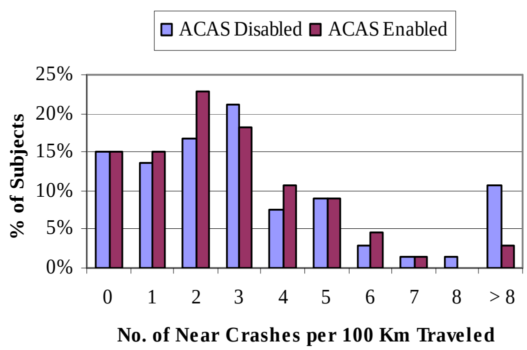


Figure D-55. Distribution of Low-Intensity Near-Crashes in Moderate LOS, ACAS-Disabled versus ACAS-Enabled



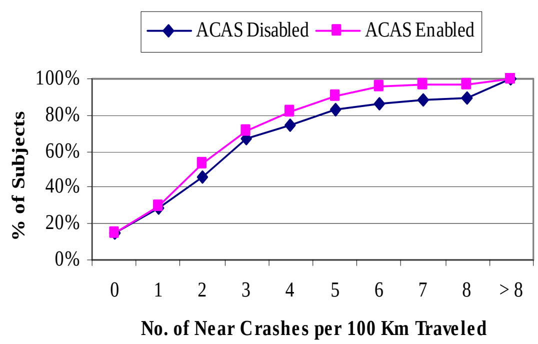
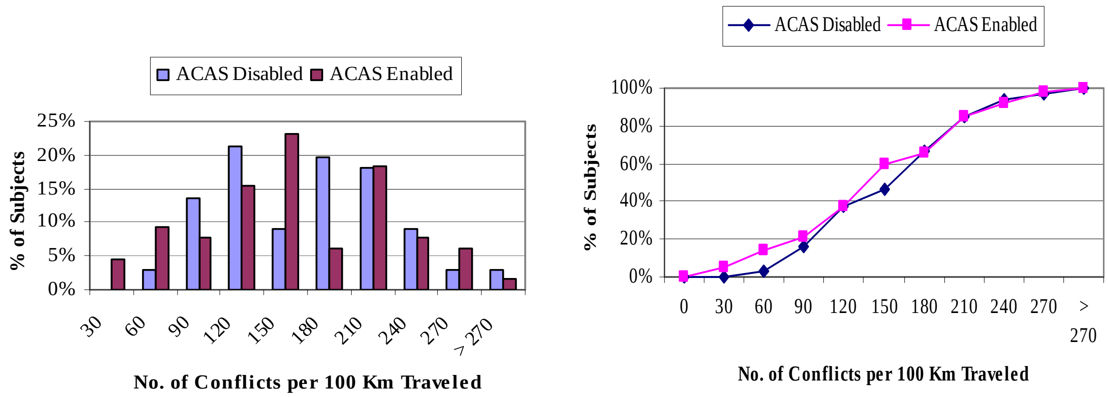
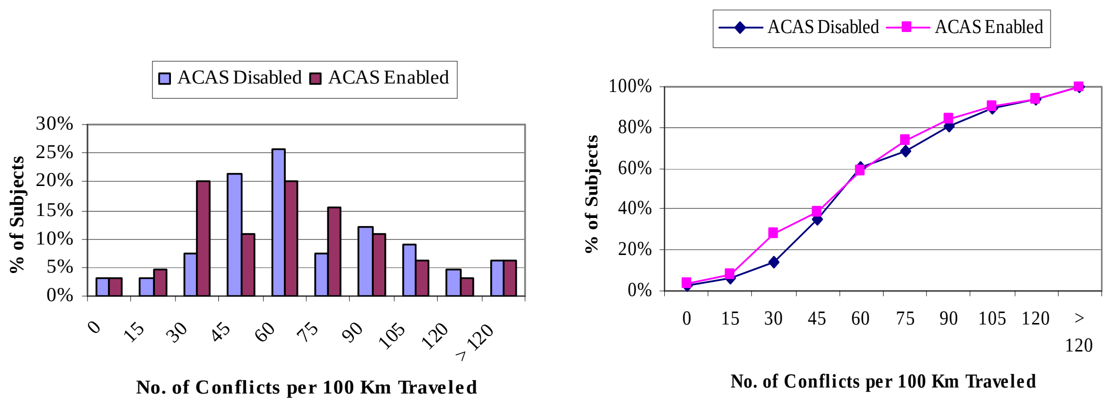


Figure D-56. Distribution of High-Intensity Near Crashes in Moderate LOS, ACAS-Disabled versus ACAS-Enabled



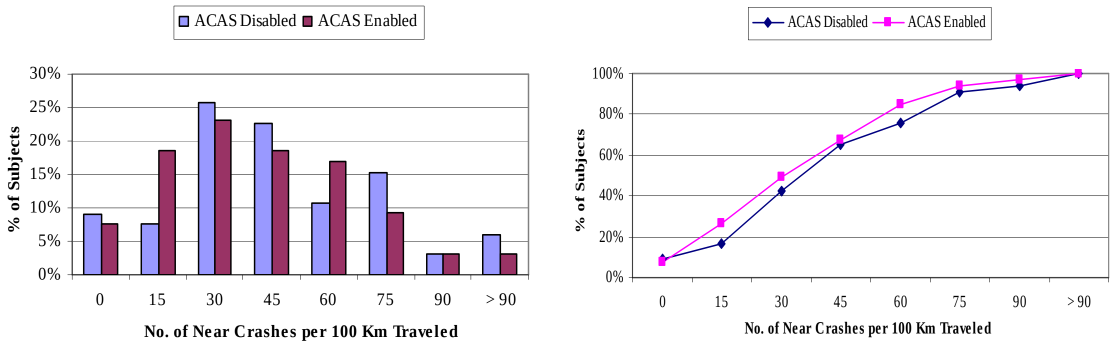
Note: ACAS-Disabled = 66 Subjects, ACAS-Enabled = 65 Subjects, in Heavy LOS

Figure D-57. Distribution of Low-Intensity Conflicts in Heavy LOS, ACAS-Disabled versus ACAS-Enabled



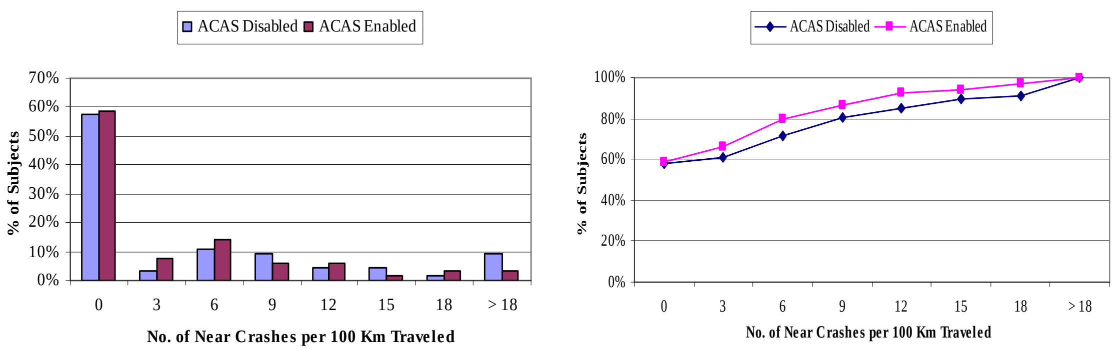
Note: ACAS-Disabled = 66 Subjects, ACAS-Enabled = 65 Subjects, in Heavy LOS

Figure D-58. Distribution of High-Intensity Conflicts in Heavy LOS, ACAS-Disabled versus ACAS-Enabled



Note: ACAS-Disabled = 66 Subjects, ACAS-Enabled = 65 Subjects, in Heavy LOS

Figure D-59. Distribution of Low-Intensity Near-Crashes in Heavy LOS, ACAS-Disabled versus ACAS-Enabled



Note: ACAS-Disabled = 66 Subjects, ACAS-Enabled = 65 Subjects, in Heavy LOS

Figure D-60. Distribution of High-Intensity Near-Crashes in Heavy LOS, ACAS-Disabled versus ACAS-Enabled

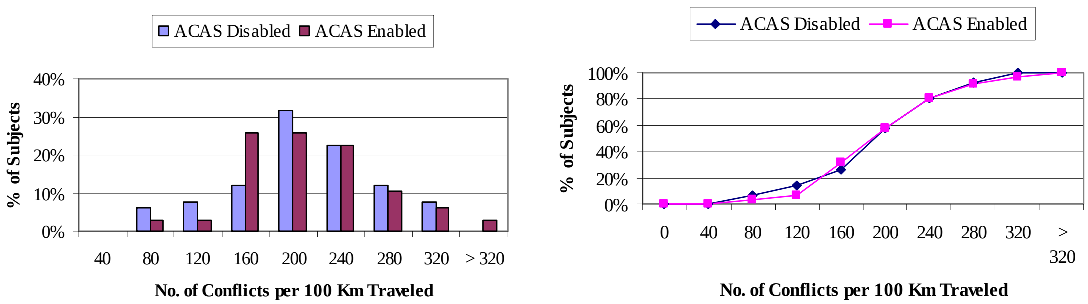


Figure D-61. Distribution of Low-Intensity Conflicts, ACAS Vehicle Speed < 25 mph, ACAS-Disabled versus ACAS-Enabled

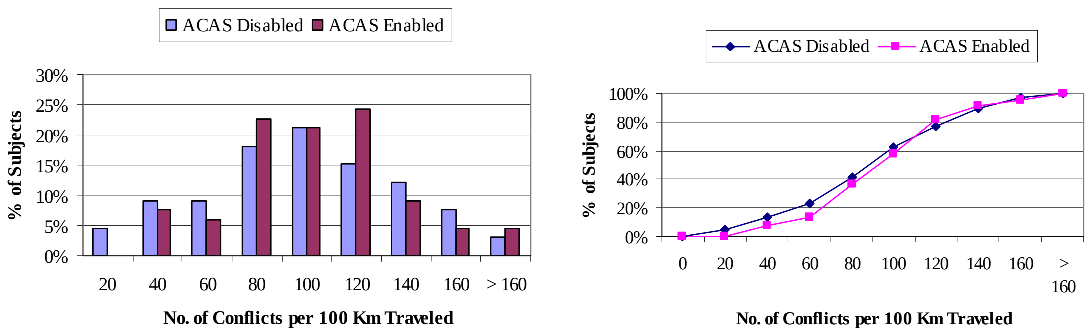


Figure D-62. Distribution of High-Intensity Conflicts, ACAS Vehicle Speed < 25 mph, ACAS-Disabled versus ACAS-Enabled

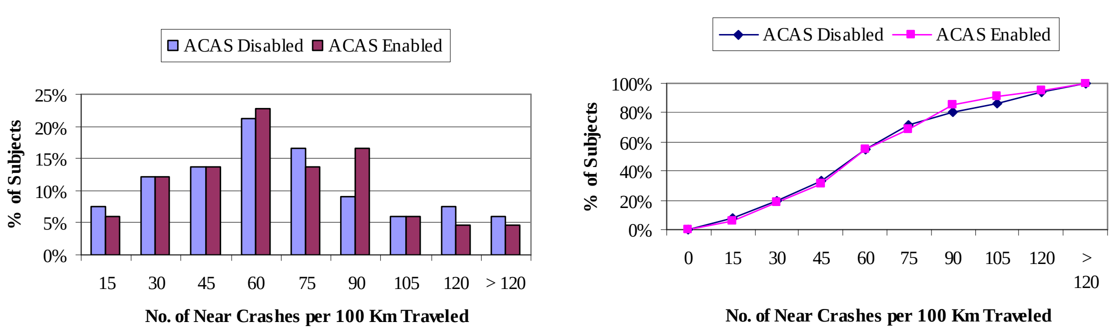


Figure D-63. Distribution of Low-Intensity Near-Crashes, ACAS Vehicle Speed < 25 mph, ACAS-Disabled versus ACAS-Enabled

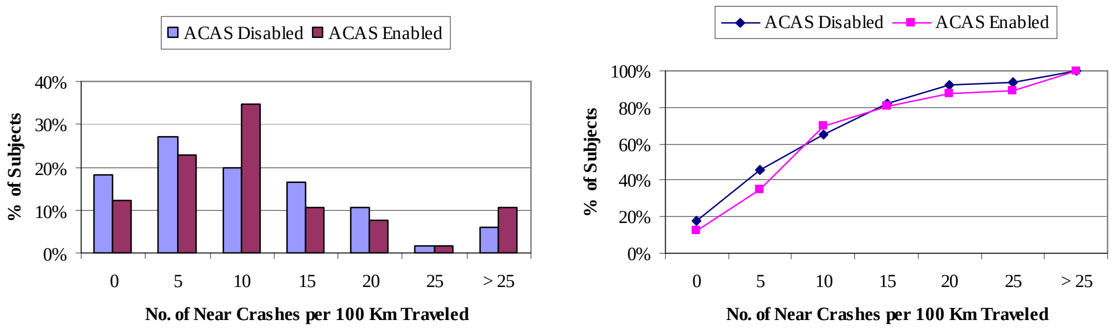


Figure D-64. Distribution of High-Intensity Near-Crashes, ACAS Vehicle Speed < 25 mph, ACAS-Disabled versus ACAS-Enabled

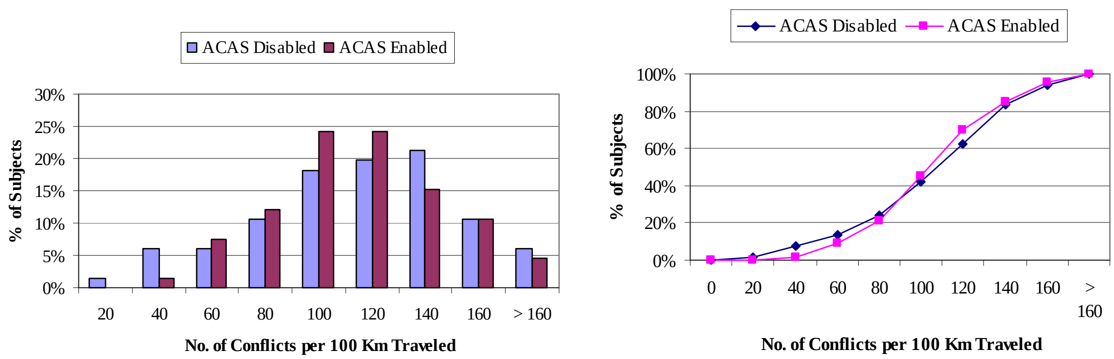


Figure D-65. Distribution of Low-Intensity Conflicts, ACAS Vehicle Speed 25 mph to 35 mph, ACAS-Disabled versus ACAS-Enabled

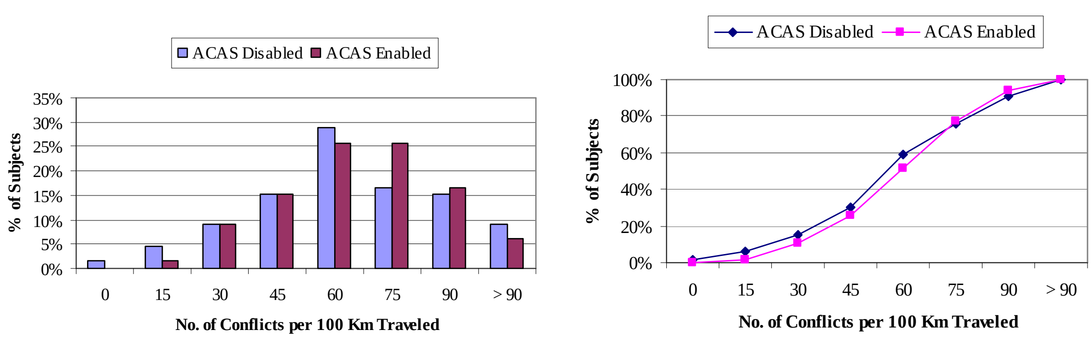


Figure D-66. Distribution of High-Intensity Conflicts, ACAS Vehicle Speed 25 mph to 35 mph, ACAS-Disabled versus ACAS-Enabled

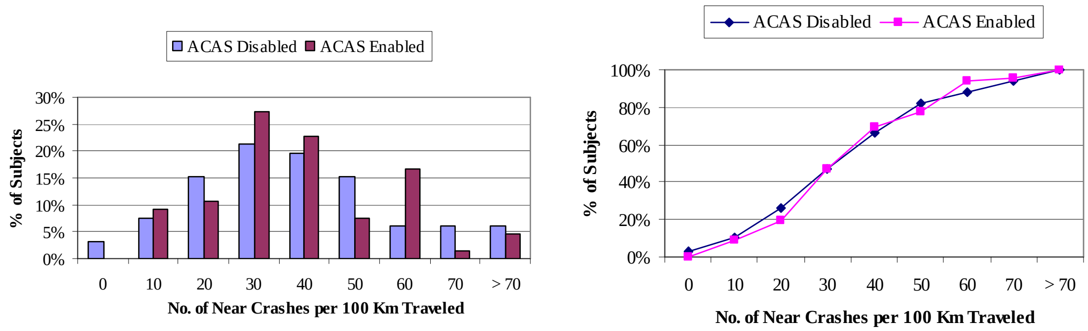


Figure D-67. Distribution of Low-Intensity Near-Crashes, ACAS Vehicle Speed 25 mph to 35 mph, ACAS-Disabled versus ACAS-Enabled

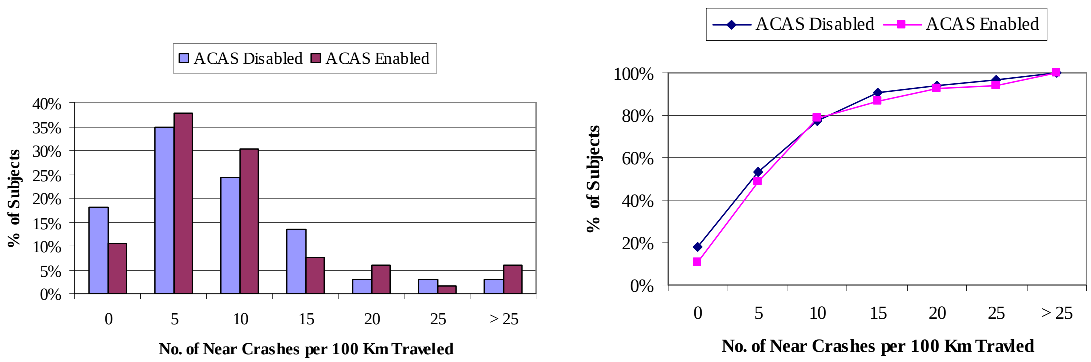


Figure D-68. Distribution of High-Intensity Near-Crashes, ACAS Vehicle Speed 25 mph to 35 mph, ACAS-Disabled versus ACAS-Enabled

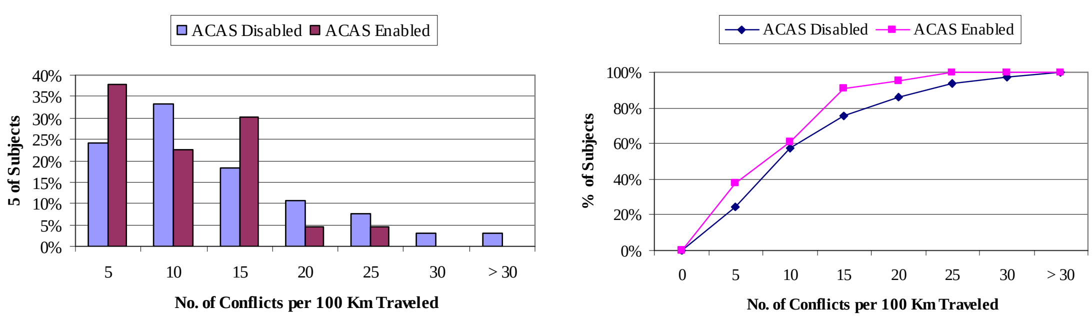


Figure D-69. Distribution of Low-Intensity Conflicts, ACAS Vehicle Speed >35 mph, ACAS-Disabled versus ACAS-Enabled

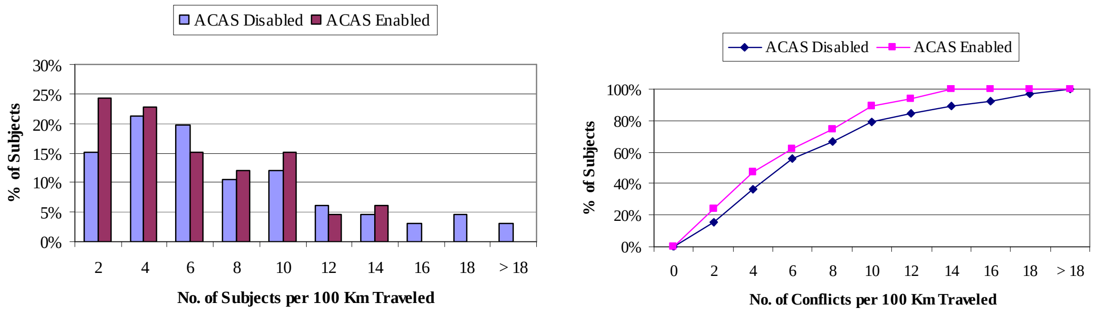


Figure D-70. Distribution of High-Intensity Conflicts, ACAS Vehicle Speed >35 mph, ACAS-Disabled versus ACAS-Enabled

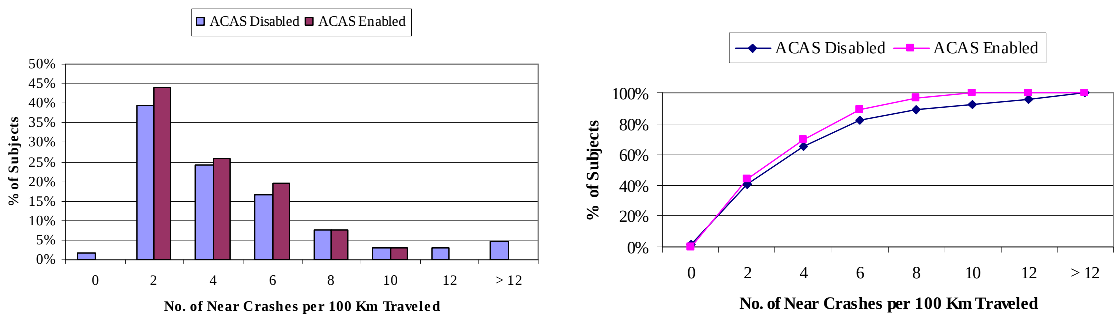


Figure D-71. Distribution of Low-Intensity Near-Crashes, ACAS Vehicle Speed >35 mph, ACAS-Disabled versus ACAS-Enabled

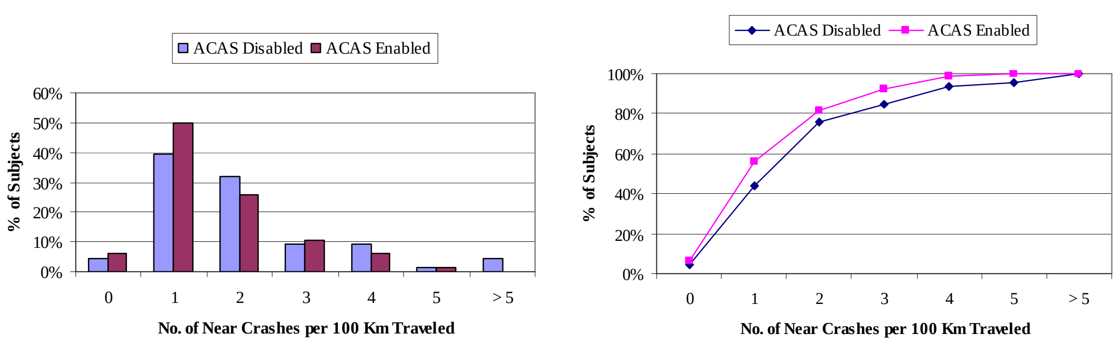


Figure D-72. Distribution of High-Intensity Near-Crashes, ACAS Vehicle Speed >35 mph, ACAS-Disabled versus ACAS-Enabled

APPENDIX E. Reasons for Subject Exclusion from FOT

UMTRI used the following grounds for excluding individuals from participating in the field operational test (FOT), at the time of the follow-up phone call:

- The spouse/partner, works for an OEM or Tier 1 supplier (automotive manufacturer or parts supplier).
- They have been driving less than two years.
- They are unable to drive cars equipped with an automatic transmission without assistive devices or special equipment.
- They have been convicted of any of the following in the past 36 months:

  a. driving while their operator's license is suspended, revoked, or denied;
  b. vehicular manslaughter, negligent homicide, felonious driving, or felony with a vehicle;
  c. operating a vehicle while impaired, under the influence of alcohol or illegal drugs, or refusing a sobriety test;
  d. failure to stop or identify under a crash (includes leaving the scene of a crash; hit and run; giving false information to an officer);
  e. eluding or attempting to elude a law enforcement officer;
  f. traffic violation resulting in death or serious injury; and
  g. any other significant violation warranting suspension of license.

- They acknowledge the need for, but fail to use, corrective devices such as eyeglasses or hearing aids.
- They are currently taking any drugs or substances, which may impair their ability to drive.
- They cannot abstain from drinking alcohol for at least 12 hours prior to any trip, with abstention from alcohol for 24 hours, being preferred.
- They have symptomatic heart disease with chest pain; shortness of breath, or light headedness which they have experienced at rest or when walking one block or less; rhythm disturbances associated with light headedness or fainting; require defibrillation; or have experienced a heart attack within the past 6 months.
- They have ever suffered brain damage from a stroke, tumor, head injury, or infection; have visual loss, blurring, or double vision; weakness, numbness, severe tremors or funny feelings in the arms, legs, or face; trouble swallowing, slurred speech; poor coordination or loss of control; trouble walking, trouble thinking, remembering, talking, or understanding.
- If they have had a stroke within the past 3 months, there is an active tumor, or if there are lingering effects or transient ischemic attack in the past year.
- They have ever been diagnosed with seizures or epilepsy and have experienced a seizure in the past 12 months.
- They suffer from a respiratory disorder such as asthma or chronic bronchitis, which results in obvious or continuous shortness of breath, especially if oxygen therapy is required.

- They often suffer from motion sickness under mild to moderate conditions or the sickness results in severe symptoms.
- They have suffered from inner ear disturbances such as dizziness, vertigo, or balance problems in the past 12 months or have Meniere's disease.
- They suffer from diabetes and, as a result, are required to take insulin, or have had symptomatic hypoglycemia in the past 3 months.
- They have migraine or tension headaches greater than two times a month, or if they take narcotic medications for the headaches.
- They are, or there is a possibility that they might be pregnant. If they were uncertain as to whether or not they may be pregnant, UMTRI provided them with a pregnancy test, for private use, prior to completing the informed consent.

APPENDIX F. Driver Travel Behavior

Table F-1. Descriptive Statistics for Travel Behavior and Imminent Alerts Across Entire FOT Duration

Entire FOT Duration	Mean	SD	SEM	Median
Number of trips	146.44	43.31	5.33	143.00
Number of trips per day	5.69	1.63	0.20	5.64
Number of valid trips	123.03	35.55	4.38	118.00
Number of valid trips per day	4.79	1.36	0.17	4.70
Distance traveled (km) in valid trips	2,392.05	1,222.08	150.43	2,142.50
Distance per valid trip (in km)	19.89	9.50	1.17	17.80
Number of hours driven	39.41	15.23	1.88	35.70
Number of hours driven per day	1.53	0.59	0.07	1.39
Number of alerts	15.08	8.22	1.01	13.50

Table F-2. Descriptive Statistics for Travel Behavior and Imminent Alerts Across ACAS-Enabled Driving Only

ACAS-Enabled Driving Only	Mean	SD	SEM	Median
Number of trips	111.32	35.92	4.42	109.50
Number of valid trips	93.26	29.05	3.58	91.00
FCW distance traveled (km) in valid trips	977.13	614.84	75.68	914.70
ACC distance traveled (km) in valid trips	665.42	745.60	91.78	390.45
Manual distance traveled (km) in valid trips	200.26	85.62	10.54	189.30
Distance traveled (km) in valid trips	1,,842.81	1069.16	131.60	1,595.81
Distance per valid trip (km)	20.32	12.02	1.48	16.33
Number of trips with ACC engaged	25.64	20.85	2.57	19.50
Number of ACC engagements	71.47	78.18	9.62	44.00
Number of alerts with ACC engaged	1.12	1.85	0.23	0.00
Number of alerts	11.29	7.00	0.86	10.00
Number of alerts per 100 km	1.85	1.36	0.17	1.52

APPENDIX G. Driver Acceptance Scale

The Driver Acceptance Scale used in the FOT was developed and tested in Europe and translated into English for use by O. Carsten. It consists of nine 5-point rating scale items that have been shown to form two components, resulting in two subscales. One subscale denotes the “usefulness” of the system, while the other designates driver “satisfaction” with the system.

Responses to the question: “Please indicate your overall acceptance rating of the FCW/ACC system” were provided for each pair of opposing (positive/negative) anchors in one of five boxes, with the center box as a “neutral” point. Each response was coded as a value ranging from (-2) to (+2) and mean scores were then calculated for each subscale. The “usefulness” subscale consists of the mean response to the pairs, useful/useless, good/bad, effective/superfluous, assisting/worthless, and raising alertness/sleep-inducing. The “satisfaction” subscale is comprised of the mean response for the pairs, pleasant/unpleasant, nice/annoying, likeable/irritating, and desirable/undesirable.

APPENDIX H. FCW Intercorrelations – Advocacy

Table H-1. Advocacy Sub-Objective Survey Measure Intercorrelations (Spearman's rho)

Subobjective	*Survey Item*	1.	2.	3.	4.	5.	6.	7.
1. ***Acceptance in Rental Vehicle***	Would you be willing to rent a vehicle equipped with FCW? *1 (very unwilling) - 7*	—	.72	.80	.53	.68	.72	.80
2. ***Interest in Purchasing***	How likely would you be to consider purchasing FCW if you were purchasing a new vehicle today? *1 (definitely not) - 5*		—	.71	.74	.74	.87	.88
3. ***Level of Trust***	How comfortable would you feel if your child, spouse, parents - or other loved ones - drove a vehicle equipped with FCW? *1 (very uncomfortable) - 7*			—	.57	.68	.76	.80
4. ***Amount Willing to Pay***	At $1000, how likely would you be to consider purchasing FCW if you were purchasing a new vehicle today? *1 (definitely not) - 5*				—	.61	.72	.72
5. ***Willingness to Endorse***	Would you recommend to your child, spouse, parents - or other loved ones – to use FCW? *(Y/N)*					—	.77	.78
6. ***Driver Acceptance Scale***	Usefulness subscale *(-2,…,+2)*						—	.89
7.	Satisfaction subscale *(-2,…,+2)*							—

Note. All correlations significant at $p \leq .05$, except where denoted as nonsignificant (NS).

APPENDIX I. ACC Intercorrelations – Advocacy

Table I-1. Advocacy Sub-Objective Survey Measure Intercorrelations (Spearman's rho)

Subobjective	*Survey Item*	1.	2.	3.	4.	5.	6.	7.
1. ***Acceptance in Rental Vehicle***	Would you be willing to rent a vehicle equipped with ACC? *1 (very unwilling) - 7*	—	.57	.39	NS	.58	.44	.54
2. ***Interest in Purchasing***	How likely would you be to consider purchasing ACC if you were purchasing a new vehicle today? *1 (definitely not) - 5*		—	.37	.43	.58	.58	.61
3. ***Level of Trust***	How comfortable would you feel if your child, spouse, parents - or other loved ones - drove a vehicle equipped with ACC? *1 (very uncomfortable) - 7*			—	.39	.37	.55	.61
4. ***Amount Willing to Pay***	At $1000, how likely would you be to consider purchasing ACC if you were purchasing a new vehicle today? *1 (definitely not) - 5*				—	.39	.43	.42
5. ***Willingness to Endorse***	Would you recommend to your child, spouse, parents - or other loved ones - to use ACC? *(Y/N)*					—	.53	.58
6. ***Driver Acceptance Scale***	Usefulness subscale *(-2,…,+2)*						—	.69
7.	Satisfaction subscale *(-2,…,+2)*							—

Note. all correlations significant at $p < .01$, except where denoted as nonsignificant (NS)

APPENDIX J. FCW Intercorrelations – Perceived Value

Table J-1. Perceived Value Objective Survey Measure Intercorrelations (Spearman's rho)

Subobjective	*Survey Item*	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. ***Overall***	Overall how satisfied were you with the FCW system? *1 (very unsatisfied) - 7*	—	NS	.60	.37	NS	.30	NS	.64	.75
2. ***Compatibility with mental model***	Overall, how easy was it to remember how to use and operate FCW while driving? *1 (not at all easy) - 7*		—	NS	.38	.28	.37	NS	NS	NS
3. ***Driving skill enhancement***	Did you feel more comfortable performing additional tasks, (e.g., adjusting the heater, operating the radio, talking on a cellular telephone, etc.) while using the FCW system as compared to manual driving? *1 (less comfortable) - 7*			—	.36	NS	.34	NS	.48	.59
4. ***Safety***	How safe did you feel while driving the car using FCW? *1 (very unsafe) - 7*				—	NS	.33	NS	.32	.35
5.	How safe did you feel driving the car manually? *1 (very unsafe) - 7*					—	NS	NS	NS	NS
6.	How easy or difficult did you find it to maintain a safe distance to the preceding vehicle when using FCW? *1 (very difficult) - 7*						—	NS	NS	.33
7.	How easy or difficult did you find it to maintain a safe distance to the preceding vehicle when driving manually? *1 (very difficult) - 7*							—	NS	NS
8.	When using FCW, do you feel you drove more or less safely than when driving manually? *1 (less safe) - 7*								—	.79
9.	Overall, I think that FCW is going to increase my driving safety. *1 (strongly disagree) - 7*									—

Note. All correlations significant at $p \leq .05$, except where denoted as nonsignificant (NS)

APPENDIX K. ACC Intercorrelations – Perceived Value

Table K-1. Perceived Value Sub-Objective Survey Measure Intercorrelations (Spearman's rho)

Subobjective	***Survey Item***	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. ***Overall***	Overall how satisfied were you with the ACC system? *1 (very unsatisfied) - 7*	—	.68	.33	.49	.76	NS	.54	.37	.74
2. ***Compatibility with mental model***	Overall, I felt the operation of the ACC system was predictable. *1 (strongly disagree) - 7*		—	.49	.54	.62	NS	.55	NS	.58
3.	When I was using ACC, I understood when I had to take control - either by accelerating or braking *1 (strongly disagree) - 7*			—	.29	.29	NS	.32	NS	.36
4.	How distracting did you find the ACC system operation (e.g., automatic acceleration and deceleration or warnings)? *1 (very distracting) - 7*				—	.54	NS	.52	NS	.57
5. ***Safety***	How safe did you feel while driving the car using ACC? *1 (very unsafe) - 7*					—	NS	.66	.35	.65
6.	How safe did you feel driving the car manually? *1 (very unsafe) - 7*						—	NS	NS	NS
7.	When using ACC, do you feel you drove more or less safely than when driving manually? *1 (less safe) -7*							—	.35	.58
8.	Relative to manual driving, how concerned were you about the traffic behind you when using ACC? *1 (much more concerned) - 7*								—	.41
9.	Overall, do you think that ACC is going to increase your driving safety? *1 (strongly disagree) - 7*									—

Note. All correlations significant at $p \leq .05$, except where denoted as nonsignificant (NS)

APPENDIX L. FCW Intercorrelations – Ease of Use

Table L-1. FCW Spearman's rho Intercorrelations by Subobjective

	Subobjective	*Survey Item*	1.	2.	3.	4.	5.	6.
1.	***Understanding of warnings***	For the visual alert, how well could you identify whether the alert signaled a cautionary situation (a moderate threat) versus a situation in which you may be about to crash (an imminent threat)? *1 (not well at all) - 7*	—	.29	NS	.44	.33	.24
2.		How startling did you find the auditory alert when it occurred? *1 (very startling) - 7*		—	NS	.26	NS	NS
3.		Do you think that the use of color improved your understanding of the FCW information presented in the HUD? *1 (strongly disagree) - 7*			—	NS	.28	NS
4.		How effective were the visual alerts at getting your attention quickly? *1 (very ineffective) - 7*				—	.37	.42
5.		How effective was the audio alert in communicating a situation in which you may be about to crash (an imminent threat)? *1 (very ineffective) - 7*					—	.68
6.		How effective was the auditory alert at getting your attention quickly? *1 (very ineffective) - 7*						—

Note. All correlations significant at $p \leq .05$, except where denoted as nonsignificant (NS).

Subobjective	***Survey Item***	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. ***Usability***	How comfortable did you feel using forward collision warning? *1 (very uncomfortable) - 7*	—	NS	NS	.44	.39	NS	.49	NS	-.31	.39	NS
2.	How comfortable did you feel driving the car manually? *1 (very uncomfortable) - 7*		—	NS	NS	NS	NS	NS	.55	NS	NS	NS
3.	How annoying were the visual alerts that signaled a cautionary situation (a moderate threat)? *1 (unacceptably annoying) - 5*			—	.60	.48	NS	.27	NS	NS	NS	NS
4.	How annoying was the visual alert that signaled a situation in which you may be about to crash (an imminent threat)? *1 (unacceptably annoying) - 5*				—	.68	.39	.25	NS	NS	NS	NS
5.	How annoying was the auditory alert that signaled a situation in which you may be about to crash (an imminent threat)? *1 (unacceptably annoying) - 5*					—	.40	.27	NS	NS	NS	-.35
6.	Did you notice that the radio was muted when an imminent alert was presented? Overall, indicate the annoyance level associated with the radio being muted with imminent FCW alerts. *1 (unacceptably annoying) - 5*						—	NS	.35	NS	NS	NS
7.	How easy or difficult did you find it to drive using FCW? *1 (very difficult) - 7*							—	NS	NS	.50	NS
8.	How easy or difficult was it to drive the car manually? *1 (very difficult) - 7*								—	NS	NS	NS
9.	How long did it take before you became comfortable with the operations of FCW? *1 (comfortable within first day) - 5*									—	-.28	.28
10.	How easy or difficult was it to understand and use the alert timing adjustment for FCW? *1 (very difficult) - 7*										—	-.42
11.	Select the statement which best describes how often you changed the FCW alert timing adjustment. *1 (never changed) - 5*											—

Note. All correlations significant at $p \leq .05$, except where denoted as nonsignificant (NS).

APPENDIX M. FCW Descriptive Statistics – Ease of Use

Table M-1. FCW Survey Measure Descriptive Statistics and Statistical Findings by Subobjective

Subobjective	Survey Item	Mean	Standard Deviation	Median	Mode
Comparison with conventional device					
	How would you rate FCW as a safety system as compared to ABS or airbags? *1 (much worse) - 7*	3.9	1.8	4.0	4.0

Subobjective	Survey Item	Age Group	Mean	ANOVA Results
Comparison with conventional device				
	How would you rate FCW as a safety system as compared to ABS or airbags? *1 (much worse) - 7*	Younger	3.1	NS
		Middle	4.0	
		Older	4.3	

Subobjective	Survey Item	Mean	Standard Deviation	Median	Mode
Demands on drivers					
	Did you experience more or less stress when driving with FCW as compared to manual driving? *1 (more stress) - 7*	4.7	1.7	4.5	4.0
	If you did change the FCW alert timing adjustment, which of the following factors caused you to change the setting: the traffic conditions *% yes*	77.3%			
	If you did change the FCW alert timing adjustment, which of the following factors caused you to change the setting: the weather conditions *% yes*	40.9%			
	If you did change the FCW alert timing adjustment, which of the following factors caused you to change the setting: whether I was in a rush *% yes*	12.1%			
	If you did change the FCW alert timing adjustment, which of the following factors caused you to change the setting: whether I was tired *% yes*	7.6%			
	If you did change the FCW alert timing adjustment, which of the following factors caused you to change the setting: whether I felt alert *% yes*	6.1%			
	How distracting were the visual alerts that signaled a cautionary situation (a moderate threat)?	5.4	1.7	6.0	7.0

1 (very distracting) - 7

Subobjective	Survey Item	Age Group	Mean	ANOVA Results
Demands on drivers				
	Did you experience more or less stress when driving with FCW as compared to manual driving? *1 (more stress) - 7*	Younger Middle Older	3.9 4.4 5.5	*Y more stressed than O, using FCW compared to manual*
	How distracting were the visual alerts that signaled a cautionary situation (a moderate threat)? *1 (very distracting) - 7*	Younger Middle Older	4.5 5.3 6.2	*Y more distracted than O by visual alerts*

Subobjective	Survey Item	Mean	Standard Deviation	Median	Mode
Use patterns					
	How comfortable did you feel using FCW in adverse weather conditions?				
	0=did not experience	10.6%			
	1 (very uncomfortable) - 7	5.5	1.7	6.0	7.0

Subobjective	Survey Item	Age Group	Mean	ANOVA Results
Use patterns				
	How comfortable did you feel using FCW in adverse weather conditions? *1 (very uncomfortable) - 7*	Younger Middle Older	5.3 5.5 5.6	NS

Subobjective	Survey Item	Mean	Standard Deviation	Median	Mode
Tolerance of nuisance/false warnings					
	Overall, indicate the annoyance level associated with unnecessary FCW alerts *1 (unacceptably annoying) - 5*	3.4	1.3	4.0	2.0
	Indicate the annoyance level associated with "when a vehicle ahead of me turned" which could result in unnecessary FCW alerts *1 (unacceptably annoying) - 5*	3.6	1.3	4.0	5.0
	Indicate the annoyance level associated with "when I passed a moving vehicle" which could result in unnecessary FCW alerts *1 (unacceptably annoying) - 5*	3.7	1.3	4.0	5.0
	Indicate the annoyance level associated with "when a vehicle ahead changed lanes" which could result in unnecessary FCW alerts *1 (unacceptably annoying) - 5*	3.8	1.3	4.0	5.0
	Indicate the annoyance level associated with "when my vehicle changed lanes" which could result in unnecessary FCW alerts	4.0	1.2	5.0	5.0

1 (unacceptably annoying) - 5				
Indicate the annoyance level associated with "when a vehicle cut in front of me" which could result in unnecessary FCW alerts *1 (unacceptably annoying) - 5*	3.7	1.3	4.0	5.0
Indicate the annoyance level associated with "when I cut in behind another vehicle" which could result in unnecessary FCW alerts *1 (unacceptably annoying) - 5*	4.0	1.1	4.0	5.0
Indicate the annoyance level associated with "when I passed a sign, light post or guardrail" which could result in unnecessary FCW alerts *1 (unacceptably annoying) - 5*	3.1	1.3	3.0	3.0
Indicate the annoyance level associated with "when I passed a parked vehicle" which could result in unnecessary FCW alerts *1 (unacceptably annoying) - 5*	3.5	1.4	4.0	5.0

Subobjective	Survey Item	Age Group	Mean	ANOVA Results
Tolerance of nuisance/false warnings				
	Overall, indicate the annoyance level associated with unnecessary FCW alerts *1 (unacceptably annoying) - 5*	Younger Middle Older	2.6 3.1 4.4	*Y and M more annoyed than O*
	Indicate the annoyance level associated with "when a vehicle ahead of me turned" which could result in unnecessary FCW alerts *1 (unacceptably annoying) - 5*	Younger Middle Older	3.1 3.1 4.6	*Y and M more annoyed by veh. ahead turn than O*
	Indicate the annoyance level associated with "when a vehicle ahead changed lanes" which could result in unnecessary FCW alerts *1 (unacceptably annoying) - 5*	Younger Middle Older	3.3 3.5 4.7	*Y and M more annoyed by veh. ahead chg. lanes than O*
	Indicate the annoyance level associated with "when a vehicle cut in front of me" which could result in unnecessary FCW alerts *1 (unacceptably annoying) - 5*	Younger Middle Older	3.3 3.4 4.4	*Y and M more annoyed by veh. cut in front than O*
	Indicate the annoyance level associated with "when I passed a moving vehicle" which could result in unnecessary FCW alerts *1 (unacceptably annoying) - 5*	Younger Middle Older	3.1 3.7 4.5	*Y more annoyed by passing moving veh. than O*
	Indicate the annoyance level associated with "when my vehicle changed lanes" which could result in unnecessary FCW alerts *1 (unacceptably annoying) - 5*	Younger Middle Older	3.9 3.6 4.8	*Y and M more annoyed by own veh. changed lanes than O*

Survey Item	Age Group	Mean	ANOVA Results
Indicate the annoyance level associated with "when I cut in behind another vehicle" which could result in unnecessary FCW alerts *1 (unacceptably annoying) - 5*	Younger Middle Older	3.5 4.0 4.6	*Y more annoyed by cutting behind another veh. than O*
Indicate the annoyance level associated with "when I passed a sign, light post or guardrail" which could result in unnecessary FCW alerts *1 (unacceptably annoying) - 5*	Younger Middle Older	2.8 2.7 3.7	*M more annoyed by stationary obj. than O*
Indicate the annoyance level associated with "when I passed a parked vehicle" which could result in unnecessary FCW alerts *1 (unacceptably annoying) - 5*	Younger Middle Older	3.0 3.5 3.9	NS

Subobjective	Survey Item	Mean	Standard Deviation	Median	Mode
Understanding of warnings					
	For the visual alert, how well could you identify whether the alert signaled a cautionary situation (a moderate threat) versus a situation in which you may be about to crash (an imminent threat)? *1 (not well at all) - 7*	6.3	1.3	7.0	7.0
	How startling did you find the auditory alert when it occurred? *1 (very startling) - 7*	4.6	2.0	5.0	7.0
	Do you think that the use of color improved your understanding of the FCW information presented in the HUD? *1 (strongly disagree) - 7*	6.2	1.1	6.0	7.0
	How effective were the visual alerts at getting your attention quickly? *1 (very ineffective) - 7*	6.2	1.2	7.0	7.0
	How effective was the audio alert in communicating a situation in which you may be about to crash (an imminent threat)? *1 (very ineffective) - 7*	6.2	1.4	7.0	7.0
	How effective was the auditory alert at getting your attention quickly? *1 (very ineffective) - 7*	6.5	1.0	7.0	7.0

Subobjective	Survey Item	Age Group	Mean	ANOVA Results
Understanding of warnings				
	For the visual alert, how well could you identify whether the alert signaled a cautionary situation (a moderate threat) versus a situation in which you may be about to crash (an imminent threat)? *1 (not well at all) - 7*	Younger Middle Older	6.3 5.8 6.7	NS

How startling did you find the auditory alert when it occurred? *1 (very startling) - 7*	Younger Middle Older	3.6 4.5 5.4	*Y more startled by auditory alert than O*
Do you think that the use of color improved your understanding of the FCW information presented in the HUD? *1 (strongly disagree) - 7*	Younger Middle Older	6.1 6.2 6.2	NS
How effective were the visual alerts at getting your attention quickly? *1 (strongly disagree) - 7*	Younger Middle Older	5.9 6.1 6.5	NS
How effective was the audio alert in communicating a situation in which you may be about to crash (an imminent threat)? *1 (very ineffective) - 7*	Younger Middle Older	5.9 6.1 6.4	NS
How effective was the auditory alert at getting your attention quickly? *1 (very ineffective) - 7*	Younger Middle Older	6.0 6.4 6.7	NS

Subobjective	**Survey Item**	**Mean**	**Standard Deviation**	**Median**	**Mode**
Usability					
	How comfortable did you feel using forward collision warning? *1 (very uncomfortable) - 7*	5.5	1.4	6.0	7.0
	How comfortable did you feel driving the car manually? *1 (very uncomfortable) - 7*	6.5	0.8	7.0	7.0
	How annoying were the visual alerts that signaled a cautionary situation (a moderate threat)? *1 (unacceptably annoying) - 5*	3.8	1.3	4.0	5.0
	How annoying was the visual alert that signaled a situation in which you may be about to crash (an imminent threat)? *1 (unacceptably annoying) - 5*	3.9	1.3	4.0	5.0
	How annoying was the auditory alert that signaled a situation in which you may be about to crash (an imminent threat)? *1 (unacceptably annoying) - 5*	3.7	1.4	4.0	5.0
	Did you notice that the radio was muted when an imminent alert was presented? Overall, indicate the annoyance level associated with the radio being muted with imminent FCW alerts. *0=did not notice*	29.2%			
	1 (unacceptably annoying) - 5	4.2	1.2	5.0	5.0
	How easy or difficult did you find it to drive using	6.1	1.2	6.0	7.0

	FCW? *1 (very difficult) - 7*				
	How easy or difficult was it to drive the car manually? *1 (very difficult) - 7*	6.8	0.5	7.0	7.0
	How long did it take before you became comfortable with the operations of FCW? *1 (comfortable within first day) - 5*	2.0	1.0	2.0	2.0
	How easy or difficult was it to understand and use the alert timing adjustment for FCW? *1 (very difficult) - 7*	6.3	1.1	7.0	7.0
	Select the statement which best describes how often you changed the FCW alert timing adjustment. *1 (never changed) - 5*	3.3	0.9	3.0	3.0

Subobjective	Survey Item	Age Group	Mean	ANOVA Results
Usability				
	How comfortable did you feel using forward collision warning? *1 (very ineffective) - 7*	Younger Middle Older	5.1 4.8 6.0	NS
	How comfortable did you feel driving the car manually? *1 (very uncomfortable) - 7*	Younger Middle Older	6.4 6.6 6.7	NS
	How annoying were the visual alerts that signaled a cautionary situation (a moderate threat)? Please check the one option that best applies. *1 (unacceptably annoying) - 5*	Younger Middle Older	3.4 3.8 4.7	NS
	How annoying was the visual alert that signaled a situation in which you may be about to crash (an imminent threat)? Please check the one option that best applies. *1 (unacceptably annoying) - 5*	Younger Middle Older	3.2 3.2 4.8	*Y and M more annoyed by imminent visual alert than O*
	How annoying was the auditory alert that signaled a situation in which you may be about to crash (an imminent threat)? *1 (unacceptably annoying) - 5*	Younger Middle Older	2.9 3.4 5.0	*Y and M more annoyed by imminent auditory alert than O*
	Did you notice that the radio was muted when an imminent alert was presented? Overall, indicate the annoyance level associated with the radio being muted with imminent FCW alerts *0=did not notice* *1 (unacceptably annoying) - 5*	Younger Middle Older	3.6 4.3 4.5	NS
	How easy or difficult did you find it to drive using FCW? *1 (very difficult) - 7*	Younger Middle Older	6.1 5.3 6.8	NS

How easy or difficult was it to drive the car manually? *1 (very difficult) - 7*	Younger Middle Older	6.4 6.8 6.8	NS
How long did it take before you became comfortable with the operations of FCW? *1 (comfortable within first day) - 5*	Younger Middle Older	1.9 1.9 2.8	NS
How easy or difficult was it to understand and use the alert timing adjustment for FCW? *1 (very difficult) - 7*	Younger Middle Older	6.1 6.2 6.8	NS
Select the statement which best describes how often you changed the FCW alert timing adjustment. *1 (never changed) - 5*	Younger Middle Older	3.2 3.5 2.8	NS

Subobjective	Survey Item	Percent "yes"
HUD		
	Do you think that any, or all, of the information shown on the HUD should be removed and displayed in the head-down instrument panel (i.e., located behind the steering wheel)? (speedometer)	4.7%
	Do you think that any, or all, of the information shown on the HUD should be removed and displayed in the head-down instrument panel (i.e., located behind the steering wheel)? (vehicle ahead symbol)	9.4%
	Do you think that any, or all, of the information shown on the HUD should be removed and displayed in the head-down instrument panel (i.e., located behind the steering wheel)? (system state messages, e.g., Malfunction)	18.8%
	Do you think that any, or all, of the information shown on the HUD should be removed and displayed in the head-down instrument panel (i.e., located behind the steering wheel)? (ACC gap/headway setting)	12.5%
	Do you think that any, or all, of the information shown on the HUD should be removed and displayed in the head-down instrument panel (i.e., located behind the steering wheel)? (ACC set speed)	9.4%
	Do you think that any, or all, of the information shown on the HUD should be removed and displayed in the head-down instrument panel (i.e., located behind the steering wheel)? (FCW alert timing setting)	12.5%
	Do you think that any, or all, of the information shown on the HUD should be removed and displayed in the head-down instrument panel (i.e., located behind the steering wheel)? (crash alerts (icons))	7.8%
	Which of the following items do you prefer to be displayed only when you are making adjustments, as opposed to being shown all of the time like in the system you experienced? (ACC gap/headway setting)	45.5%
	Which of the following items do you prefer to be displayed only when you are making adjustments, as opposed to being shown all of the time like in the system you experienced? (ACC set speed)	13.6%
	Which of the following items do you prefer to be displayed only when you are	26.2%

making adjustments, as opposed to being shown all of the time like in the system you experienced? (FCW alert timing setting)

Subobjective	Survey Item	Mean	Standard Deviation	Median	Mode
HUD, cont.	How easy was it to see the entire HUD while in your seated position?				
	1 (very difficult) - 7	6.6	1.0	7.0	7.0
	Did you ever intentionally adjust the location of the HUD in such a way that you could not see all of the information displayed, and drove with the display in that position for an extended period.				
	0=never	82.8%			
	1 (very frequently) - 7	5.2	2.5	6.5	7.0

Subobjective	Survey Item	Percent	χ2 Results
HUD			
	Do you think that any, or all, of the information shown on the HUD should be removed and displayed in the head-down instrument panel (i.e., located behind the steering wheel)? (speedometer)		χ2: *do not remove speedometer from HUD*
	% yes	4.7	
	% no	95.3	
	Do you think that any, or all, of the information shown on the HUD should be removed and displayed in the head-down instrument panel (i.e., located behind the steering wheel)? (vehicle ahead symbol)		χ2: *do not remove vehicle ahead symbol from HUD*
	% yes	9.4	
	% no	90.6	
	Do you think that any, or all, of the information shown on the HUD should be removed and displayed in the head-down instrument panel (i.e., located behind the steering wheel)? (system state messages, e.g., Malfunction)		χ2: *do not remove system state messages from HUD*
	% yes	18.8	
	% no	81.3	
	Do you think that any, or all, of the information shown on the HUD should be removed and displayed in the head-down instrument panel (i.e., located behind the steering wheel)? (ACC gap/headway setting)		χ2: *do not remove ACC gap setting from HUD*
	% yes	12.5	
	% no	87.5	
	Do you think that any, or all, of the information shown on the HUD should be removed and displayed in the head-down instrument panel (i.e., located behind the steering wheel)? (ACC set speed)		χ2: *do not remove ACC set speed from HUD*
	% yes	9.4	
	% no	90.6	
	Do you think that any, or all, of the information shown on the HUD should be removed and displayed in the head-down instrument panel (i.e., located behind the steering wheel)? (FCW alert timing setting)		χ2: *do not remove FCW alert timing/sensitivity setting from HUD*
	% yes	12.5	
	% no	87.5	

Do you think that any, or all, of the information shown on the HUD should be removed and displayed in the head-down instrument panel (i.e., located behind the steering wheel)? (crash alerts (icons))			$\chi2$: *do not remove crash alert icons from HUD*
	% yes	7.8	
	% no	92.2	
Which of the following items do you prefer to be displayed only when you are making adjustments, as opposed to being shown all of the time like in the system you experienced? (ACC gap/headway setting)			$\chi2$ = NS
	% yes	45.5	
	% no	54.5	
Which of the following items do you prefer to be displayed only when you are making adjustments, as opposed to being shown all of the time like in the system you experienced? (ACC set speed)			$\chi2$: *display ACC set speed continuously, not only when making adjustments*
	% yes	13.6	
	% no	86.4	
Which of the following items do you prefer to be displayed only when you are making adjustments, as opposed to being shown all of the time like in the system you experienced? (FCW alert timing setting)			$\chi2$: *display FCW alert timing setting continuously, not only when making adjustments*
	% yes	26.2	
	% no	73.8	

Subobjective	Survey Item	Age Group	Mean	ANOVA Results
HUD, cont.	How easy was it to see the entire HUD while in your seated position?	Younger	6.2	NS
	1 (very difficult) - 7	Middle	6.5	
		Older	6.9	
	Did you ever intentionally adjust the location of the HUD in such a way that you could not see all of the information displayed, and drove with the display in that position for an extended period.	Younger	5.8	Subset of sample responding 1-7 too small to perform ANOVA
	0 = never (83%)	Middle	4.0	
	1 (very frequently) - 7	Older	6.5	

APPENDIX N. ACC Intercorrelations – Ease of Use

Table N-1. ACC Spearman's rho Intercorrelations by Sub-Objective

	Subobjective	Survey Item	1.	2.
1.	***Comparison with conventional device***	What did you think of the timing of ACC braking in response to a vehicle ahead? *1 (too early) - 7*	—	.30
2.		How comfortable would you feel if ACC systems completely replaced conventional cruise control? *1 (very uncomfortable) - 7*		—

Note. All correlations significant at $p \leq .05$.

	Subobjective	Survey Item	1.	2.	3.	4.	5.	6.
1.	***Demands on drivers***	Did you experience more or less stress when driving with ACC as compared to manual driving? *1 (more stress) - 7*	—	.54	-.50	.56	.39	.53
2.		In comparison to driving manually, how comfortable were you physically (your posture, legs, feet, etc.) when using ACC? *1 (less comfortable) - 7*		—	-.55	.35	NS	.48
3.		In comparison to driving manually, how fatigued were you when using ACC? *1 (less fatigued) - 7*			—	-.32	NS	-.30
4.		How distracting did you find the ACC system operation (e.g., automatic acceleration and deceleration or warnings)? *1 (very distracting) - 7*				—	.44	.34
5.		How distracting did you find the ACC system components (e.g., displays or control buttons)? *1 (very distracting) - 7*					—	NS
6.		How comfortable did you feel having ACC slow your vehicle without feeling the need to depress the brake yourself? *1 (very uncomfortable) - 7*						—

Note. All correlations significant at $p \leq .05$, except where denoted as nonsignificant (NS).

	Subobjective	Survey Item	1.	2.	3.	4.	5.	6.
1.	***Use Patterns***	How comfortable did you feel using ACC in adverse weather conditions? *1 (very uncomfortable) - 7*	—	.72	.36	.32	NS	NS
2.		How willing are you to use ACC in adverse road conditions? *1 (very unwilling) - 7*		—	.39	.37	NS	.52
3.		How often did you use ACC at speeds below 55 mph? *1 (never) - 5*			—	.28	.38	.39
4.		How often did you use ACC on the interstate (at speeds of 55 mph or more)? *1 (never) - 5*				—	NS	.27

5.	Select the statement which best describes how often you changed the ACC following distance (gap) adjustment. *1 (I never changed the setting) - 5*						—	NS
6.	How willing are you to use ACC in varying traffic conditions? *1 (very unwilling) - 7*							—

Note. All correlations significant at $p \leq .05$, except where denoted as nonsignificant (NS).

Subobjective	***Survey Item***	1.	2.	3.	4.	5.	6.	7.
1. ***Usability***	How comfortable did you feel using adaptive cruise control (ACC)? *1 (very uncomfortable) - 7*	—	NS	.42	-.55	.48	.71	NS
2.	How comfortable did you feel driving the car manually? *1 (very uncomfortable) - 7*		—	NS	-.37	NS	NS	.55
3.	How easy or difficult was it to understand and use the following distance (gap) adjustment for ACC? *1 (very difficult) - 7*			—	-.42	.35	.34	NS
4.	How long did it take before you became comfortable with the operations of ACC? *1 (comfortable with ACC within the first day) - 5*				—	-.28	-.30	-.30
5.	How comfortable did you feel with your ability to change lanes (to pass other cars) using ACC? *1 (very uncomfortable) - 7*					—	.55	NS
6.	How easy or difficult did you find it to drive using ACC? *1 (very difficult) - 7*						—	NS
7.	How easy or difficult was it to drive the car manually? *1 (very difficult) - 7*							—

Note. All correlations significant at $p \leq .05$, except where denoted as nonsignificant (NS).

APPENDIX O. ACC Descriptive Statistics – Ease of Use

Table O-1. ACC Survey Measure Descriptive Statistics and Statistical Findings by Sub-Objective

Subobjective	Survey Item	Mean	Standard Deviation	Median	Mode
Comparison with conventional device					
	What did you think of the timing of ACC braking in response to a vehicle ahead? *1 (too early) - 7*	4.0	1.0	4.0	4.0
	How comfortable would you feel if ACC systems completely replaced conventional cruise control? *1 (very uncomfortable) - 7*	6.0	1.5	7.0	7.0

Subobjective	Survey Item	Age Group	Mean	ANOVA Results
Comparison with conventional device				
	What did you think of the timing of ACC braking in response to a vehicle ahead? *1 (too early) - 7*	Younger Middle Older	3.9 4.1 4.1	NS
	How comfortable would you feel if ACC systems completely replaced conventional cruise control? *1 (very uncomfortable) - 7* *1 (more stress) - 7*	Younger Middle Older	5.5 5.9 6.5	NS

Subobjective	Survey Item	Mean	Standard Deviation	Median	Mode
Demands on drivers					
	Did you experience more or less stress when driving with ACC as compared to manual driving? *1 (more stress) - 7*	5.3	1.6	6.0	6.0
	In comparison to driving manually, how comfortable were you physically (your posture, legs, feet, etc.) when using ACC? *1 (less comfortable) - 7*	5.9	1.2	6.0	7.0
	In comparison to driving manually, how fatigued were you when using ACC? *1 (less fatigued) - 7*	2.6	1.5	2.0	1.0
	How distracting did you find the ACC system operation (e.g., automatic acceleration and deceleration or warnings)? *1 (very distracting) - 7*	5.4	1.7	6.0	7.0
	How distracting did you find the ACC system components (e.g., displays or control buttons)? *1 (very distracting) - 7*	6.2	1.2	7.0	7.0

	How comfortable did you feel having ACC slow your vehicle without feeling the need to depress the brake yourself? *1 (very uncomfortable) - 7*	5.7	1.3	6.0	6.0

Subobjective	Survey Item	Age Group	Mean	ANOVA Results
Demands on drivers				
	Did you experience more or less stress when driving with ACC as compared to manual driving? *1 (more stress) - 7*	Younger Middle Older	5.5 5.0 5.8	NS
	In comparison to driving manually, how comfortable were you physically (your posture, legs, feet, etc.) when using ACC? *1 (less comfortable) - 7*	Younger Middle Older	6.2 5.4 6.2	NS
	In comparison to driving manually, how fatigued were you when using ACC? *1 (less fatigued) - 7*	Younger Middle Older	2.7 3.1 2.1	NS
	How distracting did you find the ACC system operation (e.g., automatic acceleration and deceleration or warnings)? *1 (very distracting) - 7*	Younger Middle Older	4.8 5.1 6.1	O found ACC less distracting than Y
	How distracting did you find the ACC system components (e.g., displays or control buttons)? *1 (very distracting) - 7*	Younger Middle Older	6.1 6.0 6.4	NS
	How comfortable did you feel having ACC slow your vehicle without feeling the need to depress the brake yourself? *1 (very uncomfortable) - 7*	Younger Middle Older	5.5 5.2 6.2	O more comfortable than M

Subobjective	Survey Item	Mean	Standard Deviation	Median	Mode
Use patterns					
	How comfortable did you feel using ACC in adverse weather conditions?				
	0=did not experience	31.8%			
	1 (very uncomfortable) - 7	4.6	1.9	5.0	6.0
	How willing are you to use ACC in adverse road conditions? *1 (very unwilling) - 7*	4.2	2.1	4.0	4.0
	How often did you use ACC at speeds below 55 mph? *1 (never) - 5*	2.4	1.2	2.0	1.0

	How often did you use ACC on the interstate (at speeds of 55 mph or more)? *1 (never) - 5*	4.1	0.7	4.0	4.0
	Select the statement which best describes how often you changed the ACC following distance (gap) adjustment. *1 (I never changed the setting) - 5*	2.9	0.9	3.0	3.0
	How willing are you to use ACC in varying traffic conditions? *1 (very unwilling) - 7*	4.8	1.7	5.0	5.0

Subobjective	Survey Item	Age Group	Mean	ANOVA Results
Use patterns				
	How comfortable did you feel using ACC in adverse weather conditions? *0=did not experience* *1 (very uncomfortable) - 7*	Younger Middle Older	4.1 5.0 4.9	NS
	How willing are you to use ACC in adverse road conditions? *1 (very unwilling) - 7*	Younger Middle Older	4.6 4.3 4.7	NS
	How often did you use ACC at speeds below 55 mph? *1 (never) - 5*	Younger Middle Older	2.5 2.7 3.0	NS
	How often did you use ACC on the interstate (at speeds of 55 mph or more)? *1 (never) - 5*	Younger Middle Older	4.3 4.3 4.3	NS
	Select the statement which best describes how often you changed the ACC following distance (gap) adjustment. *1 (I never changed the setting) - 5*	Younger Middle Older	3.4 3.3 2.8	NS
	How willing are you to use ACC in varying traffic conditions? *1 (very unwilling) - 7*	Younger Middle Older	5.0 4.4 5.6	NS

Subobjective	Survey Item	Mean	Standard Deviation	Median	Mode
Usability					
	How comfortable did you feel using adaptive cruise control (ACC)? *1 (very uncomfortable) - 7*	6.2	1.1	7.0	7.0
	How comfortable did you feel driving the car manually? *1 (very uncomfortable) - 7*	6.5	0.8	7.0	7.0

	How easy or difficult was it to understand and use the following distance (gap) adjustment for ACC? *1 (very difficult) - 7*	6.5	0.8	7.0	7.0
	How long did it take before you became comfortable with the operations of ACC? *1 (comfortable with ACC within the first day) - 5*	1.7	0.9	2.0	1.0
	How comfortable did you feel with your ability to change lanes (to pass other cars) using ACC? *1 (very uncomfortable) - 7*	5.6	1.5	6.0	7.0
	How easy or difficult did you find it to drive using ACC? *1 (very difficult) - 7*	6.3	1.0	7.0	7.0
	How easy or difficult was it to drive the car manually? *1 (very difficult) - 7*	6.8	0.5	7.0	7.0

Subobjective	Survey Item	Age Group	Mean	ANOVA Results
Usability				
	How comfortable did you feel using adaptive cruise control (ACC)? *1 (very uncomfortable) - 7*	Younger Middle Older	6.3 5.9 6.6	NS
	How comfortable did you feel driving the car manually? *1 (very uncomfortable) - 7*	Younger Middle Older	6.4 6.7 6.6	NS
	How easy or difficult was it to understand and use the following distance (gap) adjustment for ACC? *1 (very difficult) - 7*	Younger Middle Older	6.7 6.3 6.6	NS
	How long did it take before you became comfortable with the operations of ACC? *1 (comfortable with ACC within the first day) - 5*	Younger Middle Older	1.6 1.9 1.8	NS
	How comfortable did you feel with your ability to change lanes (to pass other cars) using ACC? *1 (very uncomfortable) - 7*	Younger Middle Older	5.9 5.0 6.3	O felt more comfortable than M
	How easy or difficult did you find it to drive using ACC? *1 (very difficult) - 7*	Younger Middle Older	6.6 6.0 6.7	NS
	How easy or difficult was it to drive the car manually? *1 (very difficult) - 7*	Younger Middle Older	6.5 6.8 6.9	NS

APPENDIX P. ACC Intercorrelations and Descriptive Statistics – Ease of Learning

Table P-1. ACC Spearman's rho Intercorrelations, and Descriptive Statistics by Sub-Objective

	Subobjective	*Survey Item*	1.	2.	3.	4.
1.	***Overall***	Overall, how easy was it to remember how to use and operate ACC while driving? *1 (not at all easy) - 7*	—	-.36	-.48	NS
2.	***Time to learn***	How long did it take before you became comfortable with the operations of FCW? *1 (comfortable with FCW within 1st day) - 5*		—	.53	NS
3.		How long did it take before you understood the operation of FCW? *1 (understood operations of FCW within 1st day) - 5*			—	NS
4.	***Utility of instructions/ training***	How useful was the training video in understanding how to use ACC and FCW? *1 (not at all useful) - 7*				—

Note. All correlations significant at $p \leq .05$, except where denoted as nonsignificant (NS).

Subobjective	Survey Item	Mean	Standard Deviation	Median	Mode
Overall					
	Overall, how easy was it to remember how to use and operate ACC while driving? *1 (not at all easy) - 7*	6.6	0.7	7.0	7.0
Time to learn					
	How long did it take before you became comfortable with the operations of ACC? *1 (comfortable with ACC within the first day) - 5*	1.7	0.9	2.0	1.0
	How long did it take before you understood the operation of ACC? *1 (understood operations of ACC within 1st day) - 5*	1.4	0.6	1.0	1.0
Utility of instructions/ training					
	How useful was the training video in understanding how to use ACC and FCW? *1 (not at all useful) - 7*	6.6	0.7	7.0	7.0

Subobjective	Survey Item	Age Group	Mean	ANOVA Results
Overall				
	Overall, how easy was it to remember how to use and operate ACC while driving? *1 (not at all easy) - 7*	Younger	6.7	
		Middle	6.4	NS
		Older	6.7	
Time to learn				
	How long did it take before you became comfortable with the operations of ACC? *1 (comfortable with ACC within 1st day) - 5*	Younger	1.6	
		Middle	1.9	NS
		Older	1.7	

How long did it take before you understood the operation of ACC? *1 (understood operations of ACC within 1st day) - 5*	Younger	1.4	
	Middle	1.3	NS
	Older	1.4	
Utility of instructions/ training			
How useful was the training video in understanding how to use ACC and FCW? *1 (not at all useful) - 7*	Younger	6.5	
	Middle	6.5	NS
	Older	6.7	

APPENDIX Q. FCW Intercorrelations – Driving Performance

Table Q-1. Driving Performance for FCW Sub-Objective Survey Measures Intercorrelations (Spearman's rho)

Subobjective	*Survey Item*	1.	2.	3.	4.	5.	6.	7.	8.
1. ***Awareness***	When using FCW, how responsive were you to the actions of other vehicles around you? *1 (very unresponsive) - 7*	—	.44	NS	.69	0.49	-.25	NS	.25
2.	When driving manually, how responsive were you to the action of vehicles around you? *1 (very unresponsive)- 7*		—	-.54	.45	.70	NS	NS	NS
3.	Overall, I found myself relying too much on the FCW system *1 (strongly disagree) - 7*			—	-.29	-.41	NS	NS	.37
4.	When using FCW, how aware were you of the driving situation (surrounding traffic, posted speed, traffic signals, etc)? *1 (very unaware) - 7*				—	.56	-.26	NS	NS
5.	When driving manually, how aware were you of the driving situation (surrounding traffic, posted speed, traffic signals) *1 (very unaware) - 7*					—	NS	NS	NS
6.	While using FCW, please tell us the number of times, if ever, you came close to experiencing a rear-end collision? *open-ended # response*						—	.28	NS
7.	While driving manually, please tell us the number of times, if ever, you came close to experiencing a rear-end collision? *open-ended # response*							—	NS
8.	Did you feel more comfortable performing additional tasks while using the FCW system as compared to manual driving? *1 (less comfortable) - 7*								—

Note. All correlations significant at $p \leq .05$, except where denoted as nonsignificant (NS).

APPENDIX R. ACC Intercorrelations – Driving Performance

Table R-1. Driving Performance for ACC Sub-Objective Survey Measures Intercorrelations (Spearman's rho)

Subobjective	*Survey Item*	1.	2.	3.	4.	5.	6.	7.	8.
1. **Awareness**	When using ACC, how responsive were you to the actions of other vehicles around you? *1 (very unresponsive) - 7*	—	.43	-.28	.70	.34	NS	NS	NS
2.	When driving manually, how responsive were you to the action of vehicles around you? *1 (very unresponsive)- 7*		—	NS	.52	.70	NS	NS	NS
3.	Overall, I found myself relying too much on the ACC system *1 (strongly disagree) - 7*			—	NS	NS	NS	NS	-.35
4.	When using ACC, how aware were you of the driving situation (surrounding traffic, posted speed, traffic signals, etc)? *1 (very unaware) - 7*				—	.48	NS	NS	NS
5.	When driving manually, how aware were you of the driving situation (surrounding traffic, posted speed, traffic signals) *1 (very unaware) - 7*					—	NS	NS	NS
6.	While using ACC, please tell us the number of times, if ever, you came close to experiencing a rear-end collision? *open-ended # response*						—	NS	NS
7.	While driving manually, please tell us the number of times, if ever, you came close to experiencing a rear-end collision? *open-ended # response*							—	NS
8.	Did you feel more comfortable performing additional tasks while using the ACC system as compared to manual driving? *1 (less comfortable) - 7*								—

Note. All correlations significant at $p \leq .05$, except where denoted as nonsignificant (NS).

APPENDIX S. ACC Descriptive Statistics – Driving Performance

Table S-1. Driving Performance for ACC Sub-Objective Survey Measures Descriptive Statistics

Subobjective	Survey Item	Mean	Standard Deviation	Median	Mode
Awareness					
	When using ACC, how responsive were you to the actions of other vehicles around you? *1 (very unresponsive) - 7*	6.3	1.0	7.0	7.0
	When driving manually, how responsive were you to the action of vehicles around you? *1 (very unresponsive)- 7*	6.3	0.8	6.0	7.0
	Overall, I found myself relying too much on the ACC system *1 (strongly disagree) - 7*	2.9	1.5	3.0	4.0
	When using ACC, how aware were you of the driving situation (surrounding traffic, posted speed, traffic signals, etc)? *1 (very unaware) - 7*	6.5	0.9	7.0	7.0
	When driving manually, how aware were you of the driving situation (surrounding traffic, posted speed, traffic signals) *1 (very unaware) - 7*	6.2	0.8	6.0	7.0
	While using ACC, please tell us the number of times, if ever, you came close to experiencing a rear-end collision? *open-ended # response*	0.3	1.3	0.0	0.0
	While driving manually, please tell us the number of times, if ever, you came close to experiencing a rear-end collision? *open-ended # response*	0.4	1.3	0.0	0.0
	Did you feel more comfortable performing additional tasks while using the ACC system as compared to manual driving? *1 (less comfortable) - 7*	5.6	1.2	6.0	6.0

APPENDIX T. ACC Descriptive Statistics – Driving Performance by Age Groups

Table T-1. Statistical Comparison of ACC Driving Performance Sub-Objective Measures by Driver Age Group

Subobjective	Survey Item	Age Group	Mean	ANOVA Results
Awareness				
	When using ACC, how responsive were you to the actions of other vehicles around you? *1 (very unresponsive) - 7*	Younger	5.9	O more responsive than Y
		Middle	6.1	
		Older	6.8	
	When driving manually, how responsive were you to the action of vehicles around you? *1 (very unresponsive)- 7*	Younger	6.0	NS
		Middle	6.3	
		Older	6.5	
	Overall, I found myself relying too much on the ACC system *1 (strongly disagree) - 7*	Younger	2.7	NS
		Middle	3.5	
		Older	2.4	
	When using ACC, how aware were you of the driving situation (surrounding traffic, posted speed, traffic signals, etc)? *1 (very unaware) - 7*	Younger	6.3	NS
		Middle	6.4	
		Older	6.8	
	When driving manually, how aware were you of the driving situation (surrounding traffic, posted speed, traffic signals) *1 (very unaware) - 7*	Younger	6.0	NS
		Middle	6.1	
		Older	6.6	
	While using ACC, please tell us the number of times, if ever, you came close to experiencing a rear-end collision? *open-ended # response*	Younger	0.2	NS
		Middle	0.5	
		Older	0.1	
	While driving manually, please tell us the number of times, if ever, you came close to experiencing a rear-end collision? *open-ended # response*	Younger	0.5	NS
		Middle	0.6	
		Older	0.1	
	Did you feel more comfortable performing additional tasks while using the ACC system as compared to manual driving? *1 (less comfortable) - 7*	Younger	5.8	NS
		Middle	5.4	
		Older	5.7	

APPENDIX U. Vehicle Control Inputs and Trip Patterns

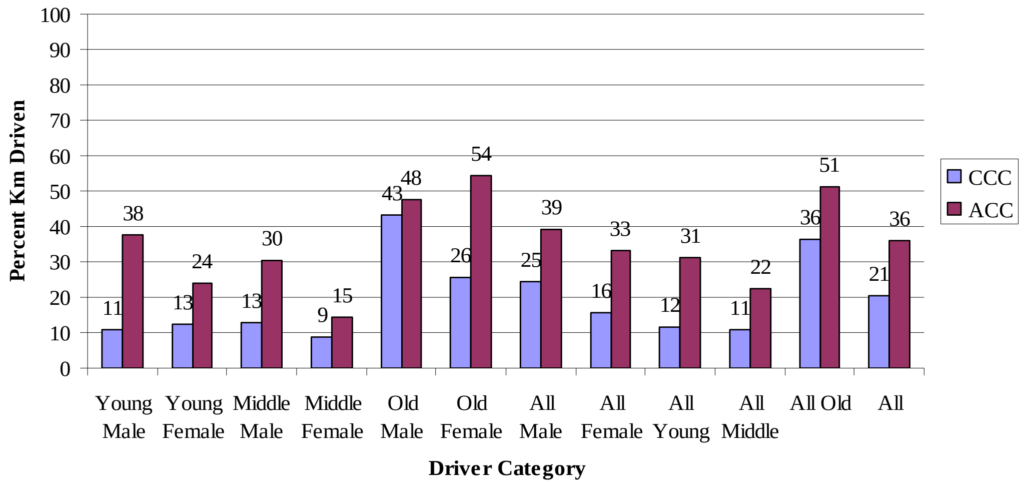


Figure U-1. Comparison of Percent Km Driven using CCC and ACC by Driver Categories

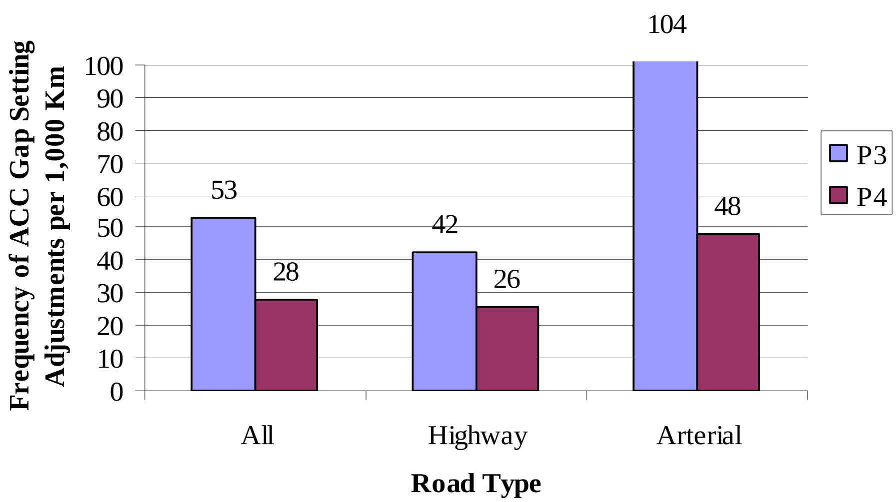


Figure U-2. Frequency of ACC Gap Setting Changes by Road Type and by FOT Period

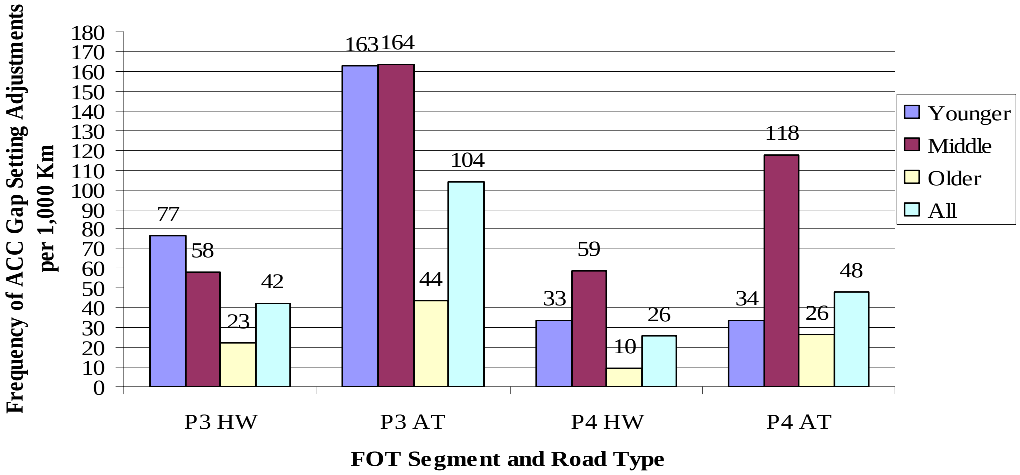


Figure U-3. Frequency of ACC Gap Setting Changes by FOT Segment, Road Type, and Driver Age Group

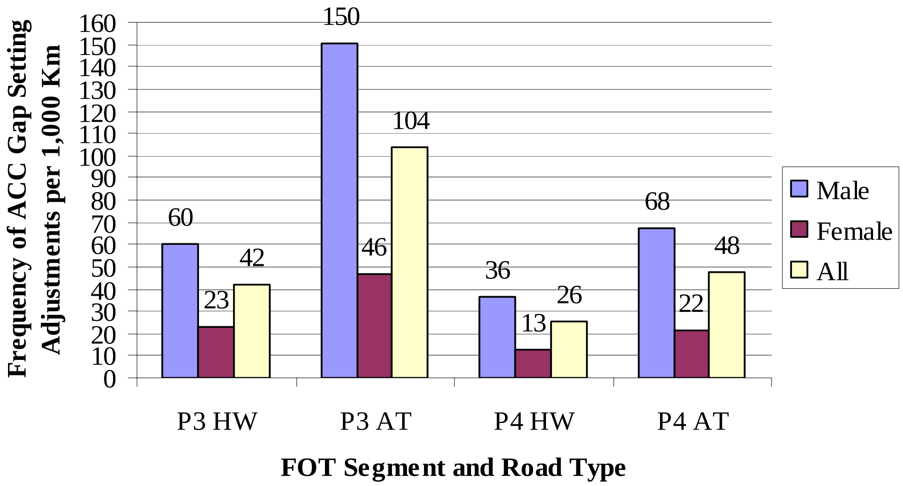


Figure U-4. Frequency of ACC Gap Setting Changes by FOT Segment, Road Type, and Gender

DOT-VNTSC-NHTSA-06-01
DOT HS 810 569
March 2006

U.S. Department of Transportation

National Highway Traffic Safety Administration

Research and
Innovative Technology
Administration
Volpe National
Transportation System Center
Cambridge, MA 02142-1093

People Saving People
www.nhtsa.dot.gov