U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

NHTSA

DOT HS 812 611

May 2019

Indicators of Driver Adaptation to Forward Collision Warnings: A Naturalistic Driving Evaluation

DISCLAIMER

This publication is distributed by the U.S. Department of Transportation, National Highway Traffic Safety Administration, in the interest of information exchange. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Department of Transportation or the National Highway Traffic Safety Administration. The United States Government assumes no liability for its contents or use thereof. If trade or manufacturers' names or products are mentioned, it is because they are considered essential to the object of the publications and should not be construed as an endorsement. The United States Government does not endorse products or manufacturers.

Nodine, E., Fisher, D., Golembiewski, G., Armstrong, C., Lam, A., Jeffers, M.A., Najm, W., Miller, S., Jackson, S., and Kehoe, N. (2019, May). *Indicators of driver adaptation to forward collision warnings: A naturalistic driving evaluation* (Report No. DOT HS 812 611). Washington, DC: National Highway Traffic Safety Administration.

REPORT DOCUMENTATION PAGE		*Form Approved* *OMB No. 0704-0188*
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE May 2019	3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE Indicators of Driver Adaptation to Forward Collision Warnings: A Naturalistic Driving Evaluation	5. FUNDING NUMBERS Intra-Agency Agreement DTNH22-14-V-00132
6. AUTHORS Emily Nodine, Don Fisher, Gary Golembiewski, Chris Armstrong, Andy Lam, Mary Anne Jeffers, Wassim Najm, Sheryl Miller, Steven Jackson, and Nicholas Kehoe	
7. PERFORMING ORGANIZATION NAMES AND ADDRESSES John A Volpe National Transportation Systems Center Cambridge, MA 02142 Leidos 11251 Roger Bacon Drive Reston, VA 20190	8. PERFORMING ORGANIZATION REPORT NUMBER DOT-VNTSC-NHTSA-15-12
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Highway Traffic Safety Administration 1200 New Jersey Avenue SE Washington, DC 20590	10.SPONSORING/MONITORING AGENCY REPORT NUMBER DOT HS 812 611
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT Document is available to the public through the National Technical Information Service, www.ntis.gov.	12b. DISTRIBUTION CODE

13. ABSTRACT

Over the past decade, several studies have determined that vehicles equipped with forward collision warning (FCW) systems can help drivers reduce their likelihood of getting into a crash. To date, the research has only addressed the initial safety benefits incurred by drivers using FCW systems based on short-term exposure (up to one month), and not how those benefits may change over time with longer exposure. In this study, the performance, safety impact, and driver acceptance of a FCW system with automatic emergency braking (AEB) were assessed. Specifically, the project investigated how the safety impact of the system changed over time. This analysis is based on data collected during a one-year naturalistic field test in which 38 participants 20 to 29 years old drove 2013 Cadillac SRXs equipped with FCW and AEB systems. Participants were divided into three exposure groups, “short-term” (approximately 3 months), “medium-term” (approximately 9 months), and “long-term” (approximately 1 year). The accuracy of the alerts and AEB events were characterized by conducting detailed analysis of each event using in-house video analysis software. Detailed vehicle dynamics analyses were also conducted for each AEB event. To assess safety impact, two areas were addressed: overall driving behavior and rear-end near-crash events. Overall, both the observed accuracy and frequency of FCW alerts in the field test were very high, while the accuracy and frequency of AEB events was not. No changes were observed in driver’s speed maintenance, following headway, or alert rate (when alert sensitivity setting was accounted for). The analysis of driver’s exposure to near-crash events showed a statistically significant decrease in the number of near-crash events per mile, from a predicted 2.634 near-crashes per 1,000 vehicle miles traveled (VMT) during the first 1,000 miles to 0.615 conflicts per 1,000 VMT during the last 18,000 miles (a 76.6% decrease). In terms of changes in near crash exposure by time, drivers showed a statistically significant decrease in the number of near-crash events per month, from a predicted rate of 2.377 conflicts during the first month to 0.815 conflicts during the fourteenth month (a 65.7% decrease). These results suggest that the safety benefits of FCW systems are sustained over longer-term exposure.

14. SUBJECT TERMS Driver behavior, driver adaptation, naturalistic driver performance, safety impact, crash warning technology, crash avoidance technology, adaptive cruise control, forward collision alert	15. NUMBER OF PAGES 155
	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	

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

Table of Contents

Figures

Tables

List of Acronyms

ACAS	Automotive Rear-end Collision Avoidance System
ACC	Adaptive Cruise Control
AEB	Automatic Emergency Braking
CAN	Controller Area Network
CPS	Collision Preparation System
DAS	Data Acquisition System
FCA	Forward Collision Alert
FCW	Forward Collision Warning
FOE	Field Operational Experiment
FTP	File Transfer Protocol
GLM	Generalized Linear Model
GPS	Global Positioning System
HDD	Hard Disk Drive
IP	Internet Protocol
IVBSS	Integrated Vehicle-Based Safety Systems
LED	Light-emitting Diode
LVD	Lead Vehicle Decelerating
LVM	Lead Vehicle Moving
LVS	Lead Vehicle Stopped
SD	Standard Deviation
SQL	Software Query Language
TTC	Time-to-collision
UI	User Interface
USB	Universal Serial Bus
VMT	Vehicle Miles Traveled
VOLPE Center	John A Volpe National Transportation Systems Center

Executive Summary

This report presents the methods and results of a study conducted by the John A Volpe National Transportation Systems Center (the Volpe Center) for the National Highway Traffic Safety Administration, to evaluate how driver behavior changes over time when the vehicle they are driving is equipped with a crash-avoidance system. The system provides drivers with a warning if they are at risk for getting into a rear-end crash, and, if necessary, automatically applies the brakes. The warnings consist of a visual display of light-emitting diodes that flash on the vehicle's windshield, and either pulses (vibrations) in the driver's seat (default setting) or an auditory tone (beep). The driver can select between the beeps or seat vibration warnings. The drivers can also adjust the timing of the warnings (far, medium, or near), based on their preferences.

The evaluation was based on naturalistic driving performance data from 24 Cadillac SRXs equipped with Forward Collision Warning (FCW) and automatic crash-imminent braking systems.[1]

The ultimate goal of the study was to determine if the safety benefits from crash avoidance technologies change over time due to driver adaptation to these technologies.

Background

Over the past decade, several studies have determined that vehicles equipped with FCW systems can provide drivers with a safety benefit in terms of a reduced likelihood of getting into a rear-end crash [1] [2]. [3] [4]. These studies estimated that between 2 and 53 percent of rear-end crashes in the United States could be prevented if all passenger cars were equipped with FCW systems. To date the research has only addressed the initial safety benefits incurred by drivers using FCW systems based on short-term exposure (up to 1 month), and not how those benefits may change over time with longer exposure.

Field Operational Experiment

This study is based on data collected during a 12-month field operational experiment (FOE), in which 38 participants (between the ages of 20 and 29 years) drove 2013 Cadillac SRXs equipped with an FCW system. Each vehicle was also equipped with a Data Acquisition System (DAS) that collected data continuously from both the vehicle's Controller Area Network (CAN) bus (including vehicle dynamics, FCW system data, and driver input to the vehicle) and from the four video views (forward scene, the driver's face, the interior of the vehicle, and the sides/rear of the vehicle) during each driver's participation.

The Cadillac FCW and automatic braking system is designed to help drivers avoid, or reduce the harm of rear-end crashes. It is based on a forward-looking radar sensor and a vision-based ranging sensor (camera), which can detect vehicles within a distance of approximately 60 meters (197 feet). It provides FCWs to the driver at speeds above 25 mph in two scenarios:

- When the driver is approaching the vehicle ahead too quickly
- When the driver is following another vehicle too closely

The system also applies the brakes in many imminent rear-end crash situations to help reduce crash damage, even if the driver has not applied the brakes. It may even help avoid some crashes at very low speeds.

Each of the 38 drivers was randomly assigned into the following three participant groups (each group was made up of approximately 50 percent males and 50 percent females):

- Long-term drivers: 12 months (n=11)

[1] The 2013 Cadillac SRX owner manual refers to the FCW application as the Forward Collision Alert (FCA) system.

- Medium-term drivers: 9 months (n=13)
- Short-term drivers: 3 months (n=14)

During the FOE, long-term drivers drove an average of 11,034 miles, medium-term drivers an average of 8,509 miles, and short-term drivers an average of 2,402 miles. Males drove slightly more than females on average (8,104 miles for male drivers compared to 6,292 miles for female drivers).

Long-term drivers received an average of 282 FCW alerts and 2.2 automatic braking activations during their participation in the FOE, medium-term drivers an average of 182 FCW alerts and 1.9 automatic braking activations and short-term drivers an average of 37 FCW alerts and 0.5 automatic braking activations.

Evaluation Goals

Drivers can adapt to advanced technologies over the long term such as FCW and automatic braking systems in ways that are positive or negative [5]. A positive adaptation would be reflected in a decrease in the exposure to driving conflicts and a change in the profile of the response to conflicts when they did occur which made a collision less likely. The decrease in exposure to driving conflicts could come because drivers simply maintained larger headways over time or because they responded more quickly to lead vehicle braking events. The change in the response to conflicts could come because drivers became more vigilant over time, say stepping on the brakes more quickly after an alert. A negative adaptation could occur because drivers came to over rely on the system, maintaining the same level of risk, a posture which is often referred to as risk homeostatis [5].

The primary goal of this study was to determine how the safety impact of the FCW and automatic braking system changed over time. More specifically, the goal was to identify changes in exposure and response to driving conflicts (also referred to as near-crash scenarios). As noted above, observing the change in frequency with which drivers get into conflict scenarios over time provides insight into how the FCW and automatic braking system impacts drivers' exposure to risk and their adaptation (positive or negative) to the technologies. Likewise, observing how a driver's response to conflict events (in terms of intensity) changes over time provides insight into the likelihood that a driver will get into a crash once they are in a high-risk scenario and how they adapt to the technology.

The study also had the following secondary goals:

- Assess the performance of the FCW system and automatic braking: This goal addressed the ability of the FCW system to issue warnings and automatic braking accurately in imminent rear-end crash events.
- Determine driver acceptance of the system: This goal addressed drivers' perceptions of the FCW system with automatic braking based on effectiveness, accuracy, usefulness, and desirability of the FCW system and automatic braking; both before and after driver participation in the field test.

FCW System and Automatic Braking Performance

This evaluation looked at the ability of the system to issue FCW alerts and apply automatic braking appropriately, with the goal of understanding the scenarios when the system does—and does not—support the safety needs that the two features were designed to address (helping drivers avoid rear-end collisions and/or reducing the severity of rear-end collisions by reducing impact speed).

Each FCW alert and automatic braking event was categorized as either true or false, based on whether or not an alert or automatic braking was required (primarily based on the presence of an in-path target) and whether or not it was issued/activated.

Key Findings

FCW Alerts

Overall accuracy of the FCW alerts observed in the study:

- Ninety-eight percent of FCW alerts were issued for in-path vehicles.
- The percentage of FCW alerts issued for in-path vehicles was slightly higher on straight roads (99 percent) compared to curved roads (86 percent).
- FCW true alert rate was much higher for moving targets (99 percent) than for stopped targets (41 percent); however, only 2 percent of all FCW alerts were issued for stopped targets.

Automatic Braking Events

A much smaller percentage of automatic braking events were triggered for in-path vehicles (26 percent) compared to the FCW alerts. Like the alerts, automatic braking events were issued for in-path vehicles more often on straight roads than on curves, and for moving targets as opposed to stopped targets. Unlike the FCW alerts, the majority of automatic braking events were for stopped targets. In 80 percent of the true automatic braking events, the driver braked before the automatic braking engaged. It did not appear that the automatic braking helped drivers avoid a crash.

- Overall, 26 percent of automatic braking events (15 cases) were true (issued for in-path targets). In 12 of these events (80 percent), drivers braked before the automatic braking engaged. Only 5 percent of all automatic braking events (three cases) were both true, and engaged before the driver braked. In two out of three of these cases, the driver avoided the crash.
- Like FCW alerts, automatic braking events were more accurate on straight roads (27 percent) compared to curved roads (14 percent) and for moving targets (50 percent) compared to stopped targets (21 percent). The majority (83 percent) of automatic braking events were triggered by stopped targets.
- It does not appear that any of the automatic braking events triggered during the FOE helped a driver avoid a crash; however, the system likely reduced the intensity of one crash.

Overall, the accuracy of FCW alerts observed in the FOE was much higher than the accuracy of automatic braking events. As a result, based on the literature on the development of mental models [[6]], it is likely that drivers were able to create a mental model of conditions when the FCW alerts were issued, and could therefore anticipate when the system would and would not produce warnings. While high accuracy of the FCW warnings is a positive outcome, as noted above it can potentially cause the driver to over-rely on the system [9] and result in unintended consequences [8]. Alternatively, drivers may make positive behavior modifications as a result of driving with the system if it causes them to drive in a way that prevents them from receiving system alerts. Based on the system accuracy observed in this FOE, it is likely that any observed behavior modifications were the result of drivers' response to the FCW alerts, not the automatic braking events.

Safety Impact

The analysis of safety impact addressed driver adaptation to the FCW system in two areas:

- *Overall driving:* How does a driver's normal, everyday driving behavior change over time when driving with the FCW system?
- *Driving conflicts:* How does the frequency in which drivers get into driving conflicts change over time when driving with the FCW system? When drivers encounter conflict scenarios, does their response to those scenarios change over time?

Key Findings

Overall Driving

The question of how overall driving changed over time addresses the issue of how driving with the FCW system impacts a driver's behavior in normal, everyday driving scenarios. Changes in overall driving behavior can be a reflection of a change in a driver's level of safety (for example, average time headway), although they do not directly impact driving conflicts (the driver could increase time headway and, simultaneously, decide to pay less attention to his or her driving):

- There were no changes in driver travel speed over time when driving with the FCW system.
- There were no changes in driver headway keeping over time when driving with the FCW system.
- Long-term drivers and long-term and medium-term drivers combined (all drivers except for short-term drivers) showed statistically-significant reductions in FCW alert rates over time. However, this reduction was due to drivers changing the alert setting to be less sensitive.
- Long-term and medium-term male drivers combined showed a statistically significant reduction in FCW alert rate over time (due to drivers changing the alert setting to be less sensitive), while female drivers showed no change. On average, female drivers' FCW alert rate was about half the rate of male drivers.

Driving with the FCW system did not have an impact on driver speed or headway keeping over time. Drivers (specifically male drivers) received fewer FCW alerts over time while in the study, however this change was due to drivers changing the FCW alert sensitivity setting. No changes were observed in alert rate when FCW setting was accounted for. Given that male drivers on average received a fairly high rate of FCW alerts (around 4 alerts for every 100 miles they drove), they likely adjusted the sensitivity setting due to a desire to receive fewer alerts.

Driving Conflicts

The question of how driving conflicts changed over time addresses the issue of safety more directly by looking at the frequency with which drivers experience driving conflicts, and the intensity of drivers' responses to conflicts in the scenarios in which they occur. Conflicts result in both actual crashes and near-crashes. Crashes are rare events, so it was not possible to measure a statistically-significant change in actual crash rates with a study of this size. In this study, to address the impact that the FCW system had on a driver's probability of getting into a crash over time, rear-end conflict (near-crash) scenarios (defined as scenarios where a driver had to intervene, by either braking or steering, to avoid a rear-end crash) were used as a surrogate measure for crashes.

When conflicts were measured per mile or per month, there was a practically and statistically-significant decrease in the conflict rate by 76.6 percent (miles) and 65.7 percent (months):

- There was a statistically-significant decrease in the number of conflicts per mile, from a predicted 2.634 conflicts per 1,000 vehicle miles traveled (VMT) during the first 1,000 miles to 0.615 conflicts per 1,000 VMT during the last 18,000 miles. This is a 76.6 percent decrease.
- There was a statistically-significant decrease in the number of conflicts per month, from a predicted conflict rate pf 2.377 conflicts during the first month to 0.815 conflicts during the fourteenth month. This is a decrease of 65.7 percent.

It is unclear whether the above decrease in conflicts over time was due to drivers preferring not to receive alerts[2] or deciding that the alerts were giving them information about just how safe they were.

Response to Driving Conflicts

Observing how a driver responds to conflict events (in terms of the intensity of the event) provides insight into whether drivers could better anticipate potential conflicts in those cases where a conflict was

[2] While the FCW alerts were predominantly true in that they were issued for in-lane vehicles, it is possible that drivers prefer not to receive them or perceive them as unnecessary if they were aware of the presence of that vehicle.

recorded. Clearly, drivers are better able to anticipate potential rear-end driving conflicts because there is a decrease in such conflicts. However, it is unlikely there would be a change in driver response to conflicts over time if:

- Drivers do not anticipate a potential conflict that they could have predicted if they had been paying attention, or
- A conflict unexpectedly occurs because of the actions of another driver in the lane ahead, which no amount of attention could mitigate.

This is exactly what happened during the FOE; there was no change in any of the three different measures of driver responses to conflicts—average MinTTC, average PeakDx, MeanDx—using either miles or months as the measure of exposure.

Driver Acceptance

This evaluation looked at drivers' perceptions of the FCW system with automatic braking both before and after their participation in the FOE, and was based on data collected via Pre and Post-FOE surveys and focus group sessions. Specifically, this evaluation addressed drivers' perceptions of system effectiveness, accuracy, usefulness, and desirability. Driver acceptance is important to consider when evaluating the effectiveness of a technology because if drivers are not willing to use a technology it cannot be effective.

Key Findings

Pre and Post-FOE Surveys

- Generally, participants felt that the system provided them with a safety benefit; 15 drivers reported that the system directly helped them avoid a collision.
- The perceived usefulness of the system decreased from the Pre-FOE survey to the Post-FOE survey. In the Pre-FOE survey participants viewed the usefulness of the system as positive, whereas in the Post-FOE survey there were more negative views than positive ones. This suggests that drivers had an unrealistic perception of system benefits prior to having hands-on experience with it.
- Drivers' opinions of the usefulness of the automatic braking feature were more positive than negative.
- In the Post-FOE survey, 61 percent of participants stated that they would like to have the FCW system in their vehicle.
- Sixty five percent of drivers reported the FCW system being at least somewhat distracting, but the majority of those participants (50 percent of all drivers) reported it being only rarely distracting.

Focus Groups

- Generally, drivers showed a high level of comprehension of the FCW system.
- Only a few drivers showed an understanding that the system's sensitivity setting could influence how many warning a driver received.
- Drivers reported experiencing a decrease in the FCW alert rate over time.
- Drivers generally agreed that the system sometimes issued alerts when they were not necessary, but still had positive perceptions of the FCW system. Some drivers felt that this was OK because it aided their alertness, while others found the alerts to be unnecessary and frustrating.
- Some participants reported that the presence of the FCW system allowed them to multitask more safely. Specifically, two drivers from the long-term exposure group admitted to making calls and

text more frequently while driving with the system, since they felt they could do so more safely than when driving without the system.

Conclusions

FCW systems could result in drivers paying less attention to their driving, if they felt confident that they would receive accurate warnings, or more attention to their driving for whatever reason (to avoid the alerts, to drive more safely). The results of this study indicate that driving the Cadillac FCW system with automatic braking is associated with a decrease in exposure to rear-end driving conflicts. This decrease in exposure is not accompanied by a change in the overall driving pattern or by a change in the response to conflicts when they do occur. While it would have been positive to have seen changes in the response to conflicts that pointed to increases in safety, the bottom line is that there was a decrease in exposure to conflicts over time. This means that the FCW system tested in this FOE is functioning largely as desired, and in a practically-significant way. There is a reduction in the exposure to conflicts somewhere in the neighborhood of 70 percent (depending on the unit of exposure). Whether the FCW system actually caused this reduction cannot be determined since there was no control group (i.e., a group of drivers with no FCW system installed).

1 Introduction

This report presents the methods and results of a study conducted by the John A Volpe National Transportation Systems Center (the Volpe Center) for the National Highway Traffic Safety Administration, to evaluate how drivers' behavior changes over time when the vehicle they are driving is equipped with a crash-avoidance system. Crash avoidance technology is becoming increasingly more common in production vehicles. The proportion of new vehicles with front crash prevention available was around only ten percent in 2009. This had increased to over 50 percent in 2015 [7]. It is critical to understand with the introduction of a new technology just how this technology impacts driver safety, not only immediately after it is introduced, but over a longer horizon. While much is known about how drivers adapt to technology over the short term [5], very little data exists about if and how drivers adapt to these systems after an extended period of time.

The system used in this study, the 2013 Cadillac SRX Forward Collision Avoidance system with automatic braking, provides drivers with a warning if they are at risk for getting into a rear-end crash, and, if necessary, automatically applies the brakes.[3] The Volpe Center's evaluation was based on naturalistic driving performance data from 38 drivers who drove these vehicles for up to one year. Leidos (formerly SAIC), under contract to the Volpe Center, collected this data during a one-year field operational experiment in 2013 and 2014.

The ultimate goal of the study was to determine if the safety benefits from crash avoidance technologies change over time, due to driver adaptation to these technologies.

1.1 Background

Over the past decade, several studies have determined that vehicles equipped with forward collision warning (FCW) systems can provide drivers with a safety benefit.

In 2011, the Volpe Center completed a study that estimated between 27,000 and 450,000 rear-end crashes (between 2 and 31% of all police-reported rear-end crashes) could be prevented in the United States (U.S.) annually if all passenger vehicles were equipped with FCW systems [1]. These estimates were based on data collected during a naturalistic field test where drivers used an integrated safety system that included a FCW system for a period of four weeks [2]. Neither system included an active brake assist feature.

Another study conducted by the Volpe Center in 2006 on an automotive rear-end collision avoidance system (ACAS) equipped with FCW warnings and adaptive cruise control (ACC), estimated that between 133,000 and 687,000 (between 3 and 17%) of rear-end crashes in the United States could be prevented if all passenger cars were equipped with the ACAS system. These estimates were based on data collected during a naturalistic field test where drivers used the ACAS for a period of 4 weeks [3].

A 2014 study conducted by Virginia Tech Transportation Institute using test track data and modeling based on 16 different production FCW systems estimated that if all vehicles in the United States vehicle fleet were equipped with FCW systems, between 9 and 53 percent of rear-end crashes could be prevented [4].

To date, the research has only addressed the initial safety benefits incurred by drivers using FCW systems during a short period of time, and has not addressed how those benefits may change over time with longer exposure.

A naturalistic driving study was selected to address the topic of driver adaptation to advanced safety systems for several reasons. First, it is necessary to expose drivers to the advanced safety systems for

[3] The Cadillac AEB system features both dynamic brake assist (adjusting braking intensity to assist drivers in avoiding or lessening the severity of crashes) and crash imminent braking (braking automatically to avoid, or lessen the severity of a crash, even if the driver does not brake).

hundreds and perhaps thousands of hours over the course of a year. Second, because safety critical events are relatively infrequent, it is important to gather data continuously over the period of exposure. Third, because it is difficult to predict how the system will perform and the scenarios in which the performance of the system will be compromised, it is important to gather data in situations as close to ones the driver would actually encounter as possible. A naturalistic study has each of these advantages. The present study is the first to address this topic using real-world, naturalistic driving data. It was also the first large-scale study conducted to assess the impacts of production-level, passenger car, automatic braking systems.

1.2 FCW System and Automatic Braking

While many vehicle models come equipped with advanced safety systems, the Cadillac SRX was selected for the study because it offered a suite of safety systems that met the study requirements, and was compatible with the team's data collection equipment. The Cadillac FCW and automatic braking system is designed to help drivers avoid or reduce the harm of rear-end crashes. It provides alerts to the driver at speeds above 25 mph in two scenarios:

- When the driver is approaching the vehicle ahead too quickly
- When the driver is following another vehicle too closely

FCWs are issued to the driver using a visual display of light-emitting diode (LED) lights that flash onto the vehicle's windshield, and either pulses (vibrations) in the driver's seat (default setting), or.an auditory tone (beep). The driver can select between the auditory (beeps) or haptic (seat vibration) warnings using a menu system in the vehicle control panel.

The drivers can also adjust the timing of the warnings (far, medium, or near), based on their preferences. The far setting (the default setting) is the most conservative, while the near setting is the most aggressive (warnings are issued later).

The Cadillac SRX also has an automatic braking component. If the system determines that a rear-end crash is imminent and the driver has not applied the brakes, it will apply the brakes to avoid a crash or to help reduce crash damage. If the system determines the the driver has applied the brakes, but not hard enough, it will increase the braking intensity to avoid a crash or to help reduce crash damage.

The Cadillac's rear-end crash avoidance system is based on a forward-looking radar sensor and a vision-based ranging sensor (camera), which can detect vehicles within a distance of approximately 60 meters (197 feet). The system will only issue warnings to the driver at speeds above 40 km/h (25 mph), but the automatic braking component is active at all speeds [8].

1.3 Evaluation Goals

The overall goal of this study is to determine how the safety impact of the FCW system and automatic braking changes over time, by identifying changes in driver behavior that resulted in either an increase or decrease in the likelihood of being involved in a rear-end crash. Specifically, the goals of study are to:

- *Assess the performance of the FCW system and automatic braking:* This goal addresses the ability of the FCW system to issue warnings and the automatic braking to accurately activate in rear-end crash imminent events.
- *Determine if the safety impact of the FCW and automatic braking system changes over time:* This goal determines if there is either a positive or negative change in driver behavior over time. In other words, do the safety benefits obtained from driving with FCW systems change after driving with the system for an extended period of time?

- *Assess driver acceptance of the FCW and automatic braking system:* This goal addresses drivers' perceptions of FCW system with automatic braking, based on effectiveness, accuracy, usefulness, and desirability of both before, and after their participation in the field test.

The first two goals, performance of the FCW and automatic braking events and the safety impact of the system over time, were addressed by the Volpe Center. The analysis of driver acceptance was conducted by Leidos.

The system capability analysis characterizes the performance of the FCW system and automatic braking to provide context for the safety impact results. It is important to understand the nature of the drivers' experiences with this system when interpreting the impact that it has on their driving. Section 2 describes the technical approach the Volpe Center used to assess system performance and the results of the analysis.

The analysis of safety impact over time addresses two types of driving metrics; overall driving and driving conflicts (also referred to as near-crash scenarios). The analysis of overall driving investigates changes in a driver's day-to day driving behavior (e.g., travel speed, following behavior, etc.), while the analysis of driving conflicts investigates the frequency with which drivers get into high-risk, near-crash driving scenarios and how they respond to these scenarios. Observing how frequently drivers get into conflict scenarios over time provides insight into how the FCW and automatic braking system impacts driver exposure to risk. Likewise, observing how a driver responds to conflict events (in terms of intensity) provides insight into the likelihood that a driver will get into a crash once they are in a high-risk scenario. Section 3.1 contains detailed definitions of overall driving metrics, conflicts, and conflict evaluation metrics. Section 3.2 describes the results of the safety impact analysis.

The FCW system driver acceptance assessment is based on the results of the subjective data collected by Leidos both before and after the field test. Section 5 presents the results of pre- and post-drive surveys and summarizes the focus group sessions.

2 Field Operational Experiment Details

The following subsections contain details about the study participants, experimental design, and data collection methods, and summarize participant exposure during the FOE.

2.1.1 Participants

The FOE participants included 38 drivers between 20 and 29 years of age who were employees of Leidos in the greater Washington, DC area. Leidos chose to focus on only one age range due to the relatively small sample size planned for the study. To streamline the day-to-day management of the vehicle fleet, Leidos employees from the Reston, Virginia offices were selected as participants in the study. This selection approach made servicing and collecting data from the vehicles more efficient, not only for the study conductors, but also for the study participants, since the vehicles were co-located every day with the study team. Leidos has over 32,000 employees overall, so the Reston, Virginia offices provided a large pool of participants to draw from who were not involved in the study or worked in related areas of transportation safety. The following subsections explain how the drivers were recruited and describe their characteristics.

2.1.1.1 Recruitment, Screening, and Orientation

When the study began, Leidos posted an announcement on the company's internal network. It described the study's requirements and encouraged employees who met the core criteria (less than 30 years old and holding a valid driver's license) to complete a recruitment screening survey (the "screener"). Questions were designed to gather information about gender, age, driving patterns (e.g., mileage, commute locations), and experience with FCW and automatic braking systems. In order to mask the intent of the FOE, participants were also asked to provide perceptions and opinions of other vehicle systems (e.g., rear parking assist, in-vehicle navigation). The research team assessed responses from 218 potential participants to determine eligibility for study participation. The results were first screened to select only those individuals who:

- Had at least 3 years of driving experience in the United States.
- Permitted a driving record check.
- Possessed a valid driver's license.
- Consented to the requirements of the study.
- Would be 29 years old or younger as of June 1, 2013 (the planned date for the FOE initiation).
- Responded "never," "less than once per month," or "not sure" to having driven a vehicle with FCW.
- Responded "never," "less than once per month," or "not sure" to having driven a vehicle with automatic braking.
- Responded "at least once per year," "less than once per year," "never," or "not sure" to having been a passenger in a vehicle with FCW.
- Responded "at least once per year," "less than once per year," "never," or "not sure" to having been a passenger in a vehicle with automatic braking.
- Drove at least 144 miles per week, on average. This minimum translates to about 7,500 miles per year, which was the 25th percentile self-reported mileage as reflected on the screener.

After applying the above requirements, the research team developed additional criteria to select which of the eligible participants would participate in the study. To maximize opportunities for FCWs and automatic braking events, drivers with higher weekly mileage estimates were selected. Work locations were also consolidated to facilitate efficient data swaps and maintenance with participants. Although the research team considered all individuals who responded "less than once per month" and "not sure" to having driven a vehicle with FCW and automatic braking to be eligible, the preference was individuals who had no experience with these systems so that a truly inexperienced participant group could be generated. For those who responded "less than once per year," the team reviewed their individual responses to a follow-up question on the screener that asked them to further explain their experience with these systems in free response (e.g., if they rented a car with this kind of system). The team removed from consideration any eligible participant who indicated they had driven a vehicle with these systems on multiple occasions.

Appendix A contains the screener survey.

After participants were selected (and agreed) to participate in the FOE, they completed a survey to provide Leidos with in-depth information about participant characteristics, driving experience, and pre-existing opinions of FCW and automatic braking systems. Participants were also asked to provide opinions of other vehicle systems (e.g., rear parking assist, in-vehicle navigation).

Appendix B contains the background survey.

All surveys were administered using the Qualtrics online survey tool. Respondents were sent an email invitation containing a link to the survey instrument. The research team then downloaded their responses for analysis.

All participants were required to attend an orientation session before they were assigned their vehicles. These sessions were conducted in groups and were typically held in the evenings. They provided an overview of the study and short descriptions (including videos) of the advanced safety systems installed on the vehicles, created by the vehicle manufacturer. Participants were also reminded of their responsibilities (e.g., survey completion, compliance with the requirement they would be the only drivers, etc.). In addition, they reviewed and signed the informed consent form required for participation.

Appendix C contain the orientation script and Appendix D contains the informed consent.

2.1.1.2 Characteristics

The following subsections describe the characteristics of the 38 FOE participants including demographics, driving patterns, and previous experience with safety systems.[4]

2.1.1.2.1 Demographics

One of the study requirements was that all participants be between the age of 20 and 29 years old as of June 1, 2013. The average age of females in the study was 27 years (range 24 to 29 years) and the average age of males in the study was 27 years (range 23 to 29 years). The majority of the participants (23) held a bachelor's degree and 6 held either a master's or doctorate degree. Of the remaining participants, 2 attended some graduate school, 1 held an associate's degree, 4 attended some college, and 1 was a high school graduate. The modal category (22) of annual gross household income was $50,000 to $99,999.

Only 2 participants expected to purchase or lease a vehicle within the next 7 to 12 months. Ten participants planned to purchase or lease a new model year vehicle more than a year from now and 18 participants did not plan to purchase or lease a new model year vehicle. The remaining 4 participants were unsure of their plans. If a purchase or lease was to be made, 29 of the participants were the primary decision maker and 8 shared decision making.

Participants were asked to describe their preference when purchasing new technology. Nearly all of the participants preferred to wait to buy new technologies, as opposed to being one of the first to buy. Over half of the participants would not buy new technologies until the "product hype" decreased, and about

[4] Background data were collected on 37 of the 38 participants in the study.

one-third of the participants indicated they would wait until the technologies were reviewed and they were referred by friends.

2.1.1.2.2 Driving Patterns

Of the 38 participants, 31 obtained their drivers' license at age 16. The remaining 6 participants obtained their drivers' license at age 17. The average number of years of driving experience was 10 (range = 7 to 13 years).

The primary personal vehicles driven by the participants were 1999 model year or newer. The most recent model year was 2013. Approximately half (19) of the vehicles were 2009 model year or newer. The primary vehicle make varied. The most frequently occurring automakers were Subaru (5), Honda (4), and Nissan (4). By chance, no participant drove a Cadillac as their primary vehicle. About one third (13) of the participants drove their primary vehicle for more than 4 years. Seven participants drove their primary vehicle for 3 to 4 years, 10 did so for 1 to 2 years, and 7 for less than 1 year.

Seventeen participants also drove a secondary vehicle. Fifty-nine percent (10) of these participants drove vehicles that were 2009 model year or newer. Secondary vehicle make varied; one secondary vehicle was made by Cadillac (CTSV sedan). The majority of participants (14) drove their secondary vehicle for less than 2 years.

Participants stated they drove between 3 and 5 days (mean = 5 days) per week solely for commuting purposes. The majority (30) drove to only one work location per day, although the work location could vary from day-to-day. Participants lived in the Washington, DC metropolitan area, and their main work location was in Northern Virginia in the Chantilly, Reston, McLean, Springfield, Vienna, and Arlington areas. Generally, morning commute patterns occurred between 6 a.m. and 9 a.m., with trips most often starting at 7:30 a.m. Evening commute patterns usually occurred between 3 p.m. and 6 p.m., with trips most often starting at 4:30 p.m. or 5 p.m.

Participants stated they drove between 5 and 7 days (mean = 7 days) per week for both commuting and non-commuting purposes. Female weekly mileage estimates ranged from 125 to 400 miles (mean = 233.95 miles); the male range was between 170 to 350 miles (mean = 259.17 miles). These estimates translate to an average annual mileage of 12,165.26 miles and 13,476.67 miles for females and males, respectively (for females the range = 6,500 to 20,800 miles and for males the range = 8,840 to 18,200 miles). Results of a Wilcoxon rank sum test indicated no significant difference in annual mileage estimates between the two genders at the 0.05 significance level. Previous Experience with Safety Systems

Based on the study requirements, only FCW and automatic braking systems were the focus in the current study. However, to mask the true concern of the research, questions about other in-vehicle technologies were also included on the participant surveys.

Figure 1 displays the frequency distribution of participant experience as a driver with different in-vehicle technologies. As shown, the participants' experience with FCW, automatic braking, and ACC was very limited, with most having no experience with these systems. However, approximately one-third reported they did have some experience with backup assistance, OnStar, and built-in navigation. It would seem that this group had a degree of experience with advanced electronics; therefore, it would appear that they would be able to understand and use the systems of interest.

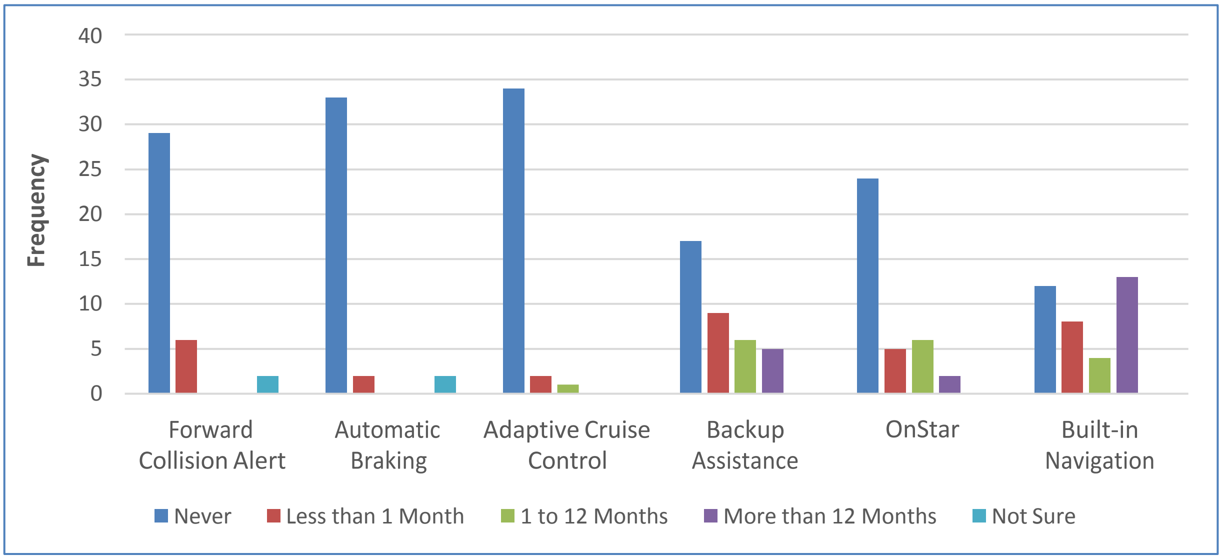


Figure 1. Driver Experience with Various In-vehicle Technologies

In the participant screener, FCW was defined as: "These systems alert the driver when the vehicle is getting too close to another vehicle in front of it." The majority of participants had no experience as a driver with FCW systems. Six of the participants used the systems for less than one month and two participants were unsure if they had used the systems previously.

Automatic braking was defined as: "If the driver has not applied the brakes when a front crash is imminent, an emergency system applies the brakes for the driver. (Cruise control does not need to be turned on for this to occur.)" The majority of participants had no experience as a driver with the automatic braking system. Two of the participants used the system for less than one month and two participants were unsure if they had used the systems previously.

2.1.2 Experimental Design

Selected study participants attended an orientation session that provided an overview of the study and a description of the safety systems installed on the study vehicles.

Drivers were randomly assigned into the following three participant groups:

- Long-term drivers: 12 months
- Medium-term drivers: 9 months
- Short-term drivers: 3 months

There were a total of 24 instrumented vehicles. The purpose of having three different participant groups was to maximize the number of participants in the study during the first 3 months of exposure. Specifically, Leidos hypothesized that the most substantial driver adaptations would occur within the first 3 months of the study. Rather than have 24 participants drive the 24 vehicles for 12 months each, Leidos proposed to have 12 drivers for 3 months, 12 for 9 months, and 12 for 12 months, thus making it possible to gather data on 36 drivers during the first 3 months and still limit the number of vehicles to 24 at any one time.

Even though the drivers were originally balanced evenly across the three test groups (12 participants in each group), one long-term driver left the study early and was recategorized as a medium-term driver, and one medium-term driver left the study early and was recategorized as a short-term driver. In both cases another participant was selected to drive the study vehicle for the remainder of the FOE, for a total of 38 participants. The final breakdown was 11 drivers in the long-term group, 14 drivers in the medium-term group, and 13 drivers in the short-term group.

Each participant drove the vehicle for the first 3 weeks with the FCW and automatic braking system turned off, to allow them to become acquainted with the test vehicle and to get baseline measures of their driving behavior. For the first week of this baseline period, the data collection system was disabled to allow drivers a chance to familiarize themselves with the vehicle prior to the start of data collection. After one week, Leidos enabled the data collection system and recorded the drivers' baseline driving data. At the end of the 3-week baseline period, Leidos turned on the FCW and automatic braking system, and asked participants to leave it on for the duration of the study.

The length of each participant's exposure to the crash avoidance system varied slightly due to scheduling. Long-term drivers drove with the system turned on for an average of 51.5 weeks, medium-term drivers for an average of 36.7 weeks, and short-term drivers for an average of 8.6 weeks. Female participants drove for an average of 29.3 weeks and male participants drove for an average of 33.4 weeks.

2.1.3 Objective Data Collection

The following subsections contain information about the study vehicles, the data acquisition systems used to log objective data, and the objective data elements collected during the field test. Additional technical information about objective data collection, including trip definitions and data logging setup, data transfer, and data reconciliation are located in Appendix E.

2.1.3.1 Study Vehicle

Each participant drove one of 24 model-year 2013 Cadillac SRXs equipped with a FCW system and automatic braking. Each study vehicle was also equipped with adaptive cruise control, a lane departure warning system, park assist/rear vision camera, and a side blind zone alert; however, data were not collected on these features since they were not the focus of the study.

2.1.3.2 Data Acquisition System

Additional equipment was installed on the study vehicles to store the data from the vehicle's CAN bus and from externally installed video cameras locally and transfer it from the vehicle to remote storage. Data were logged by the data acquisition system via Universal sSerial bBus (USB) to a 128 GB flash drive. These components were stored in the vehicle's glove compartment, and the glove compartment was locked so that participants could not gain access to the data collection equipment (see Figure 2). Vehicle data and video data were stored separately by the data acquisition system in two separate but linked files for each trip:

- Vehicle data in a flat text file (approximately 12 MB per hour of driving)
- Video data in a high-resolution AVI video format (approximately 1.2 GB per hour of driving)

Table 1 lists the specific variables collected by the data acquisition system.

Figure 2. Location of Data Acquisition System in Glove Compartment in the SRX

Table 1. List of Objective Data Elements

	Data Element
GPS	▪ Satellites ▪ Time ▪ Velocity ▪ Height ▪ Latitude ▪ Longitude ▪ Heading
Vehicle Environment	▪ Low Beam Active Status ▪ Drive Seat Belt Active Status ▪ Vehicle Odometer ▪ Brake Lights Active Status ▪ Windshield Wiper Active Status ▪ Turn Signal Active Request
Vehicle Dynamics	▪ Vehicle Lateral Acceleration ▪ Vehicle Speed ▪ Brake Pedal Position ▪ Vehicle Longitudinal Acceleration

	Data Element
	▪ Steering Wheel Angle ▪ Accelerator Pedal Position
Active Driver Assistance Systems	▪ CPS Setting ▪ Automatic Braking – CPS Axle Torque Request ▪ Driver ACC Set Speed ▪ Alert Warning Indication Request ▪ ACC Active Status ▪ Automatic Braking – CPS Axle Torque Request Active ▪ Alert Sensitivity Setting ▪ Vehicle Ahead Indication ▪ Signal
Vehicle Safety	▪ Vehicle Stability Control Status ▪ Traction Control Active Status ▪ ABS Active Status
Radar	▪ Range to Forward Object ▪ Dynamic Property of Forward Object Track 1 ▪ Confidence Level for Forward Object Track 1 ▪ Range Rate to Forward Object Track 1 ▪ Azimuth to Forward Object Track 1
Vision	▪ Range to Forward Object Track 1 ▪ Relative Lane for Forward Object Track 1 ▪ Confidence Level for Forward Object Track 1 ▪ Object Type for Forward Object Track 1
CPS = Collision preparation system ACC = Adaptive cruise control ABS = Antilock braking system	

2.1.4 Subjective Data Collection

After the field test ended each participant completed a post-FOE survey that addressed their experience with, and acceptance of, the FCW system. Similar to the pre-FOE surveys, the research team conducted surveys using the Qualtrics online survey tool. Respondents received an email invitation containing a link to the survey, and the research team then downloaded their responses for analysis.

Appendix F contains a copy of the post-FOE survey.

Additionally, all participants were invited to take part in a focus group when the study ended. The purpose of this group was to gather data in a more flexible, in-depth, and conversational manner. It also provided an opportunity to obtain observations and anecdotal information that participants were not able to include in the post-FOE survey responses. This meant researchers were able to drill down in particular topic areas, and expand the understanding of observed and objective driving behavior and responses from the surveys.

Of the 38 participants, 3 were not able to attend a focus group meeting, and were invited to take part in an individual interview. These interviews followed the same general format as the focus groups.

Six different focus group sessions were conducted. One research team member facilitated each meeting and another took extensive notes. An effort was made to keep each focus group to less than 10 participants and under 2 hours in length. The following content was included in each meeting:

- Overall reactions, particularly reported adjustments after returning to non-study vehicles
- Description and ranking of risky driving situations (forward collision risks only)
- Reports of how vehicle systems might mitigate forward collision risk
- Detailed discussion of the FCW alerts (including experience and opinions of reliability and usability)
- Detailed discussion of the automatic braking events (including experience and opinions of reliability and usability)
- General discussion of behavior adaptations during the study

Appendix G contains the protocol for conducting focus groups.

2.1.5 Field Test Exposure

The following subsections describe how far the participants drove during the FOE, and how many FCW alerts and automatic braking events they experienced.

2.1.5.1 Vehicle Miles Traveled

The participants drove an average of 7,151 miles with the FCW and automatic braking system enabled during the FOE.

Figure 3 shows the distribution of mileage driven with the FCW and automatic braking system by test group and gender. The center line on each box represents the median mileage driven. The upper and lower borders of the box represent the inter-quartile range, and the whiskers represent the minimum and maximum values.

Drivers in each test group drove a mileage that was roughly proportional to the duration of their participation; long-term drivers had an average of 11,034 vehicle miles traveled (VMTs), medium-term drivers an average of 8,509 VMTs, and short-term drivers an average of 2,402 VMTs. Males drove slightly more than females on average (8,104 miles for male drivers compared to 6,292 miles for female drivers).

Table 14 in Appendix H provides descriptive statistics for the system exposure data in Figure 3.

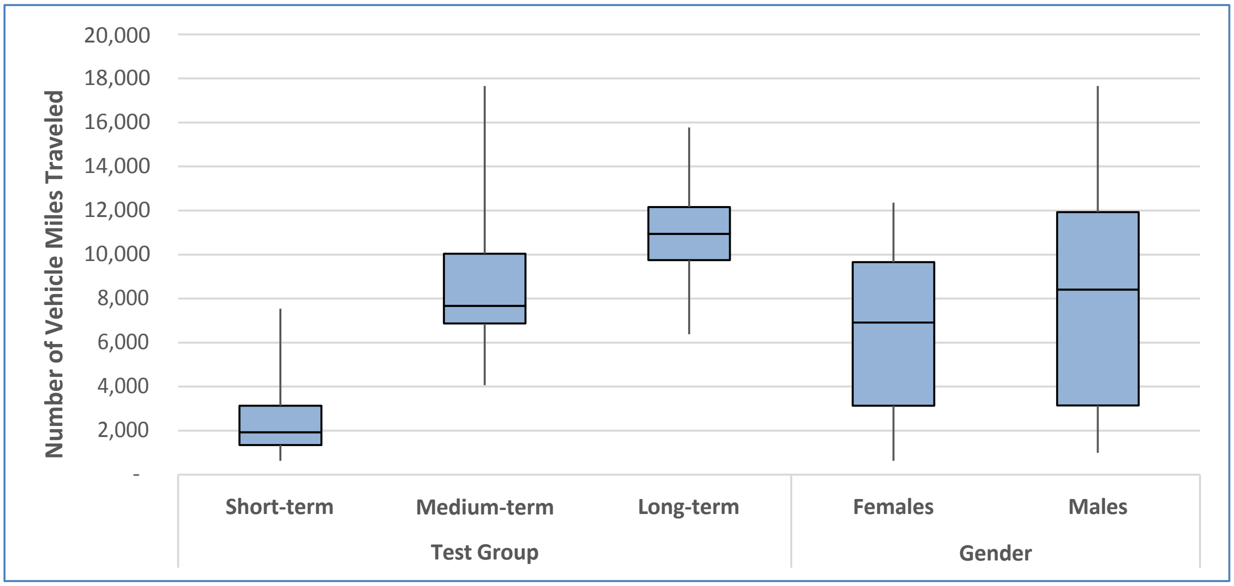


Figure 3. Average FOE Mileage by Test Group and Gender

2.1.5.2 FCW Alerts

Drivers experienced an average of 161 alerts during their exposure to the FCW system. Figure 4 shows the distribution of drivers' exposure to FCW alerts by test group and gender. The center line on each box represents the median number of FCW alerts received. The upper and lower borders of the box represent the inter-quartile range, and the whiskers represent the minimum and maximum number of alerts received. On average, male drivers received over three times the number of FCW alerts as female drivers (78 alerts for females, compared to 253 for males).

Table 15 in Appendix H provides descriptive statistics for the system exposure data in Figure 4.

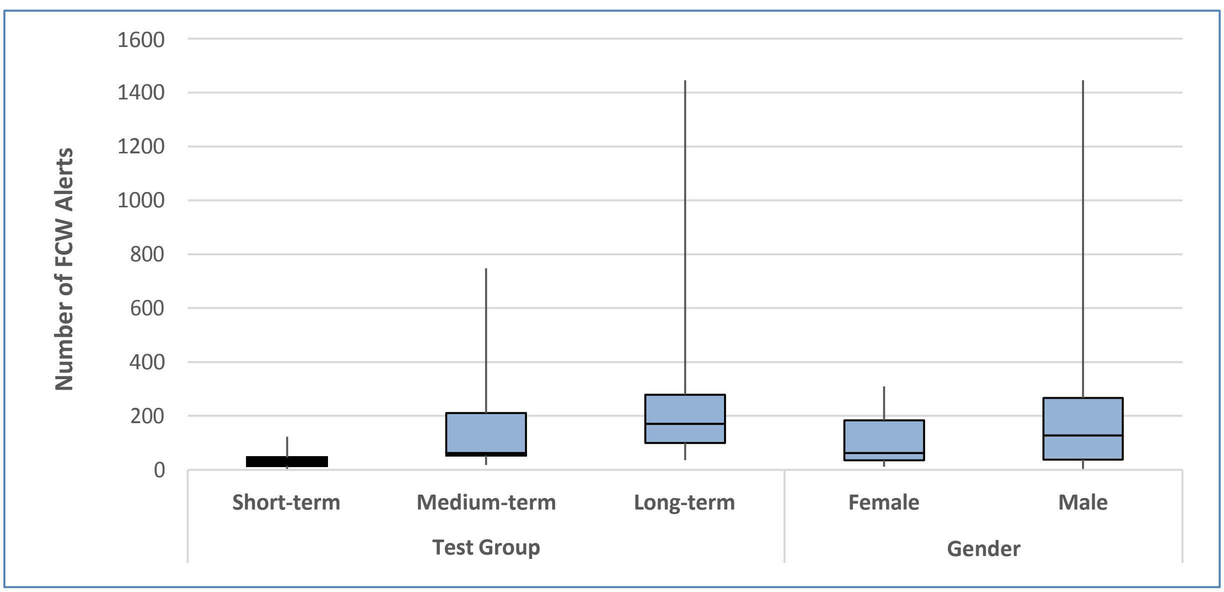


Figure 4. Average Number of FCW Alerts by Test Group and Gender

There was a large variability in the number of FCW alerts received among drivers. Figure 5 shows the distribution of FCW alerts across drivers, broken down by test group. Forty percent of drivers received 50

FCW alerts or fewer during the FOE, and 63 percent received 100 or fewer FCW alerts. Three drivers (all male) received very high numbers of alerts (604, 748, and 1,446 alerts total). The Volpe Center chose to include the data from these 3 outliers in the analysis for three reasons. First, and most importantly, the data from these 3 drivers were of high quality. Thus, there were no technical reasons to eliminate the outliers. Second, it is well known that there are large individual differences in driving behavior, such as time headway [9]. Therefore, the variations are what one would expect to see in a relatively small sample and so the outliers should be included. And third, because the drivers who received the highest frequency of alerts are likely to be the most risky drivers [10] and therefore likely to receive the most benefits from driving with a safety technology, it made sense to include them.

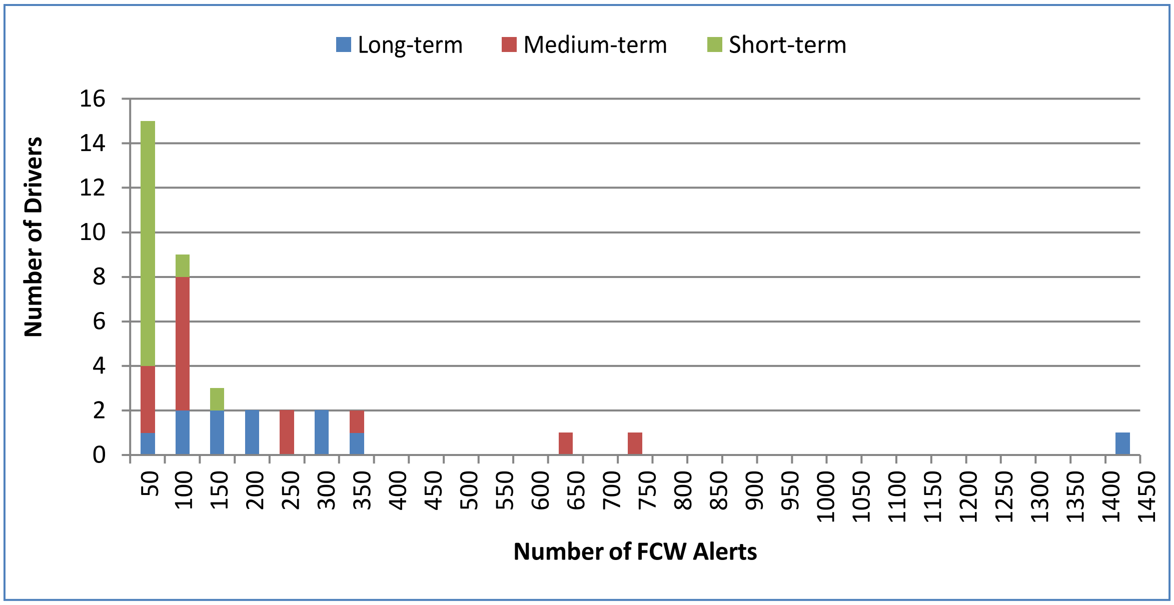


Figure 5. Distribution of FCW Alerts

FCW alerts were issued at an average range of 13.4 meters from the lead vehicle (sd = 8.12 m) with a maximum observed range of 95.1 m and a minimum observed range of 2 m. Figure 6 shows the distribution of the range to the target vehicle at the time of the FCW alerts.

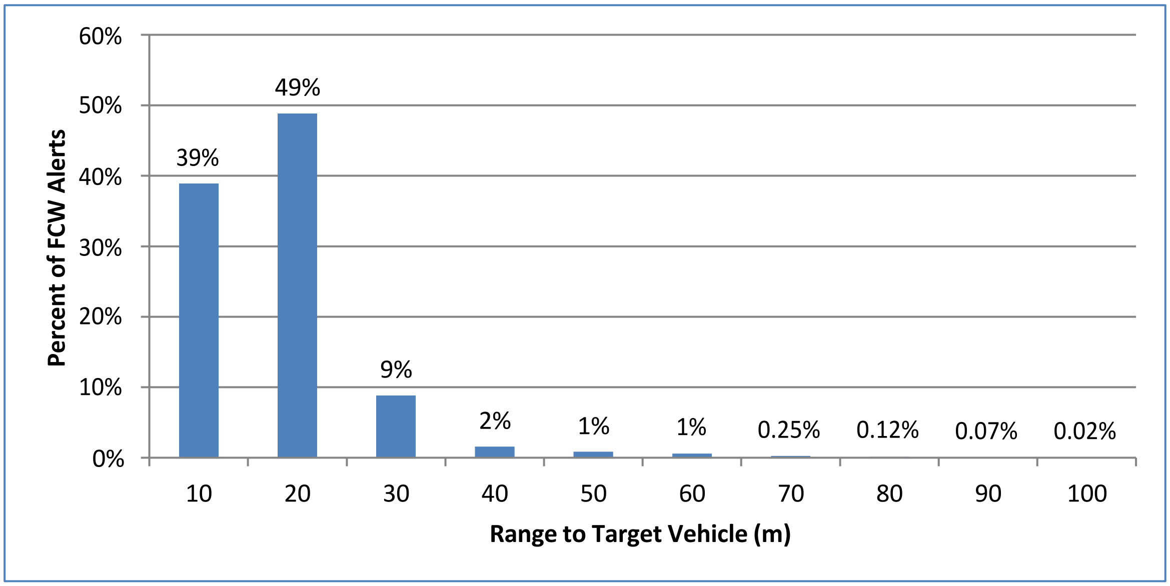


Figure 6. Distribution of Range to Target Vehicle at FCW Alert Onset

2.1.5.3 Automatic Braking Events

Twenty-four of the 38 participants in the FOE experienced automatic braking events, while 14 did not. The highest number of automatic braking events experienced by a driver was 6 (a long-term, male participant). On average, drivers experienced 1.5 automatic breaking events during their participation. Figure 7 shows the distribution of automatic braking events for each test group and gender.

Table 16 in Appendix H provides descriptive statistics for the system exposure data in Figure 7.

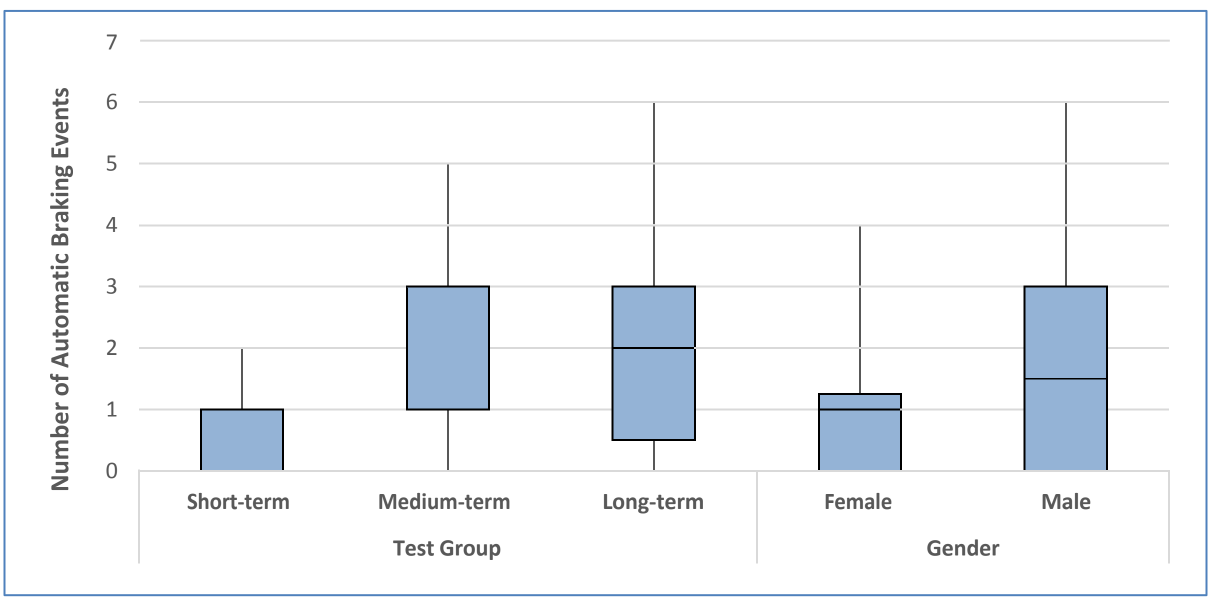


Figure 7. Average Number of Automatic Braking Events, by Test Group and Gender

Automatic braking events were issued at an average range of 13.9 m from the lead vehicle (sd = 13.7 m) with a maximum observed range of 41.5 m and a minimum observed range of 1.0 m. Figure 8 shows the distribution of the range to the target vehicle at the time of the automatic braking events.

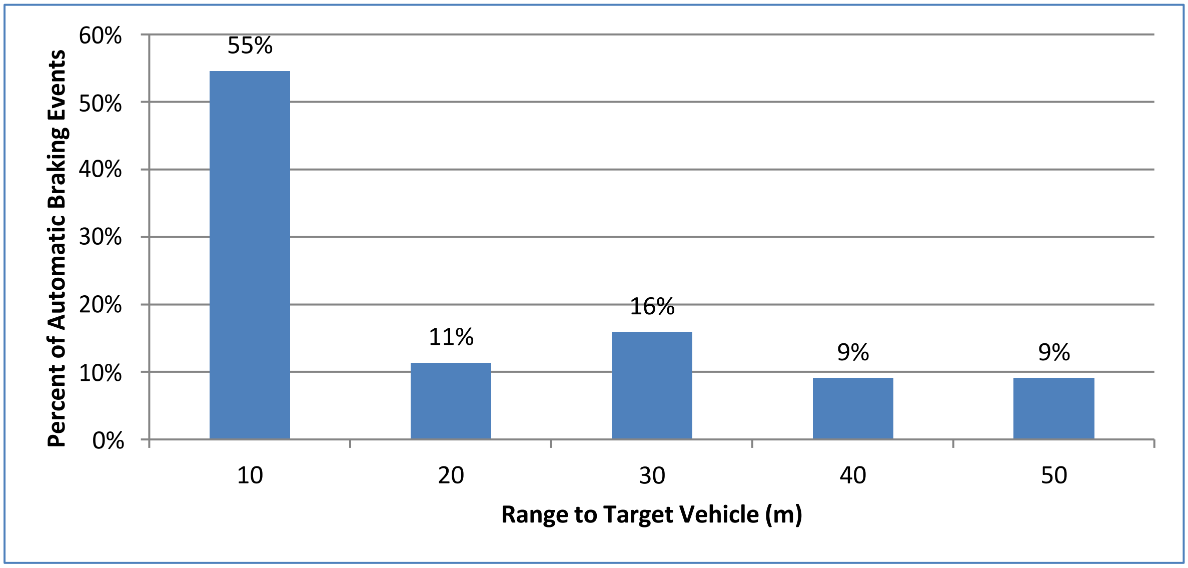


Figure 8. Distribution of Range to Target Vehicle at the Onset of Automatic Braking Events

3 FCW Alert and Automatic Braking Performance

The system performance analysis characterizes the FCW and automatic braking system's ability to issue warnings and execute automatic braking accurately. This section describes the technical approach used to analyze FCW and automatic braking system performance and presents results of the analysis.

3.1 Technical Approach

This subsection describes the technical approach used to evaluate the FCW and automatic braking system performance.

3.1.1 FCW Alert and Automatic Brake Accuracy

The Volpe Center assessed the accuracy of alerts and automatic braking events by analyzing numerical and video data and by classifying each automatic braking event by objective criteria. The purpose of this analysis is to understand the scenarios when the FCW and automatic braking system does—and does not—support the safety need the feature was designed to address (helping drivers avoid rear-end collisions).

Table 2 shows the event classifications used in this analysis, based on whether or not an FCW alert or automatic braking was required and whether or not it was issued/activated. The Volpe Center categorized all events where automatic braking was applied as either true or false events, based on whether or not automatic braking was required to help avoid a crash (based on the presence of an in-path target). For true events, the Volpe Center also analyzed the distance and closing speed to the lead vehicle, to further assess the appropriateness of the events. Missed alerts or correct rejections were not addressed in this study.

Table 2. Alert and Automatic Brake Event Classifications

	Required	Not Required
Alert or Automatic Brake Applied	True Events	False Events
Alert or Automatic Brake Not Applied	Missed Events	Correct Rejections

The Volpe Center used the video analysis tool (shown in Figure 9) to classify the FCW alerts and automatic braking events. The tool displays four video views as well as synchronized numerical data (in either graphical or tabular format). The boxes on the right are input fields where the user can enter data based on the video review. These inputs capture information from the video about the driving scenario, the driver's behavior, and environmental conditions. The Volpe Center selected these fields to be consistent with the video analysis metrics used by Leidos (the company conducting the FOE to analyze the FCW alerts). Appendix I lists all variables coded during the video analysis of FCW alerts and automatic braking events.

Figure 9. Video Analysis Tool

FCW and automatic braking performance classifications were primarily based on the location and vehicle dynamics of the target that triggered the alert or automatic brake activation. Events were classified into the following two categories:

- *In-Lane:* Alerts or automatic braking events that occur when the host vehicle is approaching a stopped, slower, or rapidly decelerating vehicle in the same lane of travel.
- *Out-of-Path:* Alerts or automatic braking events that occur when an immediate threat is not present.

The Volpe Center analyzed the vehicle dynamics of events with in-path targets in more detail to determine if an automatic braking event was required. FCW alerts and automatic braking events with out-of-path targets were broken down into the following categories:

- Target type (e.g., out of path vehicle, stationary roadside object, overpass, etc.)
- Host vehicle location (e.g., straight road, curve entry, negotiating curve, etc.)
- Target speed (e.g., stopped targets, moving targets)
- Host vehicle maneuver (e.g., changing lanes, turning, merging, etc.)

The Volpe Center also described in-path FCW alerts and automatic braking events in relation to the timing of the alert to better understand the severity of events in which the alerts were issued. Alerts were characterized in terms of:

- *Host vehicle speed*: The speed of the host vehicle at the time the alert was issued or automatic braking was applied.
- *FCW setting (close, medium, far)*: The Cadillac FCW system has a setting that allows the driver to adjust the timing of the FCW warnings. The "far" setting is the most conservative and provides

warnings to the driver earlier. The “close” setting is the most aggressive and provides warnings to the driver later.

- *Time-to-collision (TTC):* A measure that indicates the amount of time until the host vehicle strikes the lead vehicle if both vehicles continued their current trajectories. TTC is equal to the range to the lead vehicle divided by the closing speed.
- *Time Headway:* A measure that indicates the amount of time it would take the host vehicle to reach the current location of the lead vehicle if the host continued its current trajectory. Headway is equal to the range to the lead vehicle divided by the host vehicle’s speed.

3.1.2 Impact of Automatic Braking Events

While FCW alerts only provide information to the driver, automatic braking events exert control over the vehicle. As a result, true and false automatic braking events are likely to have a significant impact on the driver, both in terms of their safety and their emotional reaction to the event (facial expression). To better understand this impact, and because the sample size of automatic braking events was small relative to the size of FCW alerts, the Volpe Center conducted an in-depth evaluation of both true and false automatic braking events. The Volpe Center used both numerical (quantitative) and video (qualitative) data for these analyses. Each event was summarized based on the driver’s facial expressions and the impact that the false event had on the safety of the driver and other vehicles on the road (e.g., the impact of the brakes activating when no threat existed). These exploratory analyses were conducted to try to gain insight on the unintended consequences of false automatic braking events.

3.2 Results

The following subsections describe the results of the system performance analysis of FCW alerts and automatic braking events.

3.2.1 FCW Alerts

Overall, 6,121 FCW alerts were issued during the FOE.[5] Leidos analyzed videos of 3,428 true alerts (issued for in-lane targets) that occurred during the daytime as part of their analysis of the FOE data. The Volpe Center then analyzed videos of an additional 2,607 FCW alerts, including both additional true alerts and false alerts. The remaining 86 FCW alerts had obstructed or corrupt video files and therefore could not be analyzed. Results in this subsection are based on the 6,035 FCW alerts analyzed by the Volpe Center and Leidos combined.

3.2.1.1 FCW Alert Categories

Figure 10 shows the target location in the 6,035 analyzed FCW alerts. For all figures in this document, the numbers on the top of each bar on the chart represent the total number of events in each category. Alerts in the first category of “In-Lane Vehicle” are considered to be true alerts. All other alerts are issued for targets that are not in the path of the host vehicle and are therefore considered to be false. False alert categories are defined below:

- *One Lane Over Vehicle:* Target vehicle is in the travel lane adjacent to the host vehicle.
- *Roadside/Out-of-Path Object:* Alert is issued for an object on the side of the road (e.g., telephone pole or parked car).
- *Bridge/Overhead Sign:* Alert is issued for an overpass or an overhead sign (generally on the freeway).

[5] This number includes only events where an FCW alert was issued, but automatic braking was not activated.

- *Other:* Target does not fall into one of the above categories (e.g., perpendicular vehicle, or unidentified target).

Ninety-eight percent of FCW alerts were issued for in-path vehicles. All out-of-path target (false alert) categories combined accounted for only 2 percent of FCW alerts.

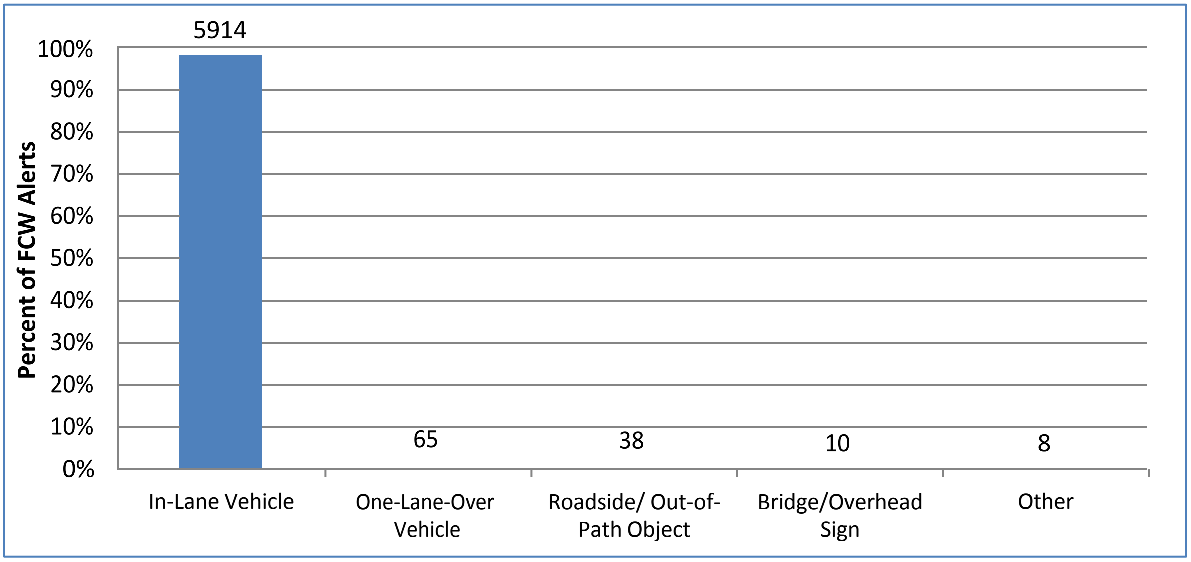


Figure 10. Target Location of FCW Alerts

Figure 11 further breaks down the target location by whether or not the host vehicle driver was braking at the time the FCW alert was issued. If the driver was braking at the time of the alert, they may consider the FCW alert to be a nuisance alert, even if it is issued for an in-path target. Overall, 22 percent of the in-path alerts were issued when the host vehicle driver had already applied the brakes.

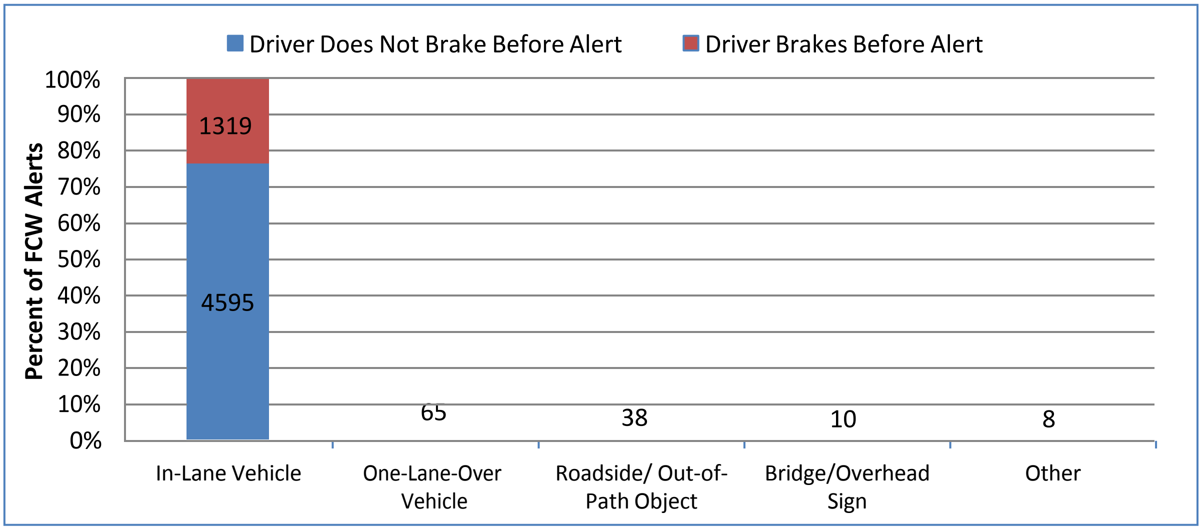


Figure 11. Target Location of FCW Alerts by Host Vehicle Driver Braking

Road curvature can impact the performance of a radar or vision-based system because radar may lose track of the target if the host vehicle is navigating through a curve (the target may no longer be straight ahead, and therefore not visible by the radar). Figure 12 breaks down target location by position of the host vehicle on a curve. Overall, 365 FCW alerts were issued when the host vehicle was navigating a curve. The accuracy of the FCW alerts was slightly lower when the host vehicle was navigating a curve;

86 percent of alerts on curves were issued for in-lane vehicles, whereas 99 percent of alerts on straight roads were issued for in-lane vehicles. The most frequent false alert types when the host vehicle was navigating a curve were alerts issued for adjacent lane vehicles (8% of curved road alerts), and alerts issued for roadside objects (5% of curved road alerts).

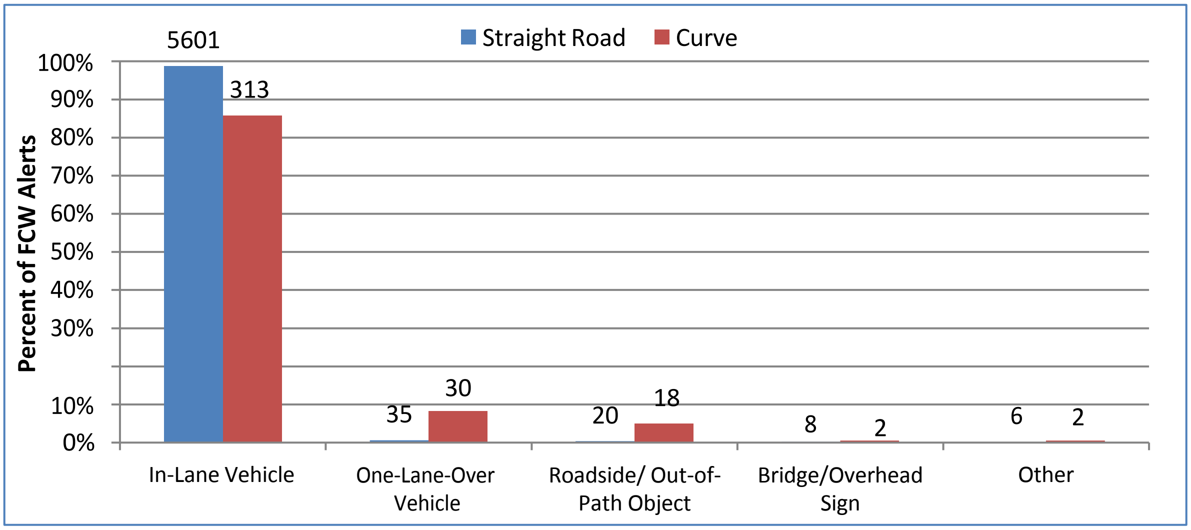


Figure 12. Target Location of FCW Alerts by Host Vehicle Road Curvature

The performance of a radar-based system can be impacted by the motion state of the target, because radar systems can pick up and track moving targets more easily than they can detect and track stopped targets. Only 2 percent of the FCW alerts (111) were issued for stopped targets (defined as targets traveling less than 2.5 mph). Figure 13 breaks down the FCW alerts by target location and target motion state. The accuracy of alerts issued for stopped targets was less than half that of alerts issued for moving targets (99% of moving targets were in-lane vehicles, whereas only 41% of stopped targets were in-lane vehicles).

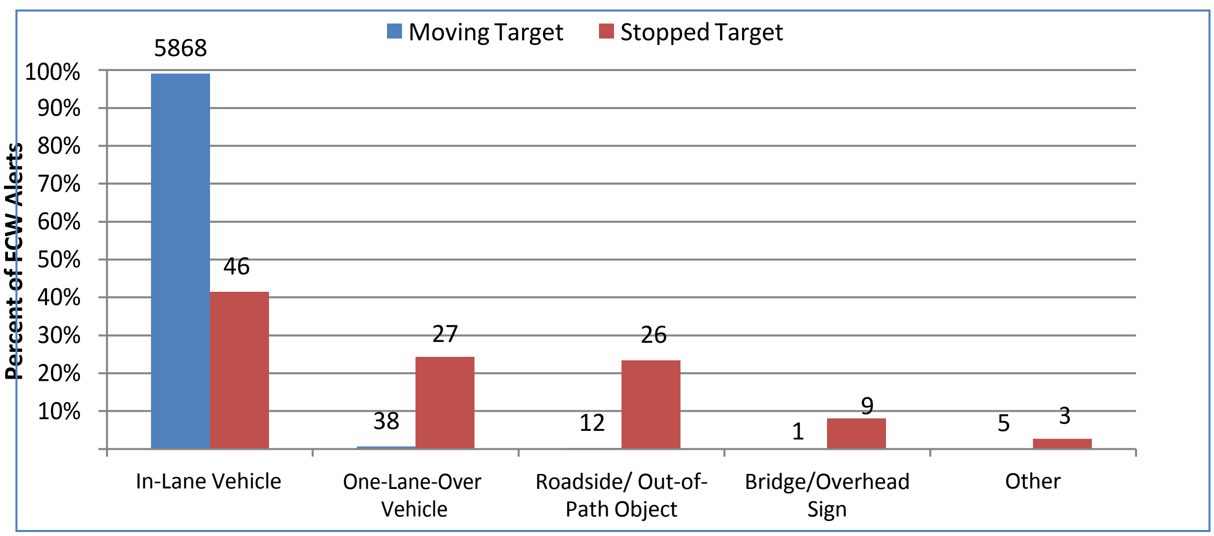


Figure 13. Target Location of FCW Alerts by Target Motion State

Finally, the target location was broken down by the host vehicle maneuver at the time of the alert to illustrate the accuracy of the FCW alerts during different driving maneuvers. As shown in Figure 14, the highest rate of false alerts (alerts issued for non in-path vehicles) occurred when the host vehicle was turning (12% false; compared to 2% false when the host vehicle was maintaining its lane less than 1 false when it was changing lanes, and 2% false when merging).

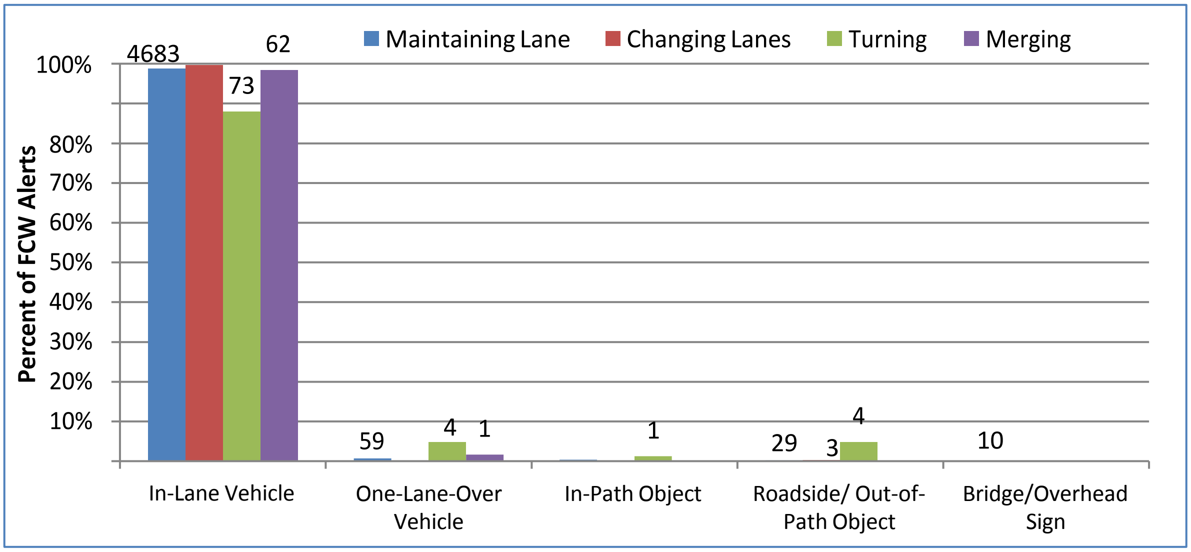


Figure 14. Target Location by Host Vehicle Maneuver

3.2.1.2 FCW Alert Timing

To evaluate FCW alert timing, the Volpe Center separated the events into the following three categories based on vehicle dynamics of the target vehicle:

- *Lead Vehicle Stopped (LVS)*: The host vehicle is approaching a stopped target.
- *Lead Vehicle Moving (LVM)*: The host vehicle is approaching a slower, constant speed target.
- *Lead Vehicle Decelerating (LVD)*: The host vehicle is approaching a target that is decelerating.

These categories are also referred to as pre-crash scenarios since they define the vehicle dynamics of driving scenarios that could escalate into a crash scenario.

Figure 15 shows the TTC (range/range rate) versus speed for the in-lane vehicle FCW alerts issued during the FOE, broken down by pre-crash scenario. The average TTC for LVS, LVM, and LVD alerts was 3.1 s (sd =0.9 s), 11.2 s (sd=13.0 s), and 7.0 s (sd= 6.7 s) respectively. NHTSA recommends forward collision warning systems have a TTC of at least 2.1 s for LVS scenarios, 2.4 s for LVD scenarios, and 2.0 s for LVM scenarios based on selected initial conditions [11]. The average observed TTC values for each pre-crash scenario in the FOE are much higher than the TTC values suggested by NHTSA and also have a high degree of variability, suggesting that the algorithm used to determine when to issue an FCW in this FOE was not based primarily on constant TTC.

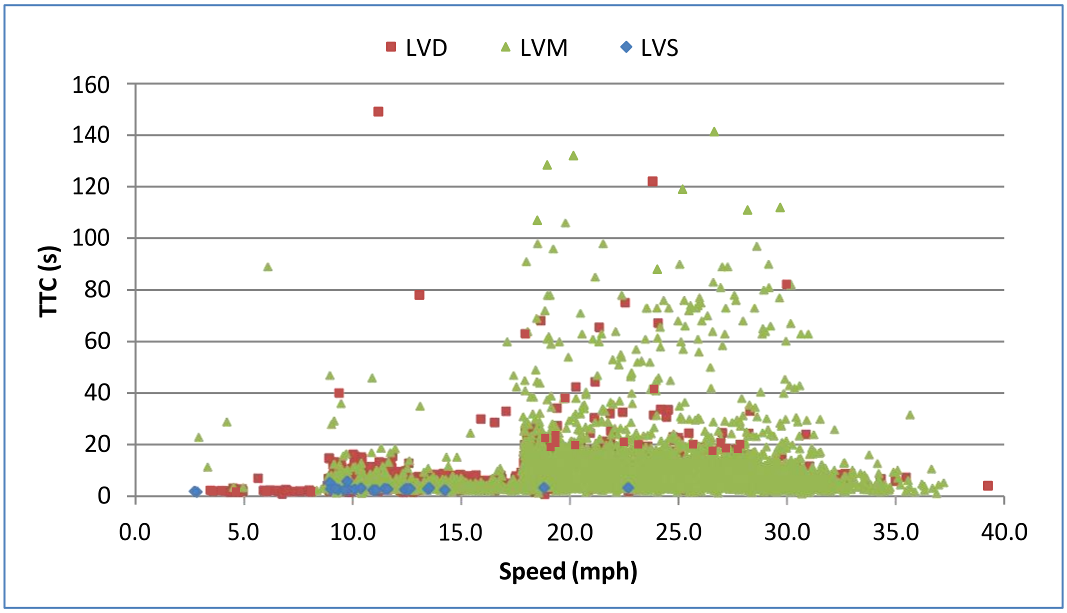


Figure 15. TTC Versus Host Vehicle Speed for FCW Alerts, by Pre-Crash Scenario

Figure 16 shows the cumulative distribution of alerts by TTC, broken down by close, medium, and far settings. There is very little difference in the distribution of TTC by alert setting.

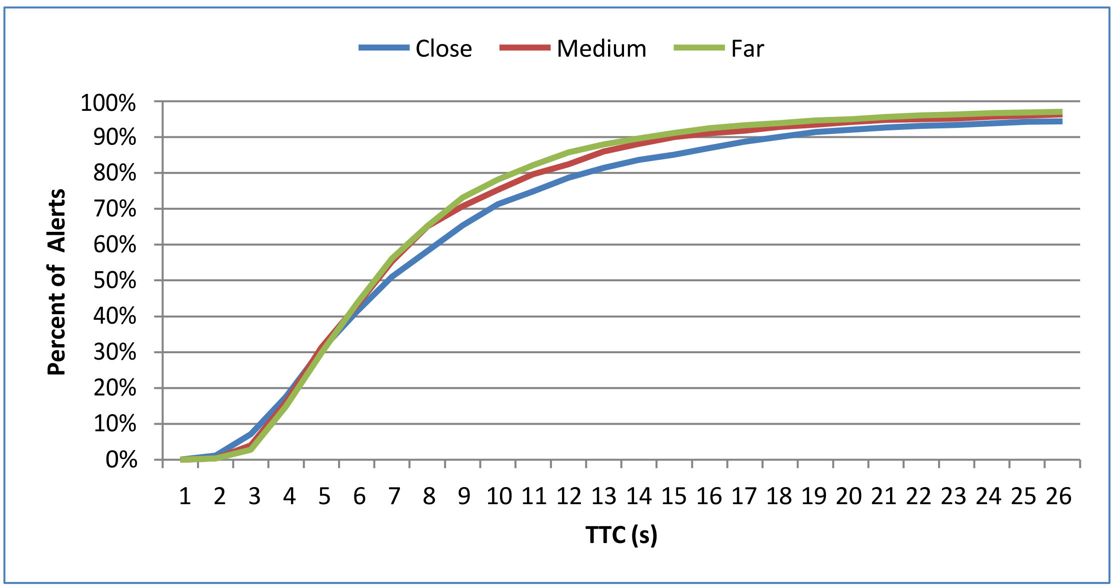


Figure 16. Cumulative TTC Distribution by FCW Setting

Figure 17 shows time headway versus speed for alerts in each of the three pre-crash scenarios. Average headways were 0.9 s (SD = 0.4 s), 0.6 s (SD = 0.4 s), and 2.9 s (SD =1.0 s) for LVD, LVM, and LVS scenarios respectively.[6] The values for headway at alert time are grouped more closely than the values of TTC at alert time.

[6] NHTSA does not provide recommendations for FCW performance based on the metric headway.

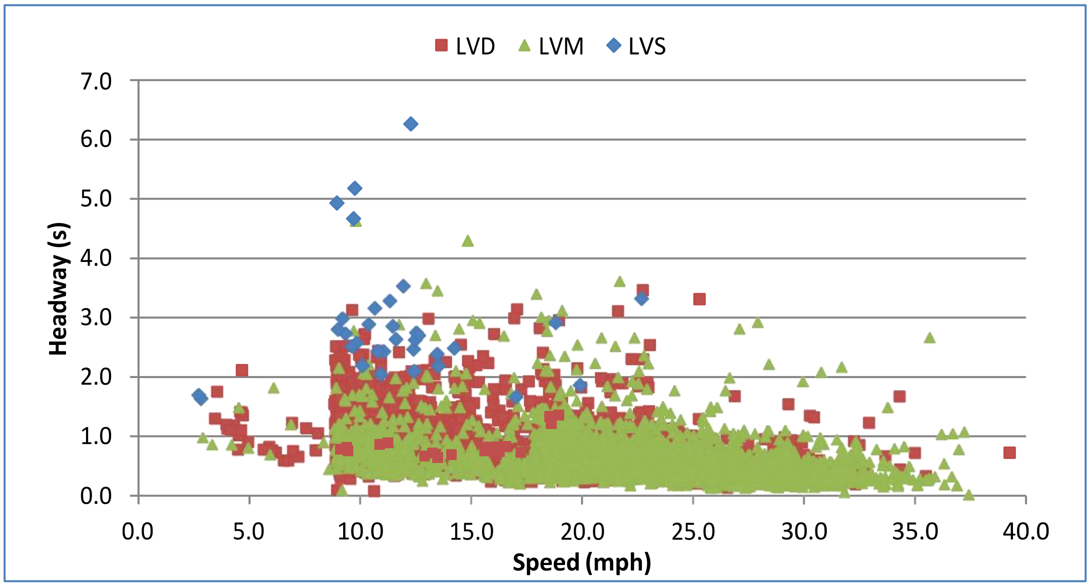


Figure 17. Headway Versus Host Vehicle Speed for FCW Alerts, by Pre-Crash Scenario

Figure 18 shows the cumulative distribution of headway at alert time, for alerts issued with close, medium, and far settings. Unlike TTC alerts in Figure 8, there is a clear differentiation between the headway at the time of the alert at different FCW settings, suggesting that the decision to issue an FCW alert is more closely related to headway than to TTC.

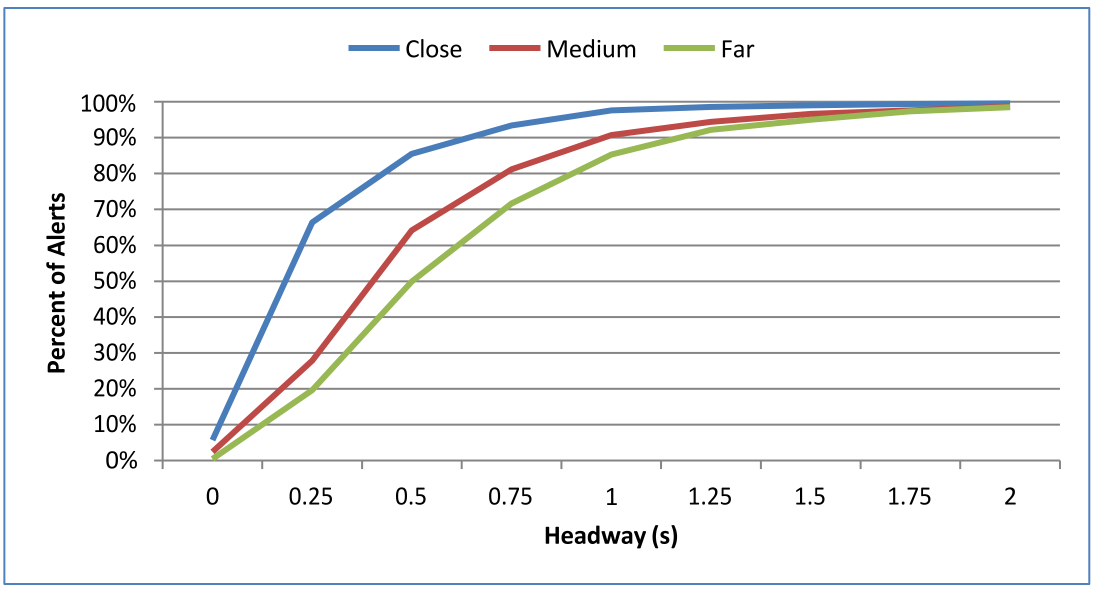


Figure 18. Cumulative Headway Distribution by FCW Setting

3.2.2 Automatic Braking Events

Fifty-eight events occurred where an FCW alert was followed by automatic braking activation. The Volpe Center analyzed videos and assessed driver impact for all these events. The following subsections summarize and discuss these results.

3.2.2.1 Automatic Braking Event Categories

Following the same approach used in analyzing FCW alert scenarios, the Volpe Center reviewed videos to determine the location of the target in each of the observed automatic braking scenarios. Figure 19 shows automatic braking events by target location (the number on the top of each bar represents the total number of events in each category). In addition to the four false alert categories listed in Section 3.2.1.1, the following automatic braking event categories are included:

- *In-Path Object*: A non-vehicle object that is in the host vehicle's path of travel (e.g., automatic gate).
- *Parking Garage/Parking Lot:* Automatic braking is triggered by a parked car or object when the host vehicle is maneuvering through a parking garage or parking lot.
- *Perpendicular Vehicle:* A vehicle that is traveling perpendicularly to the host vehicle at a rotary or intersection.
- *Unidentified Target:* A target could not be identified in the video.

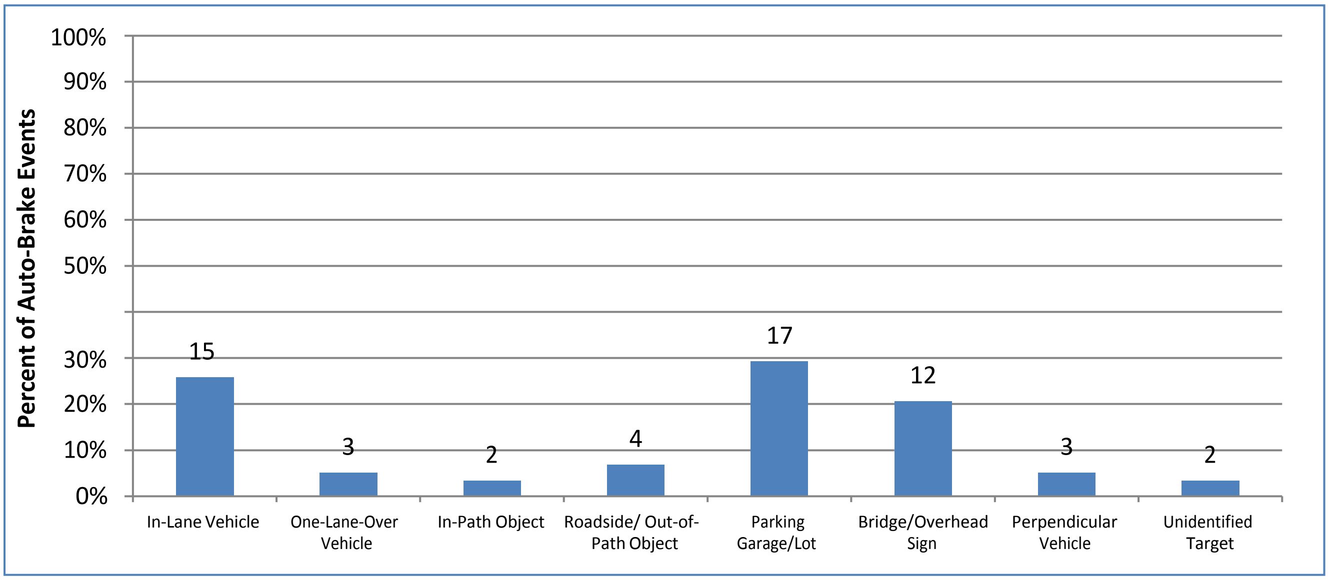


Figure 19. Target Location of Automatic Braking Events

Overall only 26 percent of automatic braking events were triggered by in-lane vehicles. The remaining 74 percent were false. Of the alerts issued for in-lane vehicles, the host vehicle driver was braking prior to the automatic braking being engaged in 12 of 15 cases. This meant that overall only 5 percent of automatic braking events (3 of 58) were scenarios where the system identified and responded to valid events before the driver did. In 2 of these 3 events, the driver was not braking because there was either no closing speed (0.0 mph) or very little closing speed (0.2 mph) to the lead vehicle and braking was not required. In the other event, the automatic braking engaged 0.1 s before the driver braked (automatic braking engaged when the lead vehicle was stopped, with headway of 0.6 s). The host vehicle crashed into the lead vehicle, meaning that the automatic braking was engaged too late to help the driver avoid a crash.[7] For more detail refer to Section 3.2.2.3.1.

[7] In this event, the host vehicle and the lead vehicle were both merging at a yield sign. The lead vehicle stopped suddenly while the host vehicle driver was looking over his shoulder to see if it was safe to merge. The automatic braking engaged when the host vehicle was going 10.9 mph and was 2.6 m away from the lead vehicle. The host vehicle struck the lead vehicle at a speed of 8.5 mph and reached a peak deceleration of 1.5g.

Similar to the FCW alert results shown in Figure 12, automatic braking event performance was slightly worse when the host vehicle was in a curve (27% of events for in-lane vehicles when the host was on a straight road, compared to 14% of events for in-lane vehicles when the host was in a curve). The most frequent category of false alerts for both curves and straight roads was roadside/out-of-path targets, with the proportion of events slightly higher when the host vehicle was in a curve (43% of events when in a curve compared to 37% of events when on a straight road). Figure 20 illustrates road curvature events.[8]

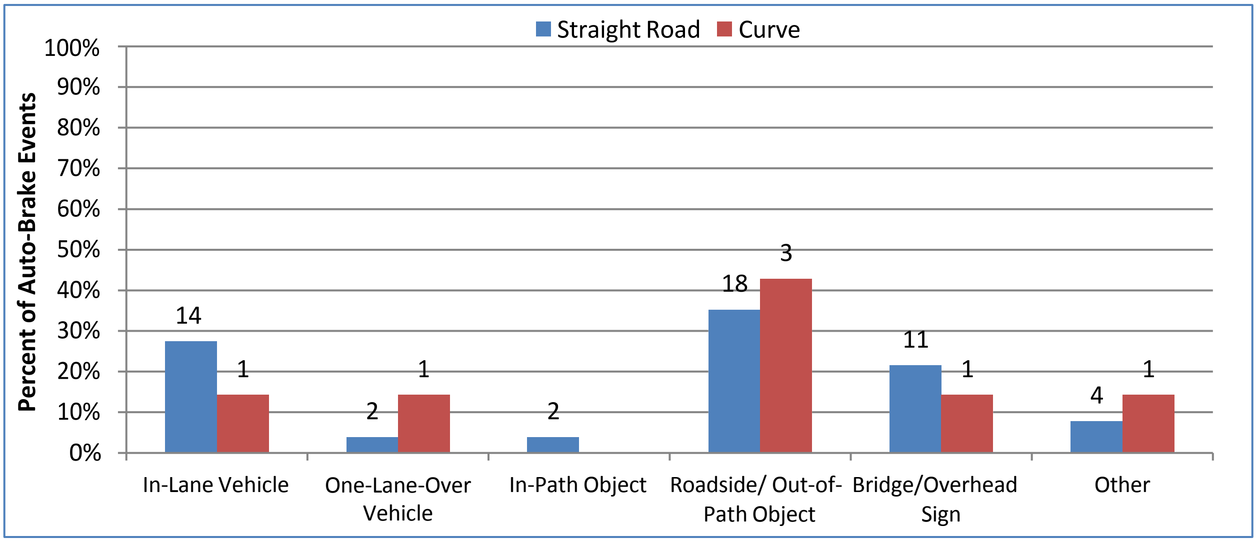


Figure 20. Target Location of Automatic Braking Events, by Road Curvature

Figure 21 shows the breakdown of target location by the speed of the target. Similar to the breakdown of the FCW alerts in Figure 13, system accuracy was better for moving targets than for stopped targets. Fifty percent of automatic braking events triggered by moving targets were true, whereas only 21 percent of automatic braking events triggered by stopped targets were true. Unlike FCW alerts, the majority (83%) of automatic braking events were triggered by stopped targets, which potentially contributed to the lower overall accuracy of the automatic brake events compared to the FCW alerts.

[8] In Figure 20 and Figure 21 the category "Roadside/Out of Path Object" encompasses both "Roadside/Out of Path Object" and "Parking Garage/Lot" from Figure 19. The category "Other" encompasses both "Unidentified Target" and "Perpendicular Vehicle" from Figure 19.

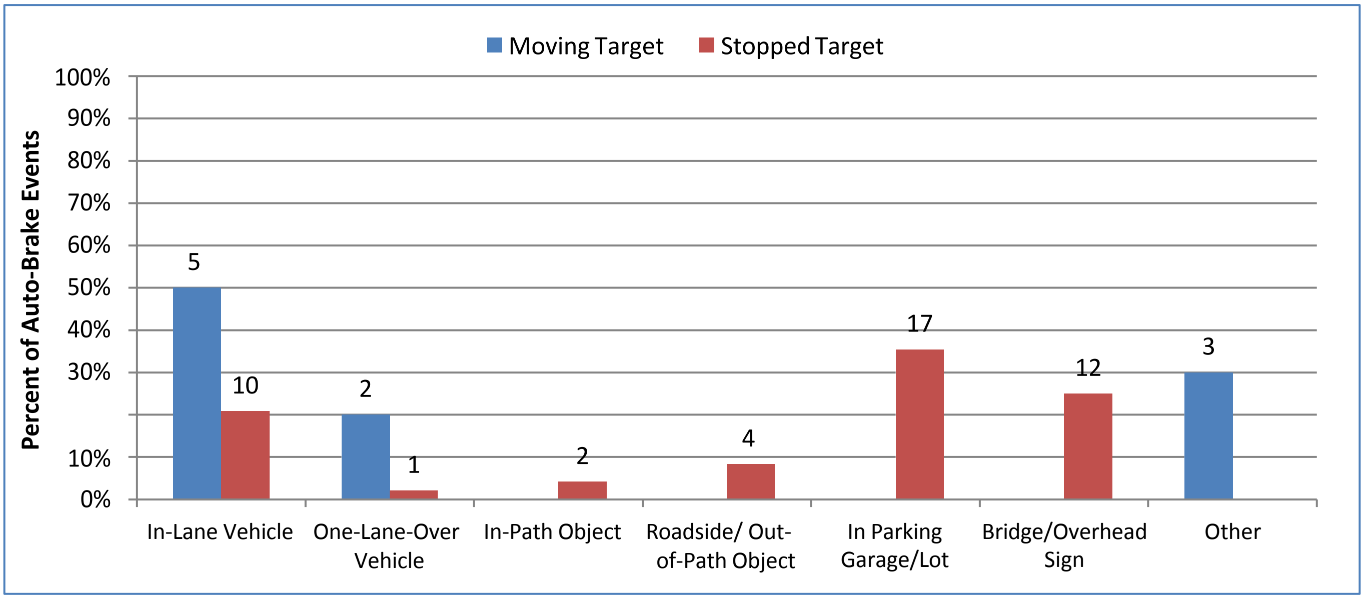


Figure 21. Target Location of Automatic Braking Events, by Target Vehicle Speed

Neither weather nor daylight appeared to contribute to the presence of false automatic braking events. Twenty-nine percent of automatic braking events that occurred in clear weather were issued for in-lane vehicles, and 33 percent of events that occurred in the rain were for in-lane vehicles. Similarly, 32 percent of events that occurred during the day were for in-lane vehicles and 33 percent of events that occurred at night were for in-lane vehicles.

3.2.2.2 Automatic Braking Event Characterization

This subsection describes the automatic braking events issued for in-lane vehicles and compares these events to the false automatic braking events.

3.2.2.2.1 Automatic Braking Event Timing

As shown in Figure 19, 15 of the 58 automatic braking events observed in the FOE were issued for in-lane vehicles. Figure 22 shows the TTC versus host vehicle speed at the onset of the automatic braking events. Figure 23 shows time headway versus host vehicle speed. Both figures are broken down by pre-crash scenario (the two LVM events are not displayed in Figure 22 because they occurred when there was no closing speed between the host and target vehicle and TTC could not be calculated). Average TTC for LVD and LVS events was 1.1 s and 1.2 s respectively, considerably lower than the average TTC for LVD and LVS alert events (3.1 s and 7.0 s respectively). The average headway for automatic braking events was 1.0 s, 1.3 s, and 1.3 s for LVD, LVS, and LVM scenarios respectively.

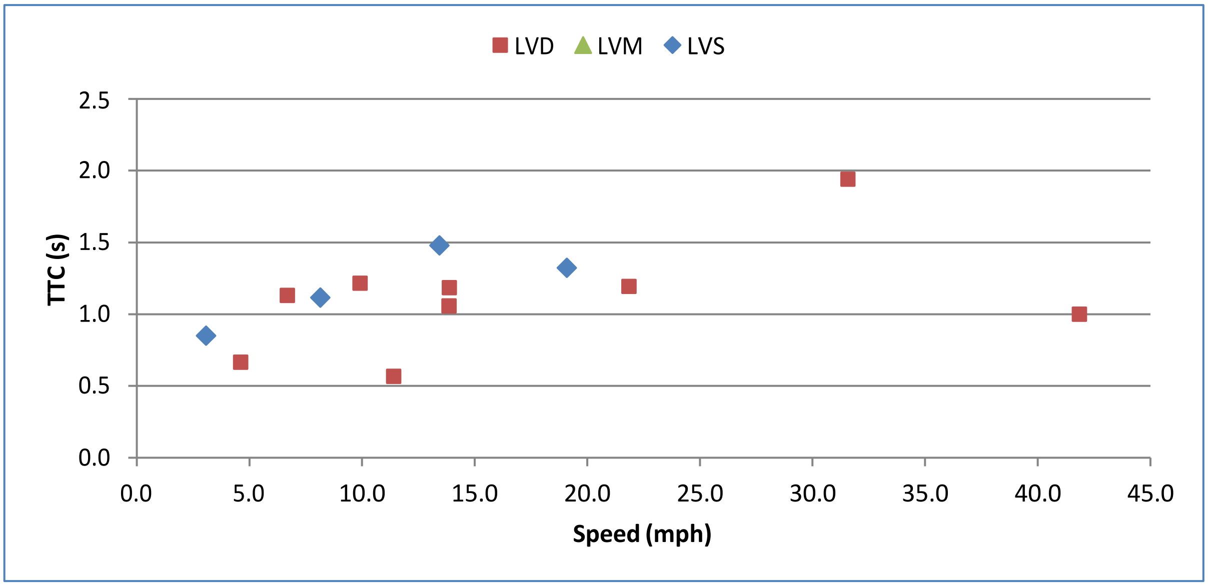


Figure 22. TTC Versus Speed for Valid Automatic Braking Events

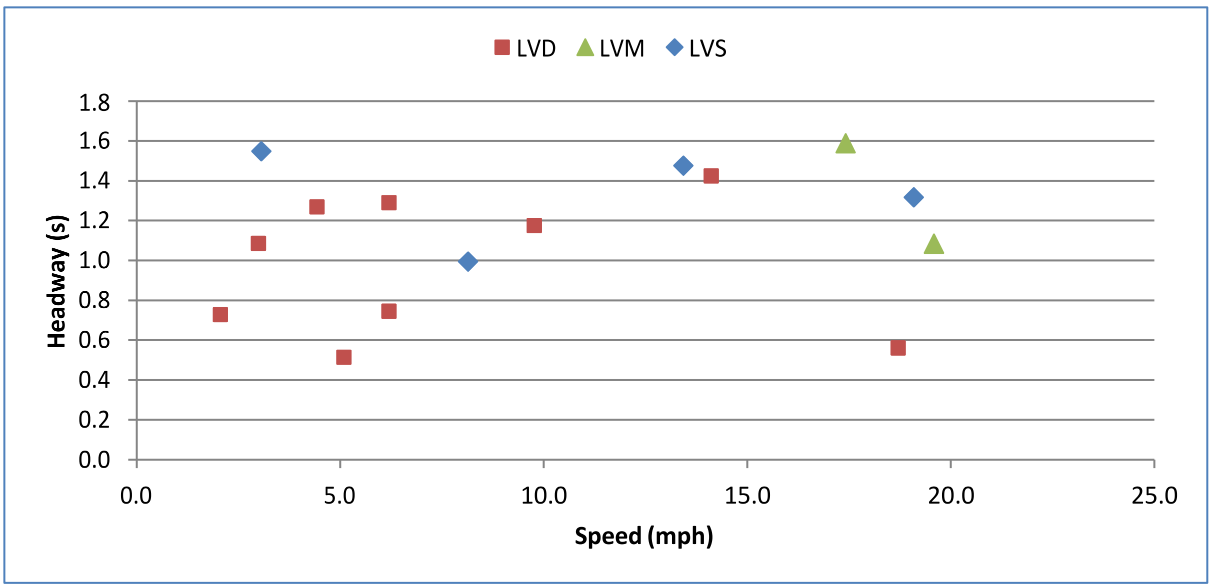


Figure 23. Headway Versus Speed for Valid Automatic Braking Events

As discussed in Section 3.2.2.1, with 12 of the 15 automatic braking events for in-lane vehicles, the driver engaged the brakes before the automatic braking engaged. Figure 24 and Figure 25 compare the timing of the events where the driver did and did not have their foot on the brake prior to the automatic braking event.

Figure 24 shows TTC versus speed for the automatic braking events that were triggered by in-lane targets. In two of the three events where the driver did not engage the brake pedal prior to the automatic braking event, there was no closing speed to the lead vehicle, and therefore TTC could not be calculated (these events are not included in Figure 24). In the remaining event the TTC at the time of the automatic braking engagement was the lowest of all observed events (0.6 s). This event led to a crash, meaning that the automatic braking was engaged too late to help the driver avoid a crash.

Figure 25 shows the headway versus speed for automatic braking events triggered by in-lane vehicles. The event without the driver braking at 0.5 s headway represents the event where the driver crashed. It has the shortest headway at the time of the automatic braking observed in the FOE. There is no apparent difference in the headway of the other two automatic braking events with no driver braking and the events where the driver did brake prior to the automatic braking system.

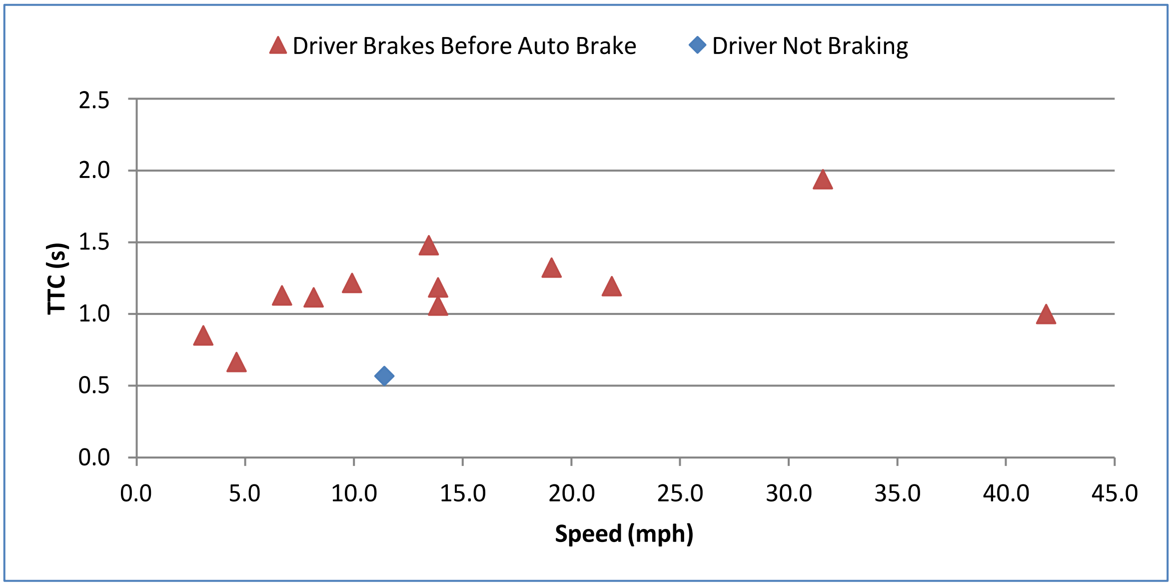


Figure 24. TTC Versus Speed for Valid Automatic Braking Events, by Host Vehicle Driver Braking

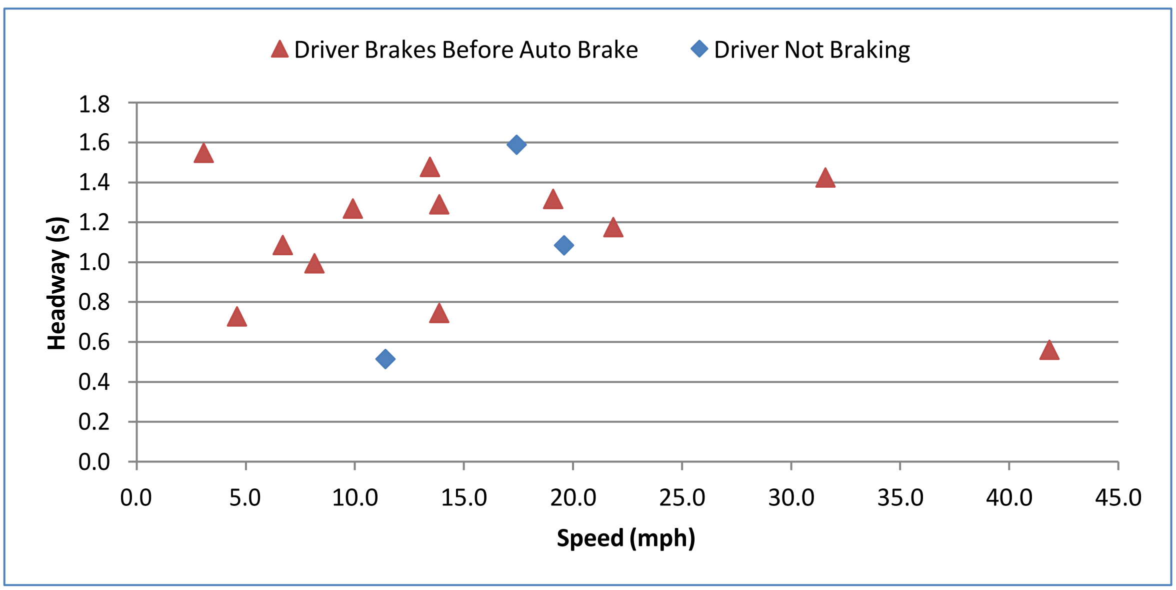


Figure 25. Headway Versus Speed for Valid Automatic Braking Events, by Host Vehicle Driver Braking

3.2.2.2.2 Comparison of In-Lane and False Automatic Braking Events

Figure 26 shows the host vehicle speed at the time of true and false automatic braking events. False events most frequently occurred when the host vehicle was traveling less than 10 mph (17 of 18 false alerts issued under 10 mph were issued when the driver was navigating a parking lot or parking garage). Valid automatic braking events most frequently occurred at speeds between 10 and 20 mph and often in stop and go traffic. The highest speed for a valid automatic braking event was 41 mph compared to 70 mph for a false automatic braking event.

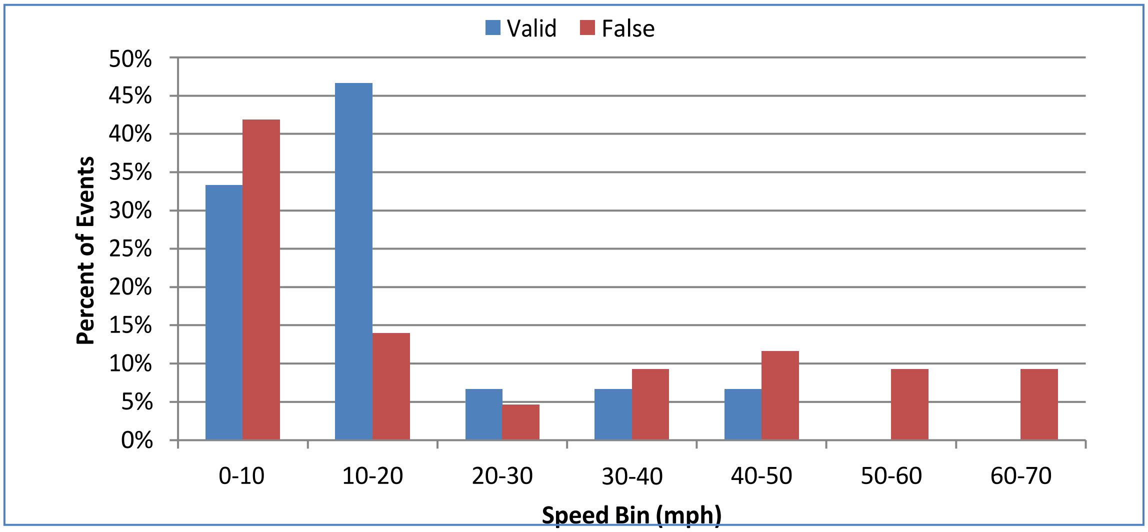


Figure 26. Speed Bin for Automatic Braking Events

Figure 27 compares the duration of true and false automatic braking events (the amount of time that the automatic braking was being applied). Valid automatic braking events lasted an average of 0.4 s, whereas false automatic braking events lasted an average of 0.75 s. The longer duration of the false automatic braking events is mainly due to slower speed events that occurred in parking lots; of the 11 events that lasted longer than 1 s, 8 occurred at a speed of 5 mph or less.

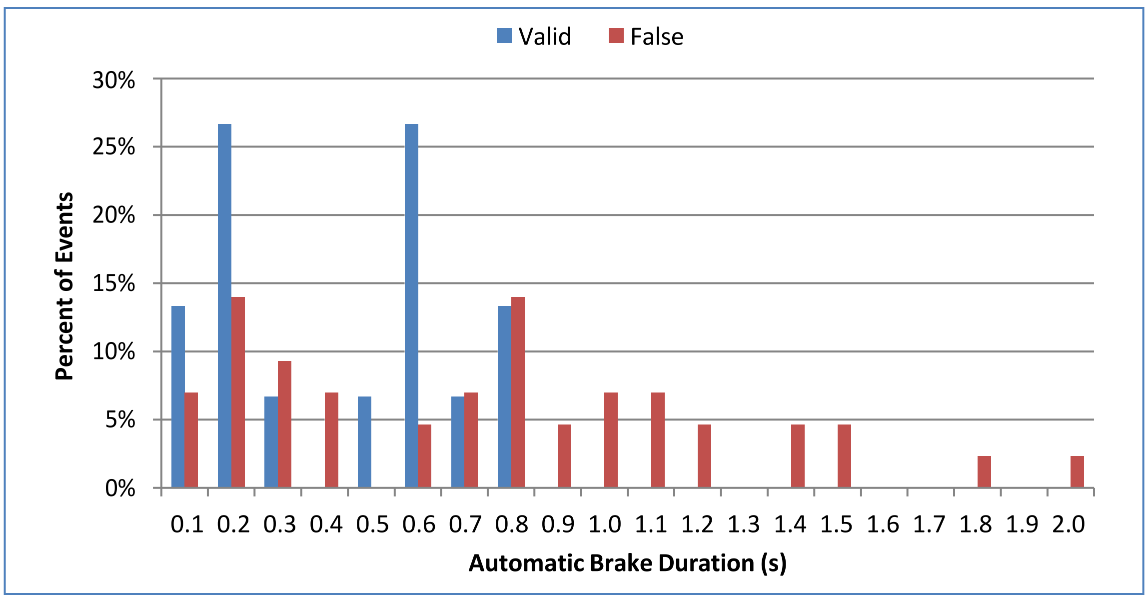


Figure 27. Duration of Automatic Braking Events

3.2.2.3 Impact of Automatic Braking Events

3.2.2.3.1 Impact of True Events

It does not appear that any of the automatic braking events in the FOE helped the driver avoid a crash. The driver responded to the threat before the automatic braking system in 12 of the 15 events where a threat was valid. In two of the three events where the driver was not braking prior to the automatic braking event there was no closing speed to the lead vehicle (the driver did not need to brake). In one event the driver crashed despite the automatic braking engaging. Since the automatic braking engaged 0.1 s prior to the driver hitting the brakes, it is likely that the automatic braking helped reduce the severity of the crash.

Figure 28 plots the speed and acceleration of the host vehicle and the range from the host vehicle to the target in the crash scenario, from 1 s before the automatic brake engaged to 1 s after. In this figure, the dashed line indicates when the automatic brake engaged, the dotted line indicates when the driver engaged the brake pedal, and the solid vertical line indicates the moment of impact with the lead vehicle. Since the driver was accelerating before the automatic brake engaged, the speed continued to increase between the time when the automatic brake was engaged and the time when the driver engaged the brake. However, acceleration decreased from 0.8 to -4.0 m/s^2 during that time, due to the automatic brake engaging.

Based on calculations using the observed level of braking applied by the automatic braking system, if the automatic braking had been applied only 0.1 s earlier, the host vehicle would have been able to stop in time to avoid hitting the target vehicle.

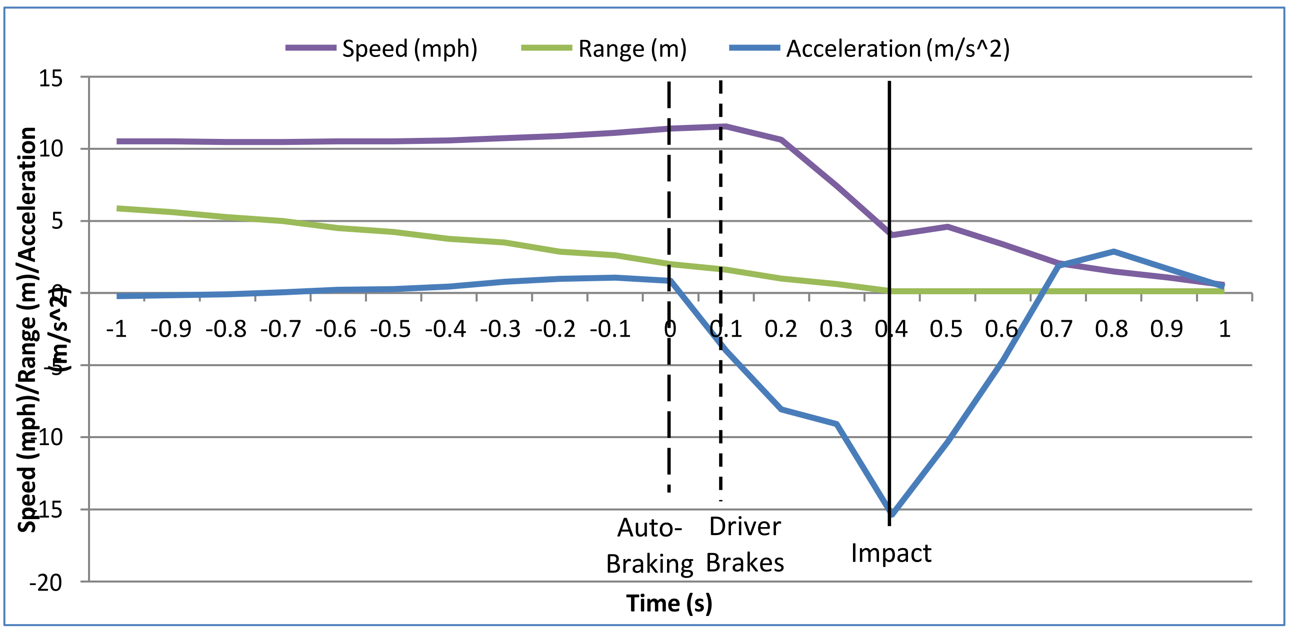


Figure 28. Vehicle Dynamics in Observed Crash Scenario

3.2.2.3.2 Impact of False Events

The Volpe Center analyzed automatic braking events to understand their impact on driver safety. Each false event was evaluated for the potential to cause a rear-end crash and the driver's observed emotional response to the event.

One potential safety implication of a false automatic braking event is that if there is a vehicle directly behind the host vehicle, the host vehicle's sporadic braking could cause the following vehicle to crash into the host vehicle. (If the vehicle brakes when there is no hazard, the driver of the following vehicle will not be expecting the braking maneuver.) For each of the 43 false automatic braking events the Volpe

Center used the rear-facing camera to determine if a vehicle was directly behind the host vehicle at the time of the automatic braking events. Following vehicles were present in 8 of 43 events (19%), no vehicle was present in 21 of the events (49%), and in the remaining 14 events the camera view was not able to determine if a vehicle was present. The Volpe Center did not observe any crashes in the 8 events where a following vehicle was present.

Another way to assess the impact of false automatic braking events is by subjective assessment of the driver's response to the event, based on their facial expressions and gestures. There was a range of observed responses to the false braking events, from no response at all to extreme fear. To create a coding scheme for the emotional response to automatic braking events, the Volpe Center watched the face video associated with false automatic braking activation, and listed each driver's response, based on subjective assessment. They then grouped like responses together into categories, resulting in five response types:

- *Annoyance*: Drivers appeared irritated about the false activation.
- *Confusion:* Drivers appeared disoriented by the event, or about the cause of the event.
- *Fear:* Drivers showed extreme discomfort about the event (coupled with aggressive braking by the vehicle).
- *Shock/Startle*: Drivers appeared surprised, but without extreme discomfort.
- *No Visible Response*: Drivers did not appear to notice the false activation, or if they did notice, they did not react.

Each false automatic braking event was reviewed and coded by two independent video reviewers. Events in which the two reviewers disagreed on the emotional response category were reviewed by a third reviewer to make a final decision.

While no direct connection between driver emotion and safety can be drawn through this type of observational analysis, it provides insight into the impact of the false events on the driver's emotional state.

Twenty drivers experienced false automatic braking events. Figure 29 shows the driver's emotional responses to the 43 false automatic braking events, based on a subjective assessment of the drivers' face videos. Drivers did not show any emotional response to 15 of the 43 events (often because they were already braking when the automatic braking engaged). The most common reaction was confusion, followed by shock (looking startled by the event), annoyance, and fear.

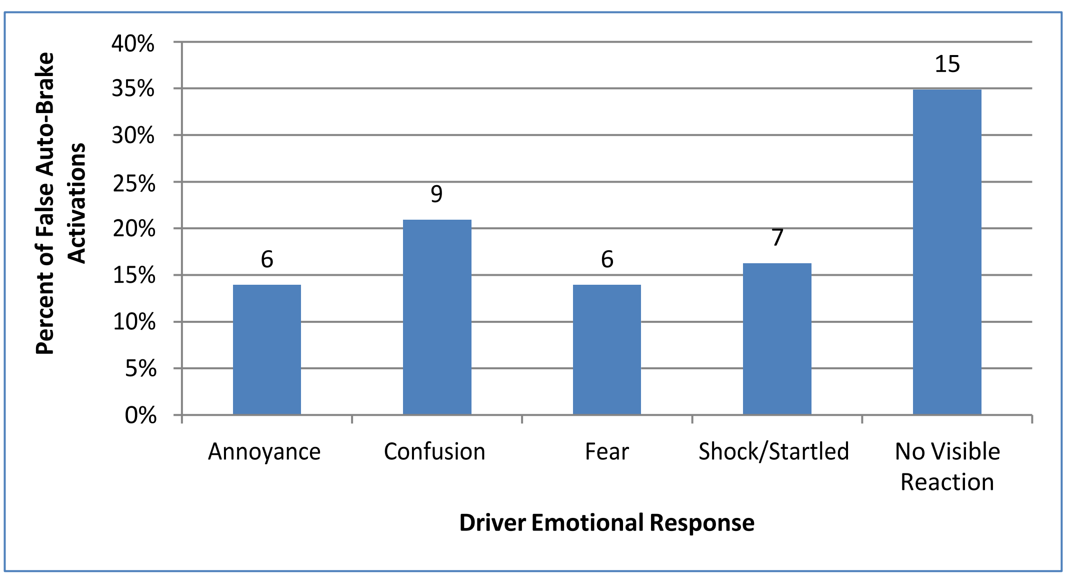


Figure 29. Driver's Emotional Responses to False Automatic Braking Events

Of the 20 drivers who experienced false automatic braking events, 7 experienced one false event, 7 experienced 2 false events, 3 experienced 3 false events, 2 experienced 4 false events, and 1 experienced 5 false events. Figure 30 breaks down driver reactions to false events by an individual driver's exposure to the events. First exposure refers to the first time an individual driver experiences a false automatic braking event, second exposure refers to the second time an individual driver experiences a false braking event, etc. Drivers were most likely to appear confused or afraid the first time they experienced a false automatic braking event. No driver displayed fear after the second exposure to automatic braking events.

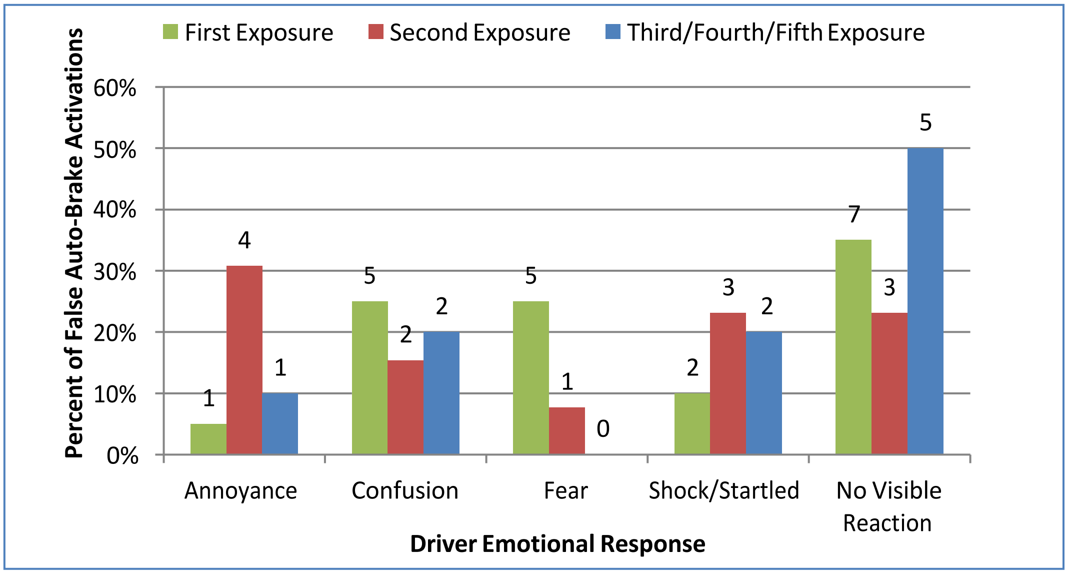


Figure 30. Driver's Emotional Responses to False Automatic Braking Events by Exposure

4 Safety Impact

The analysis of safety impact addressed driver adaptation to the FCW alerts and automatic braking in two areas:

- *Overall driving*: How does a driver's normal, everyday driving behavior change over time when driving with the FCW alerts and automatic braking?
- *Driving conflicts*: How does the frequency in which drivers get into driving conflicts change over time when driving with the FCW alerts and automatic braking? When drivers get into conflict scenarios, does their response to those scenarios change over time?

Overall driving addresses how driving with the FCW alerts and automatic braking impacts a driver's behavior in normal, everyday driving scenarios. Changes in overall driving behavior can be a reflection of a change in a driver's level of safety, although they do not impact safety directly.

Driving conflicts address safety more directly by looking at the frequency with which drivers experience driving conflict scenarios, and the intensity of drivers' responses to these scenarios. Since crashes are rare events it was not possible to measure a statistically significant change in actual crash rates with a study of this size. In this study rear-end conflict scenarios (defined as scenarios where a driver had to intervene, by either braking or steering, to avoid a rear-end crash) were used as a surrogate measure for crashes, to address the impact that the FCW alerts and automatic braking had on a driver's probability of getting into a crash over time. Observing how frequently drivers get into conflict scenarios over time provides insight into how the FCW and automatic braking system impacts driver exposure to risk, while observing how a driver responds to conflict events (in terms of intensity) provides insight into the likelihood that a driver will get into a crash, given that they are exposed to risk.

This section describes the Volpe Center's technical approach and presents results for the analyses of overall driving, driving conflict exposure, and response to driving conflicts.

4.1 Technical Approach

The following subsections describe the metrics and the statistical techniques used to analyze the driver adaptation FOE data.

4.1.1 Overall Driving

This subsection describes how overall driving safety was evaluated.

4.1.1.1 Metrics

During the analysis of overall driving the Volpe Center looked at how each driver's behavior changed over time when driving with the FCW alerts and automatic braking. Table 3 describes the metrics used in the analysis. Appendix J describes how metrics were calculated.

Table 3. Overall Driving Evaluation Metrics

Metric	Description	Units	Independent Variables
Speed	Average speed when the driver was traveling over 35 mph.[9]	Miles per hour	Exposure group Gender Lighting/weather Calendar week
Time-Headway	How closely a driver follows other vehicles, expressed in the number of seconds it would take for the driver's front bumper to reach the location of the rear bumper of the lead vehicle.[10]	Seconds	Exposure group Gender Lighting/weather Travel speed Calendar week
True FCW Alert Rates	The number of true FCW alerts[11] a driver received for every 1,000 miles traveled	Alerts per 1,000 miles	Exposure group Gender FCW sensitivity setting Calendar week

Speed and headway are metrics that reflect the overall aggressiveness and risk level of a driver's behavior. Since FCW alerts are issued to drivers when they are either closing on a lead vehicle quickly or following a lead vehicle closely, driving with the system may directly impact their following behavior. A change in the FCW alert rate over time could indicate either an overreliance on the system (if alert rates are observed to increase), or positive changes in driving behavior in response to alert feedback (if alert rates are observed to decrease).

To rule out effects of weather or calendar-based events (e.g., holidays) on the results of the overall driving analysis, the Volpe Center conducted additional analyses that normalized the weeks of each driver by the calendar week in which they occurred. These analyses showed that calendar week did not have an effect on overall driving metrics.

4.1.1.2 Statistical Approach

Analyses: Group and Driver Level

The Volpe Center computed the driving evaluation metrics for each driver for every week that they participated in the study, then plotted a given metric across all weeks. Through regression of the dependent variable (the metric used) on weeks, the Volpe Center obtained the slope of the best fitting line through the data for each driver. This slope was then used to indicate the change per unit of time (weeks). (See Appendix K for details on why the Volpe Center performed the analysis at the individual driver level rather than at the group level)

---

9 Only speeds of over 35 mph were included because these data are more likely to represent scenarios where the driver was selecting their speed, rather than scenarios where drivers were stopping, starting, or navigating based on traffic flow.

10 More specifically, the time headway is measured at a particular location along the highway where the host vehicle's front bumper and lead vehicle's rear bumper are at positions x and y respectively, and is equal to the time it would take the host vehicle traveling at its current velocity to travel the distance between position x and y.

11 True FCW alerts are alerts that were issued for an in-path target. See Section 3.1.1 for details.

Descriptive and Inferential Statistics

To determine if there was a statistically significant change in any of the metrics, the Volpe Center conducted one-sample t-tests to compare the mean of the calculated slopes in the regressions against a hypothesis of no change (i.e., a slope equal to zero). Ultimately, the one-sample t-test determines the probability of finding by chance alone a difference as large as or larger than the difference between the hypothesized population mean and the observed sample metric. For these analyses, the Volpe Center used a p value of less than 0.05 to indicate statistical significance.[12] Power analyses using G*Power [12] indicated that with a sample size of 32, a Type I error of 0.05 and a Type II error of 0.20 we should be able to detect an effect of moderate size (Cohen's $d = .52$) [X].

4.1.2 Driving Conflict Analysis

The Volpe Center used conflict scenarios as a surrogate measure for crashes to assess changes in driver safety over time when driving with the FCW alerts and automatic braking. Since the intent of the system is to help drivers avoid rear-end crashes by warning them of stopped, slower, or decelerating vehicles ahead in their lane, rear-end conflicts were examined in the analysis.

Rear-end conflicts are defined as high-risk driving scenarios where drivers had to intervene (either by braking or steering) to avoid a rear-end crash.

This subsection describes how rear-end driving conflicts were defined and identified, the metrics used to quantify exposure and response to conflicts, and the statistical approach used to analyze these metrics.

4.1.2.1 Driving Conflict Identification

The Volpe Center used a three-step approach to identify conflict scenarios:

1. Extract potential conflicts
2. Validate conflict events with video
3. Gather additional data on valid conflicts

Database Extraction

First, potential conflict events were extracted from the FOE database by identifying events where the driver avoided a rear-end crash using either an aggressive braking maneuver or a steering maneuver. The following criteria had to be met simultaneously at some point during the event for it to be considered a potential conflict.

Braking Response:

- Host vehicle speed is above 10 mph (to ensure that the vehicle is moving and may be involved in a potential rear-end driving conflict)
- Minimum TTC drops below 3 seconds (based on Volpe's analysis of data from the Crash Avoidance Metrics Partnership that tested drivers' choice of when to break as hard as needed to avoid a rear-end crash in different rear-end test scenarios on a track. This TTC threshold captures the braking behavior of 95% of the participants [1].)
- Host vehicle decelerates at a rate of at least 4 m/s^2 (this ensures that the driver actually executed a hard braking maneuver in response to the driving conflict. Based on the analysis of driving conflicts with the above two criteria, Volpe decided to use the 0.4g threshold to select only severe conflicts)

[12] In other words, when a claim is made that the mean of the sample metric is not equal to the hypothesized population mean, the probability is 0.05 that this is an error and the mean of the sample metric is equal to the population mean.

- Host vehicle brakes for at least 0.5 seconds (similar to the above criteria, this ensures that the driver braked in response to the conflict. The 0.5 second threshold ensures that the braking event was sustained as opposed to only a brake tap)

Steering Response:

- Host vehicle speed is above 10 mph
- Minimum TTC drops below 3 seconds
- Host vehicle driver initiates a steering response[13] (this ensures that the driver executed an evasive steering maneuver to resolve the conflict)

The Volpe Center defined the beginning of each conflict as the timestamp of the data record when the above criteria were first satisfied, and the end of the conflict scenario as the last data record when the above criteria were satisfied.

Video Tool Validation

Next, analysts validated each potential conflict using the video analysis tool shown in Figure 9. A potential conflict was considered to be accurate if the driver was making an evasive maneuver to avoid an in-lane lead vehicle. Events without an in-path lead vehicle were discarded from analysis. Over 98 percent of events detected by the Volpe Center's conflict identification algorithm were accurate. Fewer than 2 percent were discarded.

Video Analysis

Finally, the Volpe Center extracted additional data about valid conflict scenarios using video analysis. Similar to how analysts coded information about alert events (refer to Section 3.1.1), analysts viewed and coded each valid conflict event to extract data that was not available in the numerical database.

The following variables were collected for each valid conflict scenario:

- *Driver distraction:* Was the driver engaging in tasks unrelated to driving that contributed to him or her getting into the conflict scenario? (If yes, what was the secondary task?)
- *Pre-crash scenario:* Was the lead vehicle stopped, traveling at constant speed, or decelerating?
- *Steering response time* (steering response events only): At what time did the driver initiate the steering response?
- *Target brake onset time* (for lead vehicle decelerating events only): At what time did the lead vehicle's brake lights go on?
- *Lead vehicle turn signal*: If the lead vehicle had its turn signal on during the event, was it the left or right turn signal?
- *Lighting:* Did the event occur during the day, night, or at dusk?
- *Weather:* Was it raining or snowing during the event?

The coding definitions are the same as the variables used for the FCW alert scenarios (see Appendix I for a list of all coded variables with definitions).

---

[13] Volpe used a rough filter that included the host vehicle's yaw rate, heading angle, radius of curvature of the path of travel, and the lateral position of the host vehicle within the lane to initially capture steering response conflict events. This filter was intended to capture all steering response events, but it also captured steering events that did not qualify as steering response conflict events (e.g., turns and lane changes that were not directly related to the conflict event). Volpe then relied on video analysis to select only events in which the driver steered in response to a rear-end conflict.

4.1.2.2 Metrics

This subsection defines the metrics to analyze both exposure to conflicts and response to conflict scenarios. The metrics that quantify drivers' exposure to conflicts look at how the frequency with which drivers' exposure to conflict events changes over time, and whether or not there is a change in the intensity of conflicts over time.

Table 4 lists the metrics used to analyze exposure and response to conflicts.

Table 4. Driving Conflict Evaluation Metrics

Metric	Category	Description	Units
Conflict rate per 1,000 miles	Exposure	The frequency with which a driver experiences conflicts, normalized by 1,000 mile increments	Conflicts/1,000 miles
Number of conflicts per month	Exposure	The overall number of conflicts each driver experienced in each month of their FOE exposure	Number of conflicts
Average Minimum TTC (MinTTC)	Response	The average of the smallest observed TTCs during the resolution of each conflict in blocks (1,000 VMT, months) in which a conflict occurred	Seconds
Average Peak Deceleration (PeakDx)	Response	The average of the largest observed deceleration level observed during each conflict resolution in blocks (1,000 VMT, months) in which a conflict occurred	m/s^2
Mean Deceleration (MeanDx)	Response	The mean of the average host vehicle deceleration over the course of the resolution of each conflict in blocks (1,000 VMT, months) in which a conflict occurred	m/s^2

Conflicts per 1,000 Miles and *Number of Conflicts per Month* both express the frequency with which drivers get into conflicts. Both were included in the analysis because it is possible that adaptation would be observed with one metric but not the other. Conflict rate per 1,000 miles is calculated by counting the number of conflicts each driver experienced in their first 1,000 miles, their second 1,000 miles (miles 1,001-2,000) and so on. For number of conflicts per month, the term "month" was used as a shorthand for a 4-week period of time, so there are more than 12 "months" during the one-year FOE.

Minimum TTC (MinTTC) represents the intensity, or level of risk of the near-crash. As the host vehicle approaches a stopped or slower vehicle, the TTC decreases (the time until the vehicles would theoretically crash gets shorter and shorter), until the driver either brakes to slow the vehicle, or steers to avoid the lead vehicle. In other words, MinTTC represents the highest-risk moment in the near-crash. A higher level of MinTTC represents a less risky near-crash, where a lower level of MinTTC represents a more risky near-crash.

Peak Deceleration (PeakDx) is only calculated for conflict events where the driver resolved the conflict by braking. Higher levels of PeakDx represent more intense conflicts, whereas lower levels of PeakDx represent less intense conflicts.

Similar to PeakDx, *Mean Deceleration (MeanDx)* is an expression of driver braking in response to conflicts, so is only calculated for conflicts with a braking response. Instead of being the highest observed level of braking, it represents the average braking over the course of the event. Like PeakDx, higher values represent more intense conflicts while lower values represent less intense conflicts.

Using a similar methodology used for conflict rate metrics, the Volpe Center compiled metrics for response to conflicts by both vehicle mileage and by months within the study. Measures from individual conflicts were averaged within each window. The value for the MinTTC within the first 1,000 miles of driving was calculated by averaging the MinTTC of each of the conflicts that occurred for a given driver within their first 1,000 miles of driving. The value for the second 1,000 miles is the average of the values for MinTTC that occurred during each driver's second 1,000 miles, etc. If no conflicts occurred during a given mileage block, no MinTTC would be reported. The Volpe Center used the same approach when compiling the data into calendar months and for compiling the other driver response metrics.

4.1.2.3 Statistical Approach

The statistical approach depends on the focus of the analysis. If the focus is the change in the number of conflicts per unit of exposure (e.g., 1,000 miles or one calendar month) across increases in exposure, a Poisson regression was used. For typical motor vehicle crashes where the event has a very low probability of occurrence and a large number of trials exist (e.g., million entering vehicles, vehicle-miles-traveled, etc.), it can be shown that the binomial distribution is approximated by a Poisson distribution. The same should be true of the distribution of conflicts. If the focus was the change in the response to conflicts per unit of exposure across increases in exposure, a linear regression was used. The dependent variable in this case has a normal distribution.

4.1.2.3.1 Change in Number of Conflicts per Unit of Exposure across Increases in Exposure

The statistical approach throughout the analysis has been to obtain the summary measures of performance for each driver and determine whether the average of those summary measures indicates a change across time in conflicts per unit of exposure. This requires some justification. A full justification is given in Appendix K. Briefly, if there are differences in the average number of conflicts across the 3, 9, and 12 month groups, but no difference in the change in the number of conflicts per unit of exposure across all three groups, the slope of the regression using all of the data need not reflect the similarity across groups.

The Volpe Center performed the statistical analyses then plotted figures using either Excel or R, based on convenience. All analyses were first checked with pseudo databases where the answer was known (or could easily be computed by hand). Software used to perform the analyses is identified for each analysis.

There is a great deal of variation within drivers, and an even much larger variation across drivers, where it is important to be able to describe how the average driver safety changes as a function of exposure (descriptive statistics). Across drivers, it is also important to know whether any observed changes in safety are simply due to noise or instead represent a systematic behavior. Perhaps drivers are behaving in ways that reduce the number of conflicts per 1,000 VMT as their exposure increases (inferential statistics).

To provide both descriptive and inferential statistics for number of conflicts per unit of exposure, the Volpe Center used a Poisson regression within the framework of generalized linear models (GLM). The Poisson regression identifies the predicted change in the number of conflicts per unit of exposure with increases in exposure (the descriptive statistics), and also determines whether this change is the likely consequence of something systematic (the inferential statistics). In order to make quick sense of why a Poisson regression was used and what its parameters mean, it is necessary to explain the distribution of a Poisson random variable and why a simple linear regression was not used.

A Poisson random variable is a discrete, nonnegative random variable. So too are the number of conflicts defined as C. That is, Poisson random variables and conflicts are both integers greater than or equal to 0. Assuming that C is a Poisson random variable, the probability that exactly c conflicts are obtained in a given unit of exposure is computed as follows:

$$P(C=c)=\frac{\lambda^c e^{-\lambda}}{c!}.$$

The parameter λ is both the mean (expected value) and variance of a Poisson distribution, i.e.,

$$E[C]=\lambda,$$
$$Var[C]=\lambda.$$

It can now be shown how a function of the expected value of the number of conflicts is related to a linear function of the exposure, completing this very brief introduction to Poisson regression. First, C needs to be indexed by the *exposure x* because the distribution of C is allowed to change as a function of increases in exposure. In particular, let C_x be the number of conflicts in a given unit of exposure x (x = 1 is the exposure during the first 1,000 VM, x = 2 is the exposure during the second 1,000 VMT, and so on). In a Poisson regression the natural log of the expected value of C_x, i.e., $\ln(\lambda_x)$, is written as a linear function of the exposure x:

$$\ln(\lambda_x)=\alpha+\beta x$$

Equation 1

It is now clear what the slope of the Poisson regression represents. In particular, a one unit change in x (an increase of 1,000 VMT in this case) leads to an increase in the ln (natural log) of the mean number of conflicts by an amount β (it is the population mean, not the observed mean, which is under consideration).

Alternatively, the mean number of conflicts at the next level of exposure (x + 1) is an increase of e^{β} over the mean number of conflicts at the current level of exposure, i.e.,

$$\lambda_{x+1}=e^{\beta}\times\lambda_x.$$

Since we are dealing with counts over a given interval, one more piece of explanation is needed. In particular the number of conflicts per 1,000 VMT is the conflict exposure. Thus, Equation 1 could be written as follows:

$$\ln(\lambda_x/1000)=\alpha+\beta x$$
$$\ln(\lambda_x)=\alpha+\beta x+\ln(1000)$$

The quantity, ln(1000) is called the offset. Since this is the same for every driver (the unit of exposure) and it is not relevant to the current example, whether or not the units are in miles of thousands of miles, the latter quantity can be chosen as the unit. The offset then becomes ln(1), or just zero. And so Equation 1 is fine as is.

A linear regression is not appropriate for this analysis. First, a linear regression assumes that the dependent variable is continuous, not discrete. The Volpe Center's conflict data is integer valued. Second, a linear regression does not confine the predicted values of the dependent variable to nonnegative values. The Volpe Center's predicted conflicts can only be nonnegative. Finally, a linear regression assumes that the dependent variable has a normal distribution. The Volpe Center's conflicts have a Poisson distribution.

4.1.2.3.2 Change in Response to Conflicts per Unit of Exposure across Increases in Exposure

The analysis proceeds as above, starting with estimates at the driver level, as described in Appendix K.

The different measures of response to conflicts (MinTTC, PeakDx, MeanDx) are not Poisson distributed since they are not counts. More standard linear regression procedures can be used to analyze the change in the average response to a conflict per unit of exposure across increases in exposure. Note that MinTTC predictions are constrained to be nonnegative. This turns out not to be a problem for the range of exposures considered.

4.2 Results

This subsection describes the results from the Volpe Center's analyses of the change in the overall driving safety, the conflicts per unit exposure (1,000 VMT, one week, or one month), and the response to conflicts per unit exposure (assuming that a conflict occurred) during the study.

4.2.1 Low Risk Driving

The following subsections describe the outcome from analyzing travel speed, headway, and FCW alert rate during the FOE.

4.2.1.1 Speed

No significant changes were observed in driver's travel speed over time when driving with the FCW alerts and automatic braking overall, by test group, by gender, or in different weather/lighting conditions.

Figure 31 shows the average speed across drivers in each test group for each week during the FOE.[14] No changes in average speed were observed within each test group. Figure 32 shows the average speed by gender for each week during the FOE. The vertical bars in the figure show which test groups were driving during each week. While the average speed of male drivers trended slightly downward during the last few weeks of the long term drivers' exposure, this change was due to the driving patterns of two drivers. One decreased his average speed from approximately 56 mph to 44 mph, and the other decreased his average speed from approximately 58 mph to 48 mph. Other drivers did not show any changes in average speed.

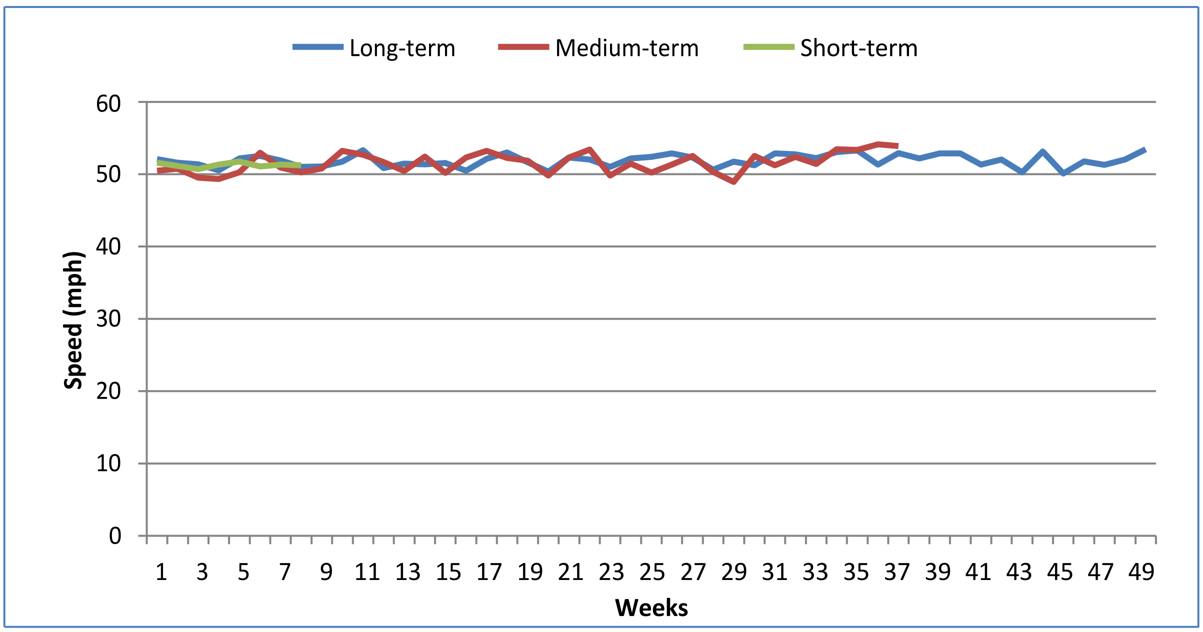


Figure 31. Average Speed during the FOE, by Test Group

[14] To remove variability in the overall average caused by a change in sample size, in this figure and all others in this section, only weeks where the majority of drivers in each test group were driving are included in the overall averages. For example, for the 14 mid-term drivers, since 8 were still driving during week 37, but only 6 were driving during week 38, data were truncated at week 37. Including only a small number of participants from the group made it appear that a trend was occurring over time, when in reality the change was due to which drivers remained in the sample. The statistical analyses in this section contain all weeks of driving from all drivers.

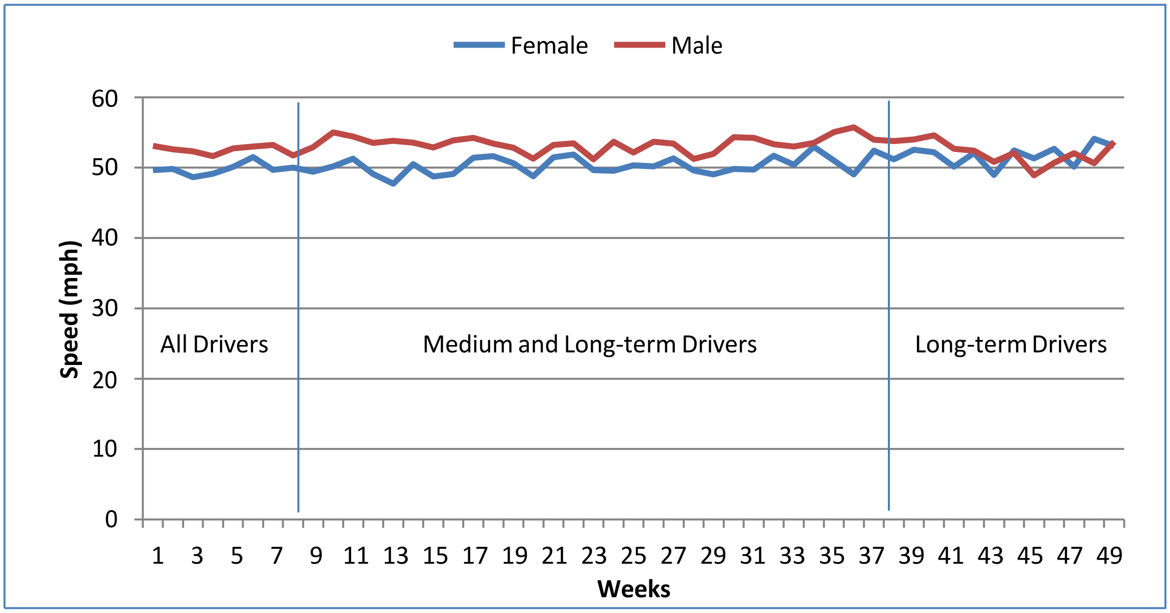


Figure 32. Average Speed during the FOE, by Participant Gender

As discussed in Section 4.1.1 speed was regressed on FOE week for each driver and the average of the slopes was calculated. Table 5 shows the results of the one-sample t-tests of the hypothesis. There was no change in speed across time (i.e., the population slope was zero) for each test group and gender. A p value of less than 0.05 represents a statistically significant increase or decrease in speed over time. Significant changes were not observed overall in any of the test groups or in either gender.

Table 5. Results of One-Sample t-test for Driving Speed, by Test Group and Gender

	All Drivers	Long-term	Medium-term	Short-term	Female	Male
Mean Slope	-0.038	0.005	0.030	-0.147	-0.071	-0.001
s	0.440	0.139	0.092	0.743	0.516	0.348
n	38	11	14	13	20	18
t Stat	-0.528	0.119	1.239	-0.714	-0.613	-0.012
p	0.601	0.907	0.237	0.489	0.547	

Table 6 shows the results of the one-sample t-test for change in driving speed, broken down by time of day and weather conditions. Drivers did not show any changes in travel speed over time in any of the four lighting/weather categories tested (p>0.05).

Table 6. Results of One-Sample t-test for Driving Speed, by Lighting and Weather

	Day/Clear	Day/Adverse	Night/Clear	Night/Adverse
Mean Slope	-0.048	0.019	-0.020	-0.139
s	0.408	1.592	0.376	0.821
n	38	32	38	37
t Stat	-0.717	0.068	-0.324	-1.029
p	0.478	0.946	0.748	0.310

4.2.1.2 Headway

Time headway, or the size of the gap a driver chooses to leave between himself and lead vehicles, is a measure of overall driver risk. Shorter headways are more risky because they leave less time for the driver to respond to a sudden maneuver by the lead-vehicle, while longer headways are less risky.

Figure 33 and Figure 34 show the average headway across drivers by test group and gender during the 53 weeks of the FOE. Figure 34 also shows which test groups were included in the average during a given week. The figures illustrate that overall, drivers in each test group and each gender did not change their headway-keeping behavior over time when driving with the FCW alerts and automatic braking.

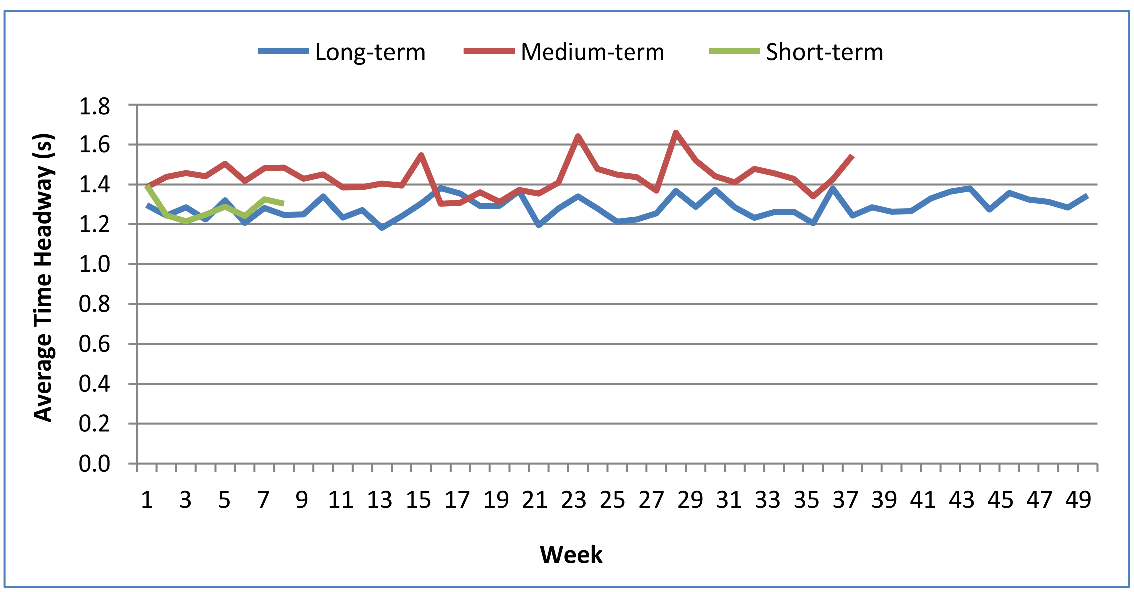


Figure 33. Average Time Headway During the FOE, by Test Group

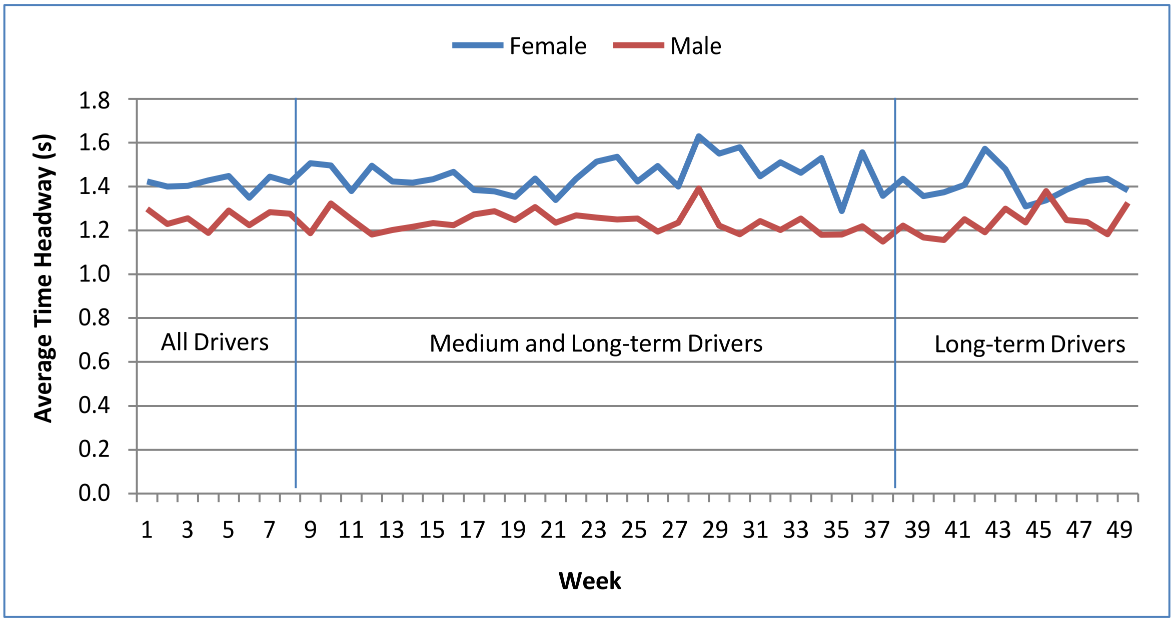


Figure 34. Average Time Headway During the FOE, by Gender

Table 7 shows the results of the one-sample t-tests conducted for driver headway keeping overall, and for each test group and gender. Significant changes were not observed overall in any of the test groups or in either gender ($p > 0.05$ for all comparisons).

Table 7. Results of One-Sample t-test for Headway, by Test Group and Gender

	All	Long-term	Medium-term	Short-term	Female	Male
Mean Slope	0.001	0.001	0.000	0.002	0.002	0.000
s	0.021	0.005	0.007	0.036	0.024	0.018
n	38	11	14	13	20	18
t Stat	0.355	0.783	0.113	0.239	0.377	0.076
p	0.725	0.452	0.912	0.815	0.710	0.940

Table 8 shows the one-sample t-test results for each 5 mph speed bin between 35 and 70 mph. Significant changes ($p>0.05$) were not observed in any of the speed bins.[15]

Table 8. Results of One-Sample t-test for Headway, by Speed Bin (mph)

	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70+
Mean Slope	-0.001	0.000	0.001	0.007	0.000	0.004	0.003	0.021
s	0.022	0.019	0.026	0.024	0.026	0.039	0.090	0.148
n	38	38	38	38	38	38	38	36
t Stat	-0.234	-0.072	0.187	1.764	-0.060	0.568	0.213	0.853

[15] While multiple t-tests were performed, no results were statistically significant. Therefore, in this case a Bonferroni correction was not required.

Table 9 shows the results of the one-sample t-tests for headway, broken down by weather and lighting conditions. Similar to the results broken down by test group, gender, and speed bin, no significant results were observed in the change in headway over time by weather condition.

Table 9. Results of One-Sample t-test for Headway, by Lighting and Weather

	Day/Clear	Day/Adverse	Night Clear	Night/Adverse
Mean Slope	0.000	-0.012	-0.003	0.018
s	0.025	0.108	0.027	0.077
n	38	31	38	37
t Stat	-0.032	-0.613	-0.611	1.411
p	0.974	0.545	0.545	0.167

4.2.1.3 True FCW Alert Rate

Unlike the other metrics of overall driving behavior, the frequency with which drivers received FCW alerts decreased over time when driving with the FCW alerts and automatic braking.[16]

Figure 35 shows the average alert rates across drivers in each test group during each week of the FOE, ignoring the sensitivity settings. Both the long- and medium-term drivers show an overall trend toward a reduction in the rate of FCW alerts over time, but only the reduction in the alert rates of long-term drivers was statistically significant (see Table 10).

Figure 36 shows the average alert rates across male and female drivers during the 53 weeks of the FOE, ignoring the sensitivity settings. While males showed an overall trend toward a decrease in FCW alert rate over time, female drivers did not. It is worth noting that on average, male drivers experienced alerts about twice as frequently as female drivers in the first half of the FOE, which may be why male driver alert rates decreased while female driver rates did not.

[16] Volpe used a linear regression since the trend through week 49 appears roughly linear. Alert rates were frequent enough that negative predicted alert rates were not an issue. Had the alert rate been smaller, a Poisson regression would have been used.

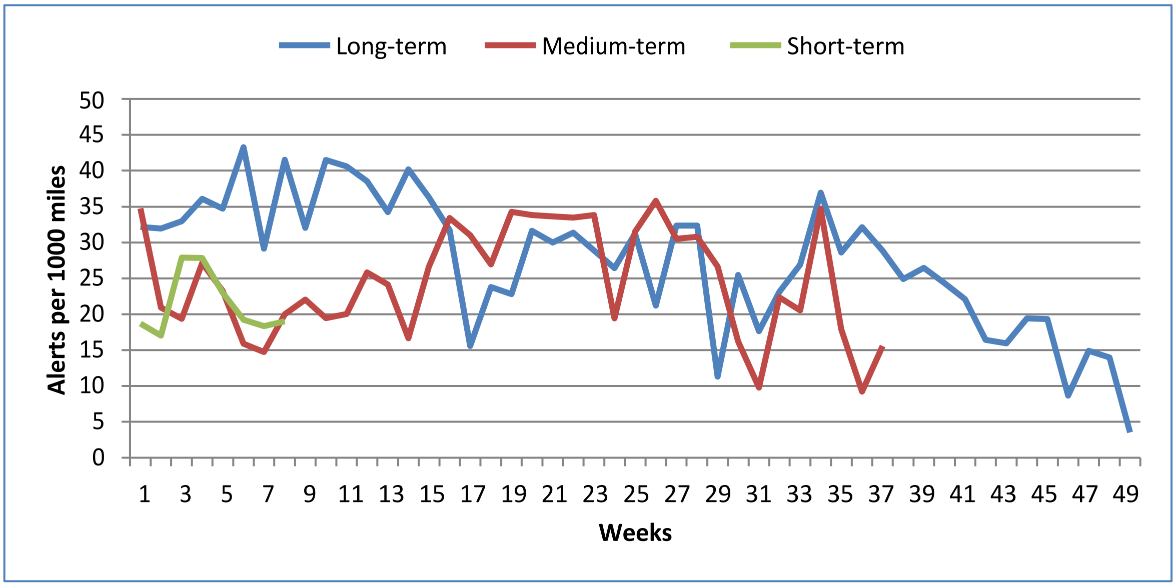


Figure 35. Average FCW Alert Rate During the FOE, by Test Group

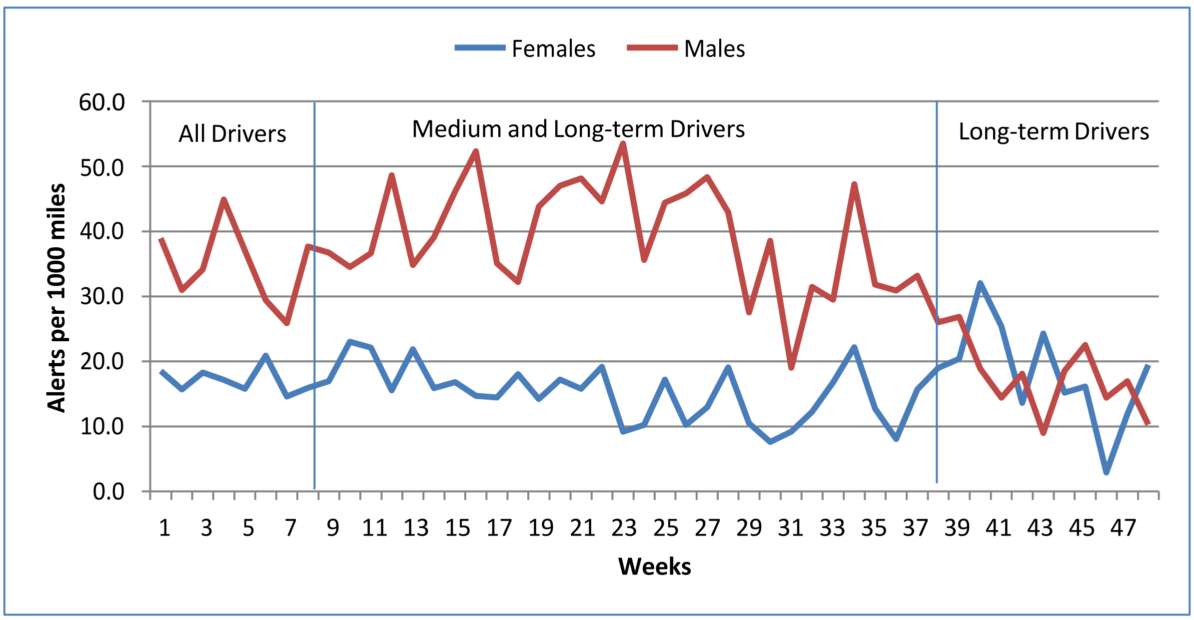


Figure 36. Average FCW Alert Rate During the FOE, by Gender

Table 10 shows the results of the one-sample t-tests for all drivers combined, each test group, and gender. As mentioned previously, long-term drivers had a highly significant reduction in alert rates during the FOE (significant results are indicated in red in the table). All drivers combined, medium-term drivers, and male drivers showed a trend toward a decrease in alert rates. The table does not show two additional analyses, in particular, long and medium-term drivers combined (all drivers excluding short-term drivers) showed a highly significant decrease in alert rates over time ($p<0.003$), and that long and medium-term male drivers (all males excluding short-term drivers) showed a highly significant decrease in alert rates over time ($p<0.03$).

Table 10. Results of One-Sample t-test for FCW Alert Rate, by Test Group and Gender

	All	Long-term	Medium-term	Short-term	Female	Male
Mean Slope	-0.286	-0.525	-0.232	-0.129	-0.010	-0.577
s	1.116	0.539	0.525	1.844	0.932	1.243
n	37	11	14	12	19	18
t Stat	-1.556	-3.229	-1.653	-0.242	-0.045	-1.969
p	0.128	0.009	0.122	0.813	0.965	0.065

4.2.1.3.1 True Alert Rate by FCW Setting

As mentioned in Section 1.2, the FCW system allowed drivers to select from three sensitivity settings; far, medium, and close ("far" being the most sensitive and "close" being the least). During the field test:

- 18 drivers used only one FCW setting
- 14 drivers drove in two of three FCW settings; and
- 5 drivers drove in all three settings

The Volpe Center examined the trend in setting changes over time, and found that of the 19 drivers who used more than one FCW setting, 16 showed a trend towards a less sensitive setting as their exposure to the system progressed (for example, changing from far to near partway through the study). The other three drivers showed no trend (for example, changing from medium to near, and then back to medium).

Based on these trends, the Volpe Center reran the alert rate analyses discussed in the previous section, considering each driver's alert rate only within each FCW setting, as a means of determining if the changes in alert rates were due to drivers changing the sensitivity settings. The results showed that when controlling for alert setting changes, overall, no changes were observed in alert rates over time, in any test group or for either gender (Table 11).

Table 11. Results of One-Sample t-test for FCW Alert Rate, Independent of FCW Setting

	All	Long-term	Medium-term	Short-term	Female	Male
Mean Slope	0.210	-0.061	0.149	0.556	0.275	0.072
s	2.726	1.113	1.264	7.665	1.276	4.291
n[17]	52	17	20	13	27	25
t Stat	0.918	-0.238	0.594	0.724	1.263	0.173
p	0.363	0.815	0.560	0.483	0.218	0.864

The Volpe Center also conducted separate analyses for each FCW alert setting for all drivers (Table 12) and for only long- and medium-term drivers (since with limited exposure, short-term drivers were less likely to display a trend in alert receiving behavior) (Table 13). No changes in alert rate were observed when FCW settings were analyzed individually.

[17] In these analyses, the trend in alert rate over time was considered for each driver in each setting they drove in, resulting in multiple data points for drivers who drove in multiple settings.

Table 12. Results of One-Sample t-test for FCW Alert Rate by FCW Setting – All Drivers

	Close	Medium	Far
Mean Slope	0.411	-0.250	0.338
s	2.499	4.750	1.636
n	15	15	20
t Stat	1.007	-0.444	1.181
p	0.331	0.664	0.252

Table 13. Results of One-Sample t-test FCW Alert Rate by FCW Setting – Long- and Medium-Term Drivers

	All	Long-term	Medium-term
Mean Slope	-0.136	0.280	0.040
s	1.218	1.046	1.316
n	11	10	16
t Stat	-0.407	0.866	0.140
p	0.692	0.409	0.891

The results of the analysis by alert rate settings suggest that while alert rates did decrease over time, it was due to driver preference for a less sensitive FCW setting, rather than a change in driver behavior.

4.2.2 Changes in Conflicts per Unit of Exposure Across Increases in Total Exposure

The units of exposure for conflicts were either 1,000s of VMT or months. Analyses were performed separately for each unit of exposure; these are described in the following subsections. The Volpe Center's goal was to determine whether there was a change in the number of conflicts per unit of exposure across increases in exposure. Reference data for the tables in this subsection are cross-referenced to Appendix L.

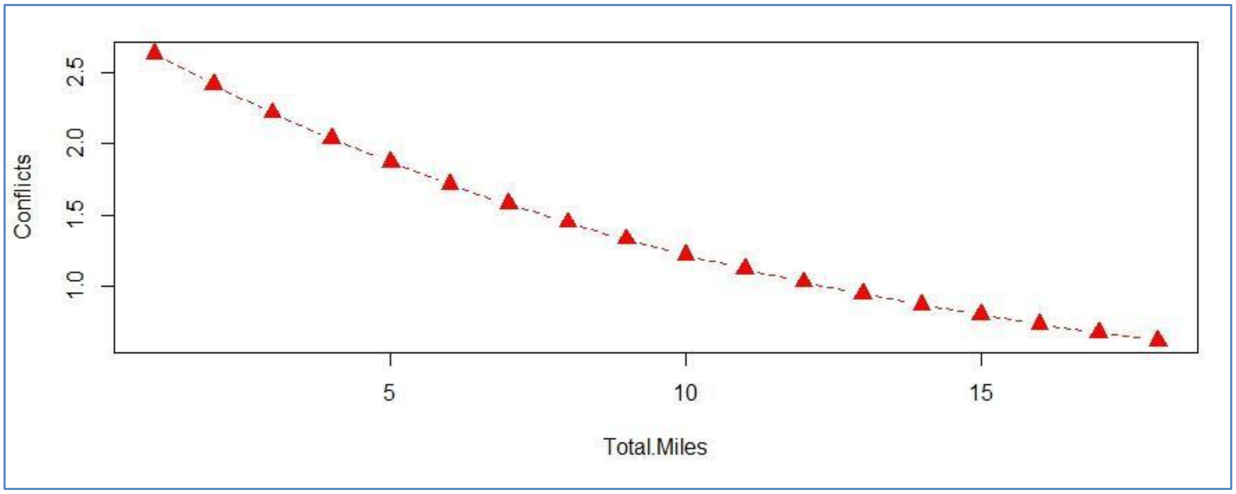
4.2.2.1 Changes in Conflicts per 1,000 VMT Across Increases in Total VMT

There were a total of 35 drivers in the sample. Table 18 shows the number of conflicts recorded for each driver during each successive 1,000 miles of vehicle travel. A Poisson regression was used to obtain the intercept and slope for each driver. The number of conflicts per 1,000 VMT at each number of total miles traveled was regressed on the total vehicle miles traveled, using the GLM function in R to determine for each driver the intercept and slope, assuming that conflicts per 1,000 VMT were Poisson distributed (Equation 1). Table 19 lists the slope and intercept for each driver, along with the total miles driven (1,000s) at the end of the study. The average intercept and slope were, respectively, 1.054 and -0.0856.

The next step was to determine whether there is a change in the number of conflicts per 1,000 VMT across increases in exposure. Note that among the 35 drivers who experienced conflict events, two participants drove 1,000 miles or fewer (Drivers 10 and 26). Since there was not enough information to compute a slope (there is only one point for each driver) these drivers were excluded. Driver 21 was also excluded due to similar issues. The intercept and slope for this driver were respectively, -67.92591 and

22.64197. This differs by a factor of roughly 50 from the other estimates. Based on Table 18 the driver had 0, 0, and 1 conflicts respectively, at 1,000, 2,000, and 3,000 miles. The average slope with Driver 21 included in the 33 drivers for whom an estimate of the slope is obtained was 0.6031. The average without this driver in the analysis was -0.0856.

With the above average intercept and slope, Equation 1 (suitably rearranged) was used to predict the number of conflicts per 1,000 VMT as a function of the total exposure, as shown in Figure 37. The predicted number of conflicts per 1,000 VMT drops from 2.634 during the first 1,000 miles to 0.615 during the last 1,000 miles (18,000 miles). This is a decrease of 76.6 percent.



$$\hat{\lambda}_x = e^{1.054-0.0856x}$$

Figure 37. Predicted Number of Conflicts per 1,000 VMT as a Function of Total Exposure

There are two approaches to determine if this decrease is statistically significant; both use the statistical packages in R. First, the Volpe Center determined whether the mean slope (averaged across drivers) was statistically significantly different from zero. The null hypothesis is that the population slope is zero (H_0: $\beta = 0$) and the alternative hypothesis is that the slope does not equal zero (H_a: $\beta \neq 0$). The probability of a Type I error was set at 0.05. In Figure 38 the individual slopes are plotted against the total miles driven in the study. The solid red line represents no change, and the blue dashed line is the regression of the slopes on total VMT. The resulting value of t was marginally significant (t = - 2.0144, df = 31, p = 0.05272).

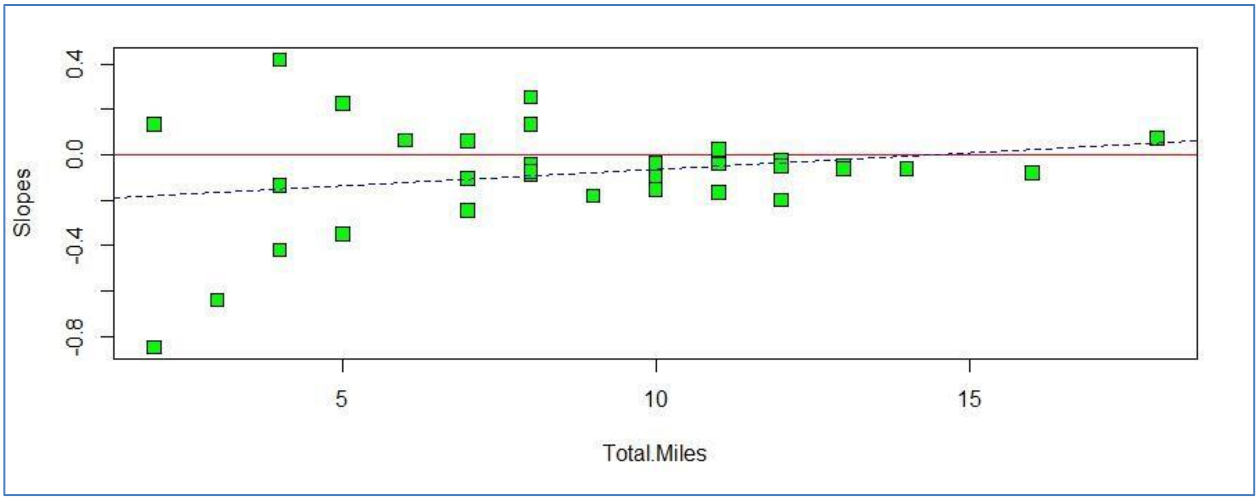


Figure 38. Slopes from Regression of Number of Conflicts per 1,000 VMT on 1,000 VMT Traveled for Each Driver Versus Total VMT Traveled by Driver

The Volpe Center performed a second statistical test because the slopes for the participants who drove very few miles can be substantially larger than the slopes of those who drove a great many miles. For example, suppose that for a given individual the number of conflicts is a uniform discrete random variable equal to 1 or 2 with probability 0.5. Then the slopes for this individual can be 0, 1 or -1. But if this same individual drove over 10 months, the slope can be at most ± 0.01515 (five 1's followed by five 2's or conversely). Thus, a binomial test was used to determine whether the number of slopes in the Poisson regression less than 0 is larger than one would predict by chance, where it is assumed that the probability is 0.5 that a slope will be less than 0. The size of the slope is not significant, only its sign. In this case a total of 23 out of the 32 slopes were less than 0. The probability that there would be 23 slopes of one sign and 9 of the opposite sign (9 positive and 23 negative, or 9 negative and 23 positive) is only 0.0201. Thus, the hypothesis that there is no change in the slopes over time can be rejected.

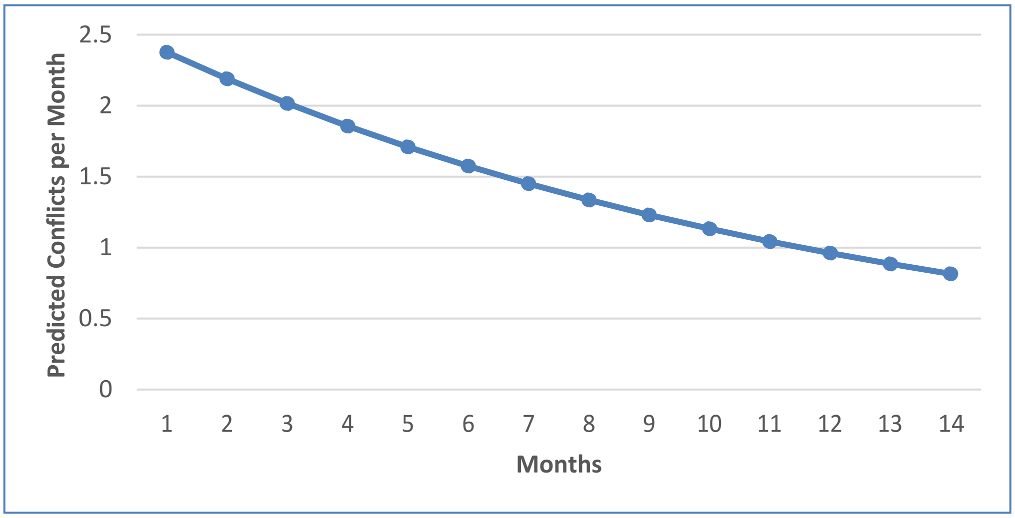
The above results apply to 32 out of 33 drivers (96% of the population). If the individual driver removed is not an outlier, then for 4 percent of the population there will be an increase in conflicts per 1,000 VMT across increases in exposure. This cannot be ruled out. But for the vast majority of drivers, this is not the case.

4.2.2.2 Changes in Conflicts per Month Across Increases in Total Time

The Volpe Center also measured exposure to conflicts in months, regardless of how many miles were driven in the month. Table 20 in Appendix L lists the number of conflicts per month across the months of participation. When time is the unit of exposure, there was a very clear difference in the change in conflicts over time of those who had the car for 2 months or less (8 drivers) and those who had the car for more than 2 months (27 drivers). There will be additional details about differences between these two sets of participants in the discussion of the analyses on the 27 drivers who had the car for more than 2 months (all such drivers had at least one conflict).

A Poisson regression was used to determine how the number of conflicts per month changed across time. Table 21 in Appendix L lists the best fitting parameters (slope and intercept) for each driver, along with the total months of participation. The average intercept and slope for the 27 drivers who drove the vehicle 2 months or longer were, respectively, 0.9482 and -0.8232.

The Volpe Center used the above parameters to predict the change in conflicts per month in the longer term drivers (Figure 39). The predicted number of conflicts per month drops from 2.377 during the first month (compared to 2.634 conflicts per 1,000 VMT during the first 1,000 miles) to 0.815 during the fourteenth month (compared to 0.615 conflicts per 1,000 VMT during the last 1,000 miles to 18,000 miles). This is a decrease of 65.7 percent (compared to 76.6%). To confirm, none of the drivers who drove the vehicle for 2 months or less were included in this comparison.



$$\hat{\lambda}_x = e^{0.9482 - 0.0823x}$$

Figure 39. Predicted Number of Conflicts per Month as a Function of Total Exposure

The question is now whether the observed change is statistically significant. The slopes of the 27 drivers who drove more than 2 months (Table 21 in Appendix L) are plotted against the total number of months that the car was driven (Figure 40). The red solid line represents no change. The blue dashed line is the regression of slopes on total VMT. The hypothesis that there was no change in the number of conflicts per month over time can be rejected: t = -2.3242, df = 26, p = 0.02819. A binomial test also indicated that the null hypothesis could be rejected: 5, 27, .5; p = 0.001514.

Finally, the Volpe Center analyzed in more detail the differences between those drivers who drove the car for 2 months or less and those drivers who drove the car for more than 2 months. As noted at the beginning of this subsection, the average intercept and slope for those drivers who owned the car for more than 2 months were 0.9842 and -0.0823. The average intercept and slope for those drivers who owned the car for 2 months or less were, respectively, -16.0297 and 8.5307. A simple binomial test indicates that the likelihood of finding only two or fewer negative slopes out of eight total slopes is 0.1445 (one-tail). The two-tail p value is 0.2891. It has already been noted that there is a great deal more opportunity for slopes like this to occur with only two points in the regression. Thus, we do not see a significant increase. Further analyses might indicate that instead of a slow decrease in conflicts per month, there was actually a small increase in the second month, followed by a much larger decrease over the next months. Since the Volpe Center's focus is on the long-term effects of FCW systems on driver adaptation, there was no further analysis.

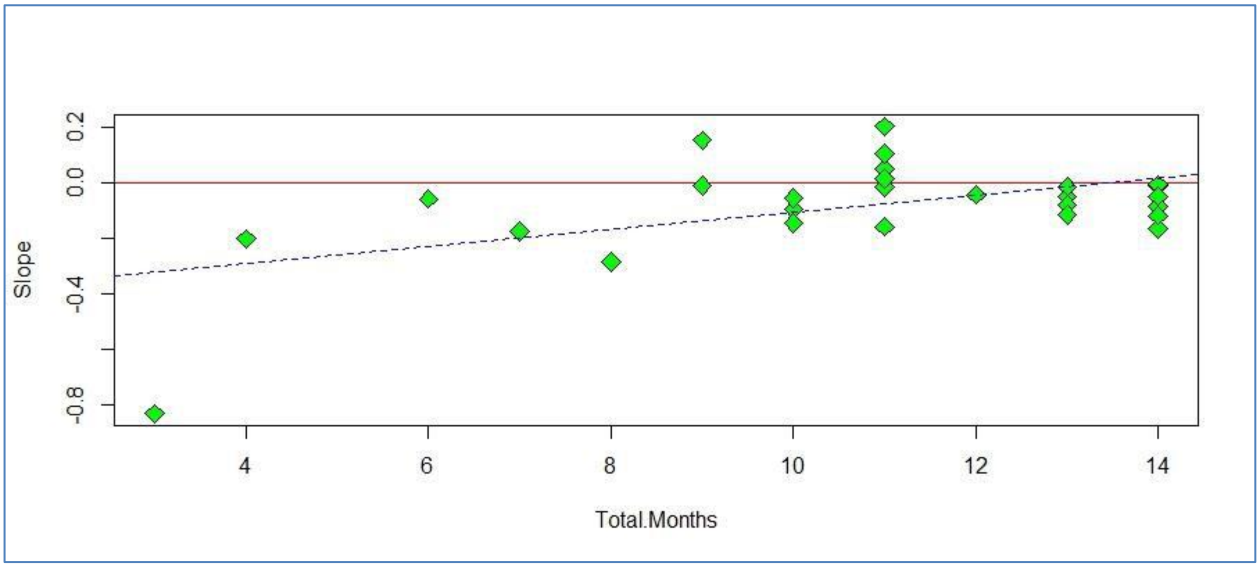


Figure 40. Slopes from Regression of Number of Conflicts per Month Traveled for Each Driver Versus Total Months Traveled by Driver

4.2.3 Changes in Response to Conflicts per Unit Exposure Across Increases in Total Exposure

There are three different measures of responses to conflicts: the minimum time to collision (MinTTC), the peak deceleration (PeakDx), and the mean deceleration (MeanDx).[18]

4.2.3.1 Changes in Response to Conflicts per 1,000 VMT across Increases in Total VMT

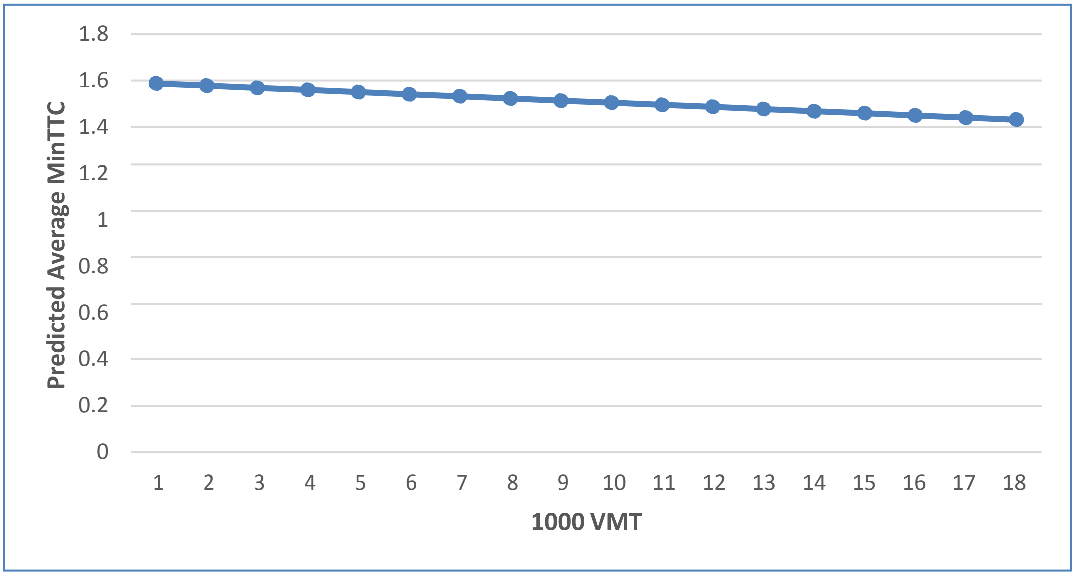
The Volpe Center evaluated the changes in responses to conflicts per given unit of exposure across increases in total exposure when the unit of exposure is 1,000 VMT and a conflict has occurred in that unit of exposure. The three changes in responses were: minimum time to collision, peak deceleration, and mean deceleration.

4.2.3.1.1 Changes in Average Minimum TTC per 1,000 VMT across Increases in Total VMT

Table 22 in Appendix L shows the average minimum time to collision for each month in which there was at least one conflict. The slopes and intercepts were computed for each driver (at the individual driver level) using a linear regression in R, as shown in Table 23 (Appendix L). There are only 31 slopes and intercepts because four drivers had only one 1,000 mile block of driving in which they had at least one conflict (this includes the two drivers who drove only 1,000 miles or fewer – D10 and D26, and two additional drivers who drove more than 1,000 miles; but in only one of those additional units of exposure was there at least one conflict – D21 and D27).

The average of the slopes across drivers is -0.009, while the average of the intercepts is 1.596. Figure 41 displays the change in predicted MinTTC across exposure. The intercept and slope used for the predictions are based on an average of the intercept and slope from the linear regression performed for each individual driver. There is a slight decrease, suggesting that drivers may be becoming more risky.

[18] The average MinTTC (average PeakDx, MeanDx) in a given unit of exposure is the average of the minimum time to collision (peak deceleration, mean deceleration) over all conflicts in a unit of exposure that has a conflict. There are many units (in fact most units) with no exposure.



Predicted Average MinTTC = -0.009+1.596*x*

Figure 41. Predicted Average MinTTC per 1,000 VMT as a Function of Total Exposure

The Volpe Center evaluated whether the decrease shown in Figure 41 is statistically significant, using the same two approaches described above. First, was the mean slope (averaged across drivers) statistically significantly different from zero when the null hypothesis is that the population slope is zero (H_0: $\beta = 0$) and the alternative hypothesis is that the slope does not equal zero (H_a: $\beta \neq 0$). The probability of a Type I error was set at 0.05. Figure 42 plots the individual slopes against the total miles traveled in the study. The red solid line represents no change. The blue dashed line is obtained from the regression of the slopes on the total VMT. The resulting value of t was not significant ($t = -0.4984$, $df = 30$, $p = 0.6219$). The same was true of the binomial test (13, 31, .5; $p = 0.4731$).

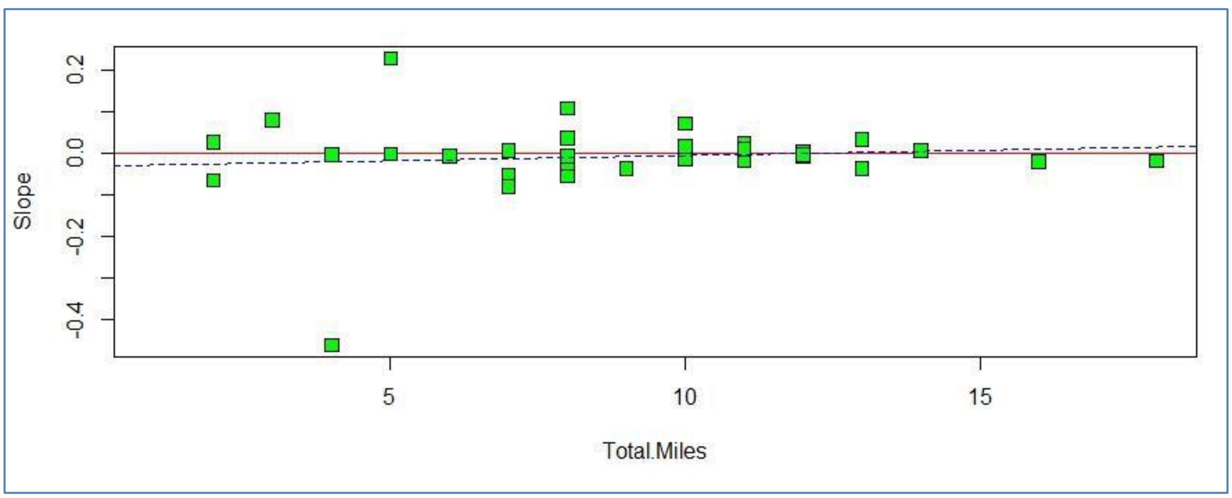
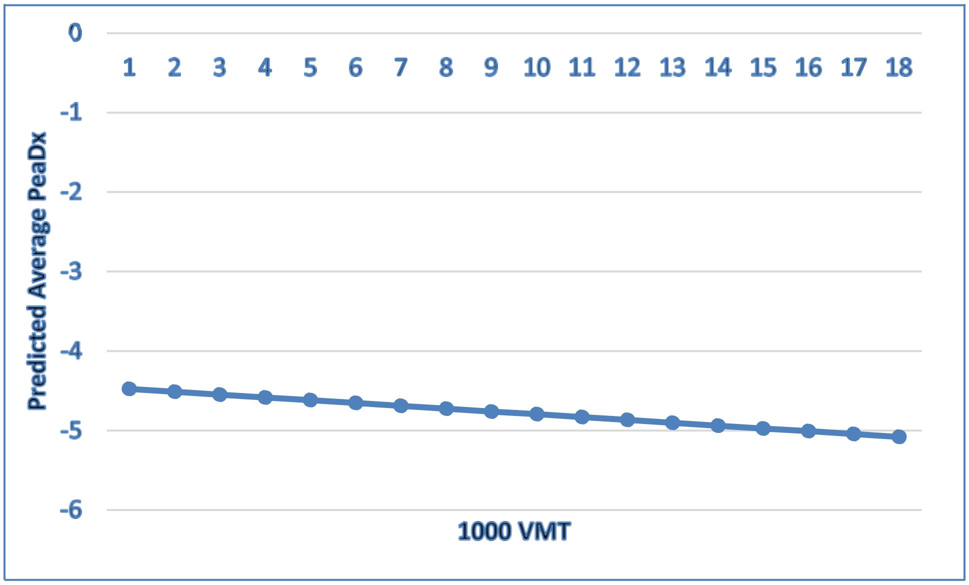


Figure 42. Slopes from Regression of Average MinTTC per 1,000 VMT on 1,000 VMT Traveled for Each Driver Versus Total VMT Traveled by Driver

4.2.3.1.2 Changes in Average Peak Deceleration per 1,000 VMT Across Increases in VMT

The Volpe Center evaluated changes in the average peak deceleration per 1,000 VMT across increases in total miles traveled. Table 24 in Appendix L shows the average peak deceleration for each 1,000 VMT in which there was at least one conflict where the driver responded by braking.[19] There were 31 drivers who could be used to determine the changes in the average peak deceleration per 1,000 VMT across increases in total miles traveled. The average peak deceleration per 1,000 VMT was regressed on the miles traveled for each driver. Table 25 in Appendix L lists the slopes and intercepts.

The average slope and intercept (across drivers) are, respectively, -4.441 and -0.036. Figure 43 displays the predicted average peak deceleration per 1,000 VMT. The intercept and slope used for the predictions are based on the average of the intercept and slope obtained from the linear regression performed for each individual driver. The average peak deceleration is becoming more negative, suggesting the drivers may be becoming more risky.



Predicted Average PeakDx = -4.441 - 0.036*x*

Figure 43. Predicted Average Peak Deceleration per 1,000 VMT as a Function of Total Exposure

Figure 44 plots the individual slopes against the total miles driven in the study. The red solid line represents no change. The blue dashed line is obtained from the regression of the slopes on the total VMT. The Volpe Center tested the null hypothesis that the mean change in the average peak deceleration per 1,000 VMT (i.e., the mean slope) did not differ significantly from a population slope of 0. The null hypothesis could not be rejected: t = -0.57596, df = 30, p = 0.5689. A binomial test was also used and proved insignificant: 15, 31, .5; p = 1.0.

[19] Steering response conflicts were not included in this analysis since resolving a conflict by steering into another lane of travel does not require deceleration.

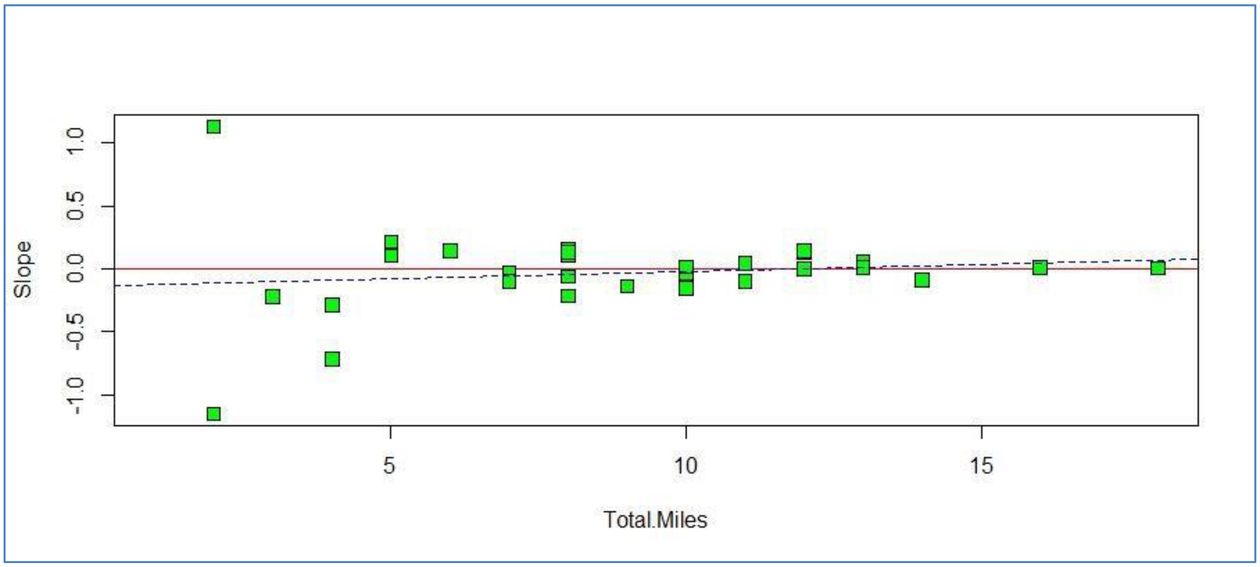


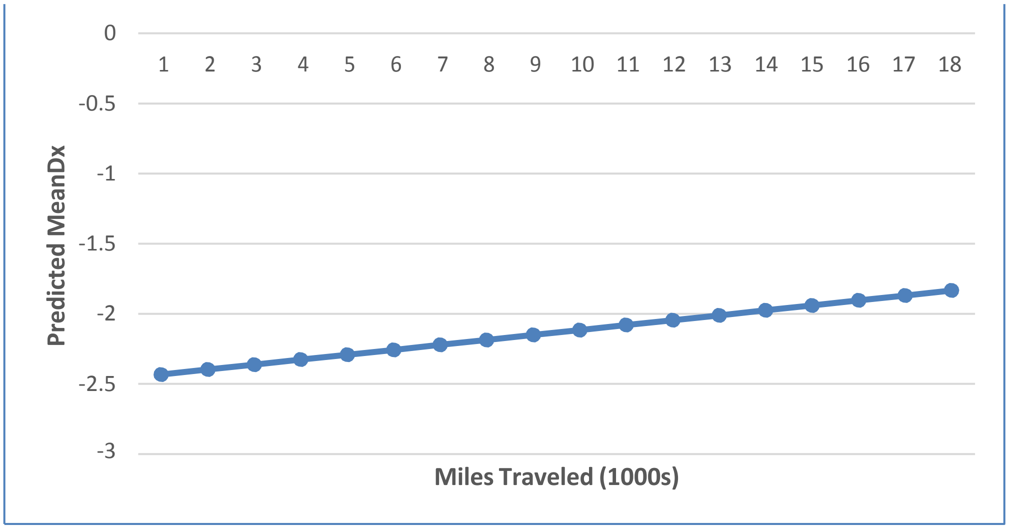
Figure 44. Slopes from the Regression of Average Peak Deceleration per 1,000 VMT on 1,000 VMT Traveled for Each Driver Plotted Against Total VMT Traveled by Driver

4.2.3.1.3 Changes in Mean Deceleration per 1,000 VMT Across Increases in VMT

Finally, the Volpe Center evaluated whether there is a change in the mean or average deceleration per 1,000 VMT across increases in miles traveled. Table 26 in Appendix L lists the data for each driver. For each driver, the mean deceleration per 1,000 VMT in a given block of exposure in which a conflict occurred was regressed on the miles driven (1,000s). Table 27 in Appendix L lists the intercepts and slopes (a total of 31 drivers had data which were usable).

The average of the intercepts across drivers was -2.468, the average of the slopes was 0.035. The intercept and slope were used to predict the mean deceleration for each 1,000 miles of exposure (

Figure 45). The average deceleration is getting smaller across increases in miles traveled, suggesting that drivers may be becoming somewhat less risky.



Predicted MeanDx = -2.468 + 0.035*x*

Figure 45. Predicted Mean Deceleration per 1,000 VMT as a Function of Total Exposure

Figure 46 shows the slopes from regression of mean deceleration per 1,000 VMT on 1,000 VMT traveled for each driver plotted against the total VMT traveled by driver. The red solid line represents no change. The blue dashed line is obtained from the regression of the slopes on the total VMT. A simple t-test was used to determine whether the change in the mean deceleration per 1,000 VMT across miles traveled was statistically significant. The null hypothesis was that the population slope was zero, i.e., there was no change. The null hypothesis could not be rejected: t = 1.035, df = 30, p = 0.3089. A binomial test was also run. Again, the null hypothesis could not be rejected: 17, 31, .5; p = 0.7201.

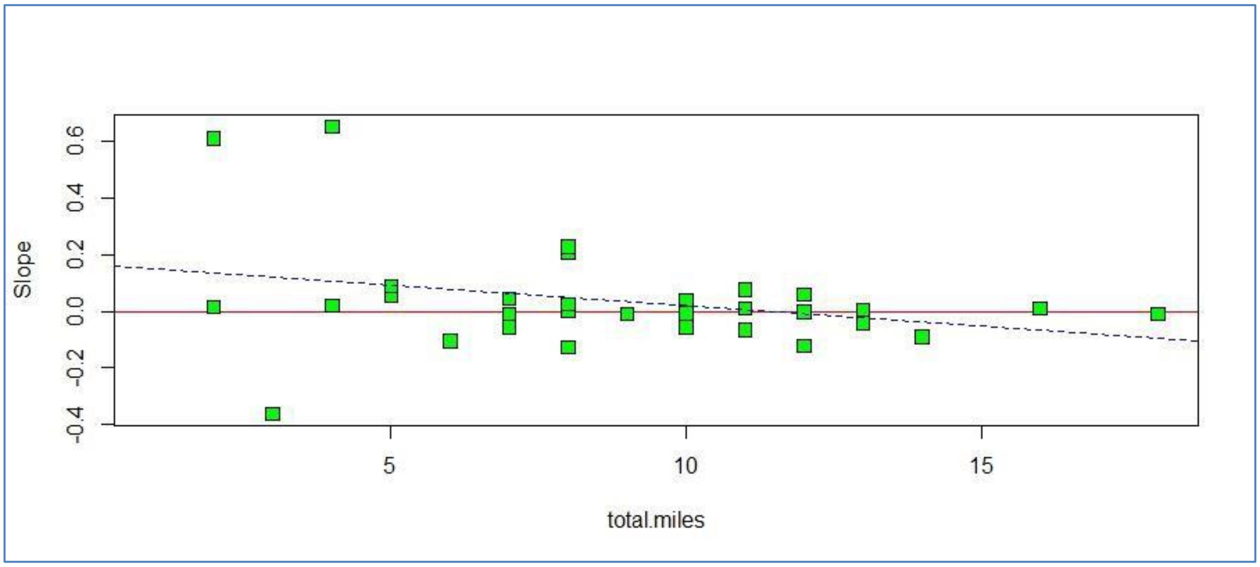


Figure 46. Slopes from Regression of Mean Deceleration per 1,000 VMT on 1,000 VMT Traveled for Each Driver Versus Total VMT Traveled by Driver

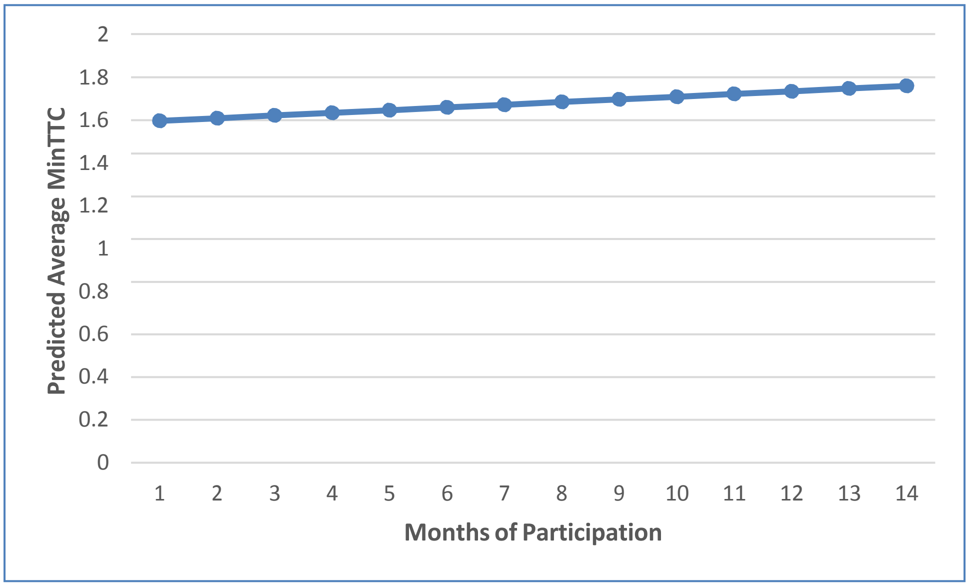
4.2.3.2 Changes in Response to Conflicts per Month across Participation Duration

The Volpe Center evaluated the change in the response to conflicts per month across time during those months where a conflict occurred. The three responses analyzed were the average of the minimum time to collision, the average peak deceleration, and the average mean deceleration during those months in which a conflict occurred. All participants who owned the vehicle for 2 months or less were excluded from the analyses (Drivers 2, 10-11, 20-22, 26-27), for the reasons described in Section 4.2.2.2.

4.2.3.2.1 Changes in Average Minimum TTC per Month Across Increases in Duration of Participation

Table 28 in Appendix L lists the average minimum time to collision per month per driver. Since all 27 drivers who drove more than 2 months had at least 2 months in which conflicts were observed, all 27 drivers were used in the analysis.

A linear regression was used to determine how the number of conflicts per month changed across time for each driver. Table 29 in Appendix L lists the best fitting parameters (slope and intercept) for each driver, along with the total months of participation. The average intercept and slope for the 27 drivers who drove the vehicle 2 months or longer were, respectively, 0.01265 and 1.5840. These parameters are used to predict the average minimum TTC over months of driving in Figure 47. There is a slight increase in the average minimum TTC, suggesting that drivers may be becoming slightly more cautious.



Predicted Average MinTTC = 0.0126 + 1.5840*x*

Figure 47. Predicted Average MinTTC per Month as a Function of Total Participation

The Volpe Center also evaluated whether the increase in the average MinTTC is significantly different from the hypothesis of no change. In Figure 48 the slopes from the regression of average MinTTC per month on months of ownership for each driver are plotted against total months of participation by driver. The red solid line represents no change. The blue dashed line is obtained from the regression of the slopes on the total VMT. The Volpe Center ran a t-test of the null hypothesis that there was no change in the average MinTTC across months of participation. The test was not significant: $t = 0.61063$, $df = 26$, $p = 0.5467$. A binomial test also indicated that there was no change: 10,27, .5; $p = 0.2478$.

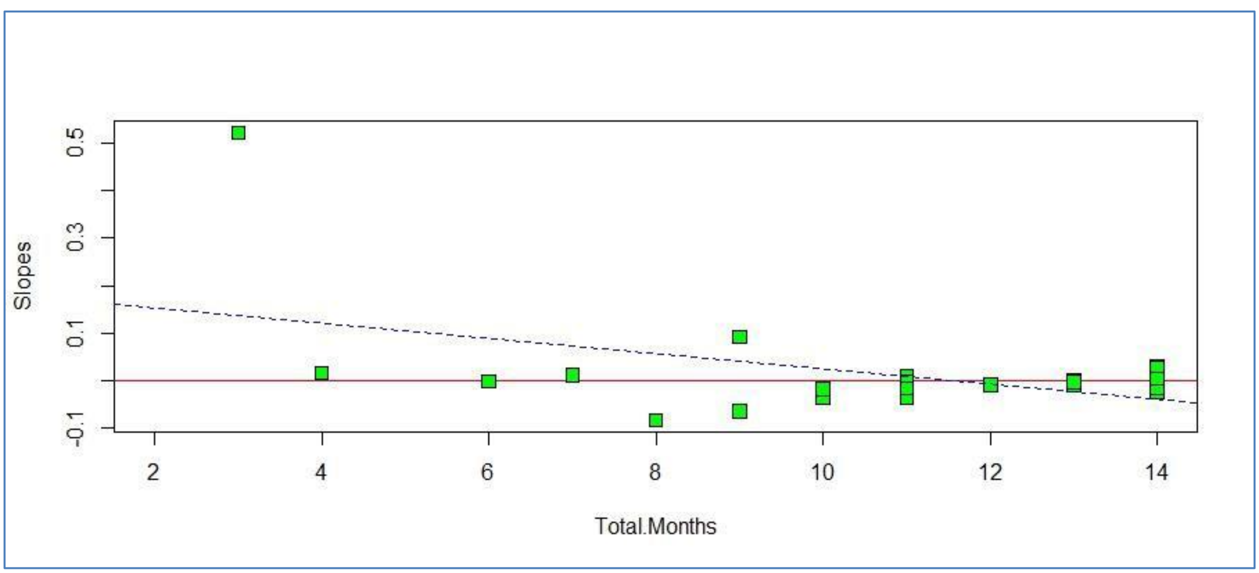
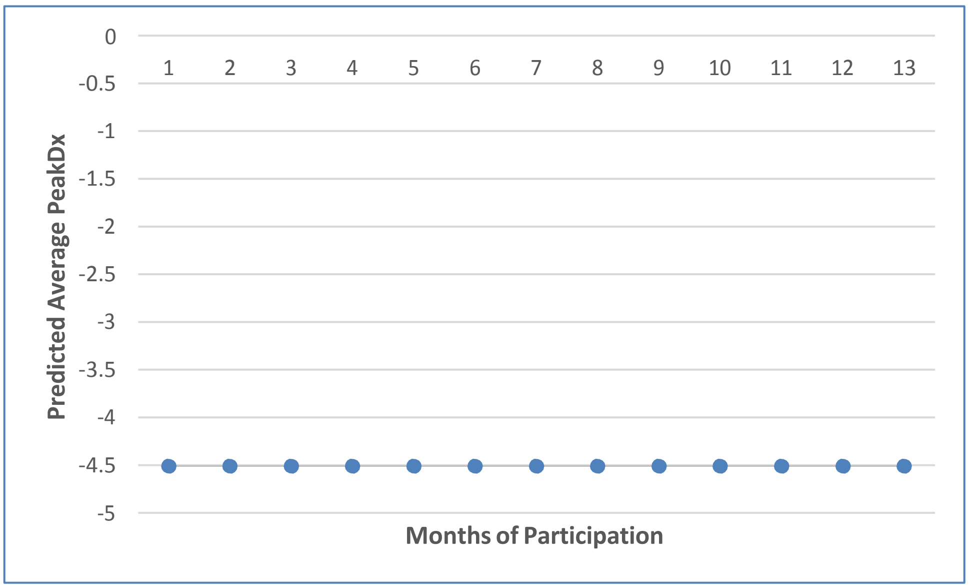


Figure 48. Slopes from Regression of Average MinTTC per Month on Months of Ownership for Each Driver Plotted Against Total Months of Participation by Driver

4.2.3.2.2 Changes in Average Peak Deceleration per Month across Increases in Months of Participation

Table 30 in Appendix L lists the average peak deceleration per month per driver. Again, a total of 27 drivers were included in the analysis (all those who drove more than 2 months).

A linear regression was used to determine how the average peak deceleration per month changed across time for each driver. Table 31 in Appendix L lists the best fitting parameters (slope and intercept) for each driver, along with the total months of participation. The average intercept and slope for the 27 drivers who owned the vehicle three months or longer are, respectively, 0.01265 and 1.5840. These parameters are used to predict the average peak deceleration over months of participation. The predictions appear in Figure 49. There is no change in the average peak deceleration, indicating drivers are neither becoming more or less cautious.



Predicted Average PeakDx = -4.5116

Figure 49. Predicted Average PeakDx per Month as a Function of Total Months of Participation

In Figure 50 the slopes from each driver of the regression of the average peak deceleration on the months of participation are plotted against the total months of participation. The red solid line represents no change. The blue dashed line is obtained from the regression of the slopes on the total VMT. Not surprisingly, there was no statistically significant change in the average peak deceleration across months of participation: $t = 0.61063$, $df = 26$, $p = 0.5467$. A binomial test also indicated that there was no change: 14, 27, .5; $p = 0.5185$.

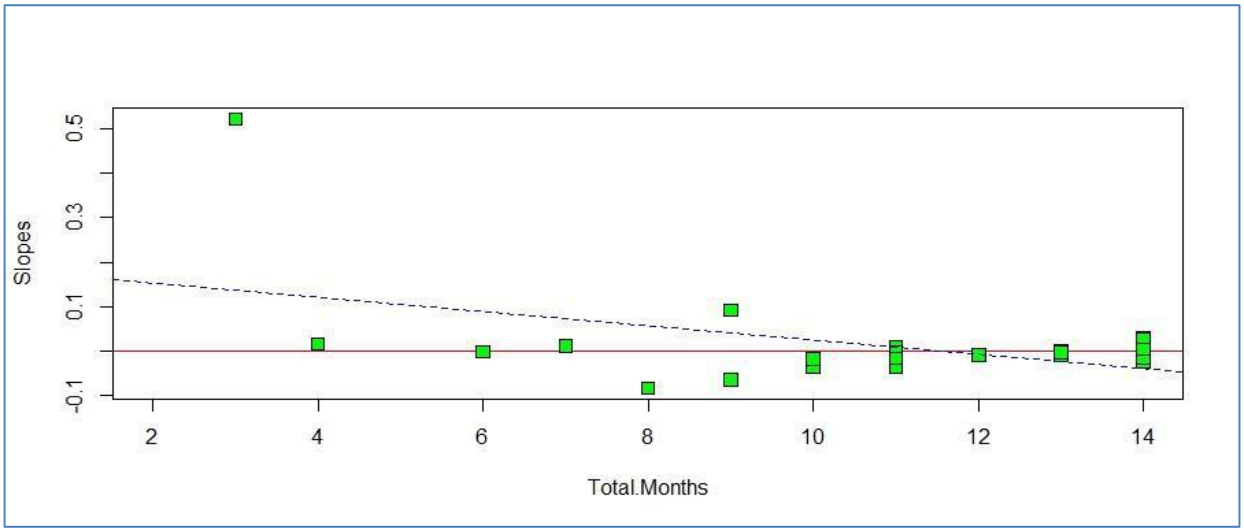


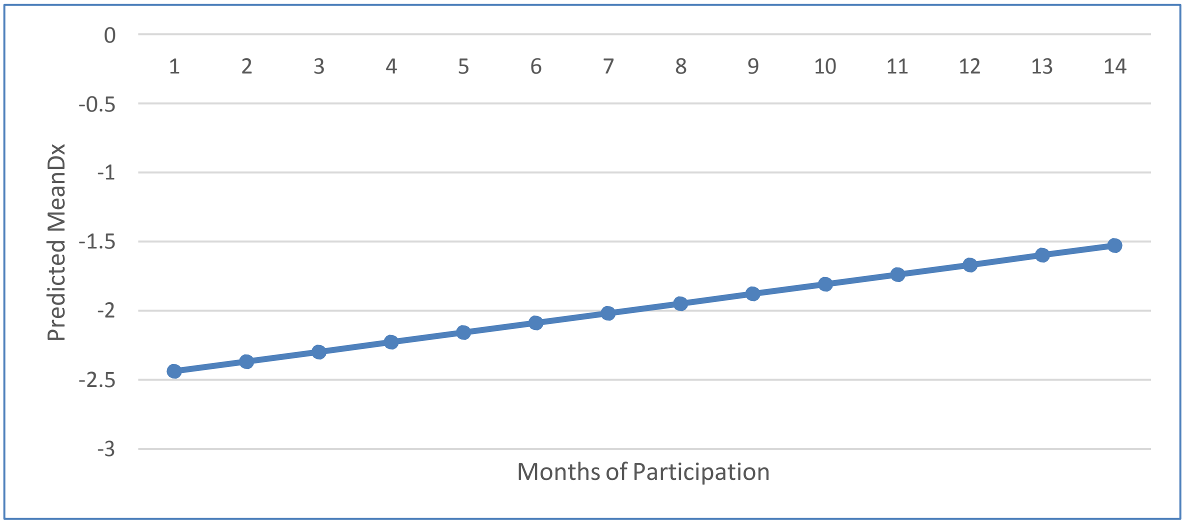
Figure 50. Slopes from Regression of Average PeakDx per Month on Months of Participation for Each Driver Versus Total Months of Participation by Driver

4.2.3.2.3 Changes in Mean Deceleration per Month across Increases in Months of Participation

Table 32 in Appendix L lists mean deceleration per month per driver. A total of 27 drivers were included in the analysis (all those who drove more than 2 months).

A linear regression was used to determine how the mean deceleration per month changed across time for each driver. Table 33 in Appendix L lists the best fitting parameters (slope and intercept) for each driver, along with the total months of participation. The average intercept and slope for the 27 drivers who owned the vehicle three months or longer were, respectively, -2.507 and 0.070.

Figure 51 shows how these parameters are used to predict the mean deceleration over months of participation. There was a slight decrease in the mean deceleration (when the unit of exposure was time), like there was when the unit of exposure was 1,000 VMT, suggesting drivers may be becoming more cautious.



Predicted MeanDx = -2.507 + 0.0699*x*

Figure 51. Predicted MeanDx per Month as a Function of Total Months of Owner Participation

In Figure 52 the slopes from the linear regression of each driver of the mean deceleration on the months of participation are plotted against the total months of participation. The red solid line represents no change. The blue dashed line is obtained from the regression of slopes on the total VMT. There was no statistically significant change in the average peak deceleration across months of participation: t = 1.4467, df = 27, p = 0.1595, although this may be a power issue. A binomial test also indicated that there was no change: 13, 27, .5; p = 0.4815.

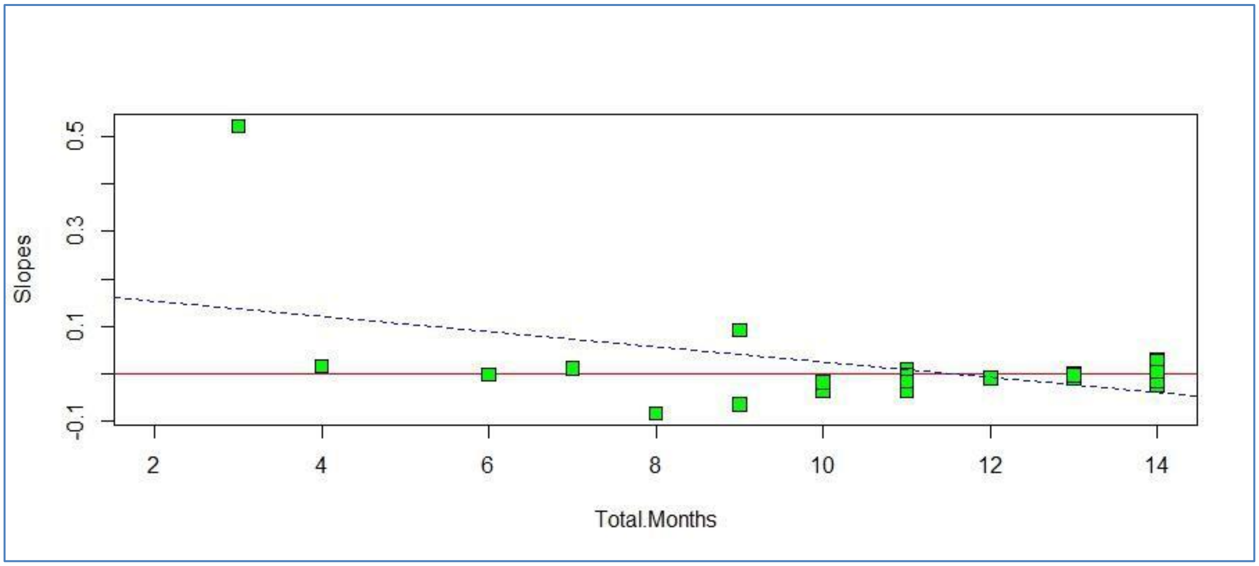


Figure 52. Slopes from Regression of MeanDx per Month on Months of Participation for Each Driver Versus Total Months of Participation by Driver

5 Driver Acceptance

This section describes the results from the driver acceptance analyses conducted by Leidos.

5.1 Pre- and Post-FOE Surveys

The following subsections discuss findings from the pre- and post-FOE surveys relating to effectiveness and accuracy, usefulness, and desirability of the FCW system, as well as the impact of the system on driver distraction and driver behavior. Of the 38 drivers who participated in the FOE, 37 completed pre- and post-FOE surveys. Where appropriate, anecdotes from focus group sessions are included to provide further context to survey results. The focus group sessions are summarized in more detail in Section 5.2.

5.1.1 System Effectiveness and Accuracy

Fifteen participants reported that the FCW system was the main reason why a collision was avoided. Of these 15 participants, 7 said that the FCW prevented multiple collisions and 8 believed that the system prevented a single crash. Of those participants who believed the system prevented multiple collisions, 2 believed the system prevented an estimated 2 collisions, and 2 believed it prevented an estimated 3 collisions. Of the remaining 2 participants, 1 believed the system prevented 4 collisions, and the other believed it prevented 5 collisions. The 15 participants had the option to provide details on how the system prevented collisions. Fourteen out of 15 said that the system prevents potential collisions by bringing their attention to the road ahead, or by alerting the driver that the vehicle ahead was stopping; for example, because of occasional (and expected) slowdowns in traffic flow or when the participant was driving too quickly. The remaining participant did not provide much detail in her response, but noted that in a parking scenario a single collision was avoided due to the FCW system.

FCW alerts could also occur in situations where they were unnecessary because there was no danger (i.e., a false positive alert). Participants were asked to describe how often a false positive alert happened during the study (see Figure 53). One participants did not believe that they had ever received an alert when there was no danger. Nine believed this to be a rare occurrence. More participants believed this happened sometimes (12) or often (12) during the study. Three participants believed that the FCW warnings were always incorrect. During one focus group session, two participants discussed the FCW system: “Even if I was paying attention and I was not going to hit anyone, if that light came on, I would be slamming on the brakes because it scared me” [a participant interrupts] “and that is dangerous, what if you cause an accident?” [first participant continues] “Right, it’s not necessarily a good thing. It was startling and did make me hit the brakes.”

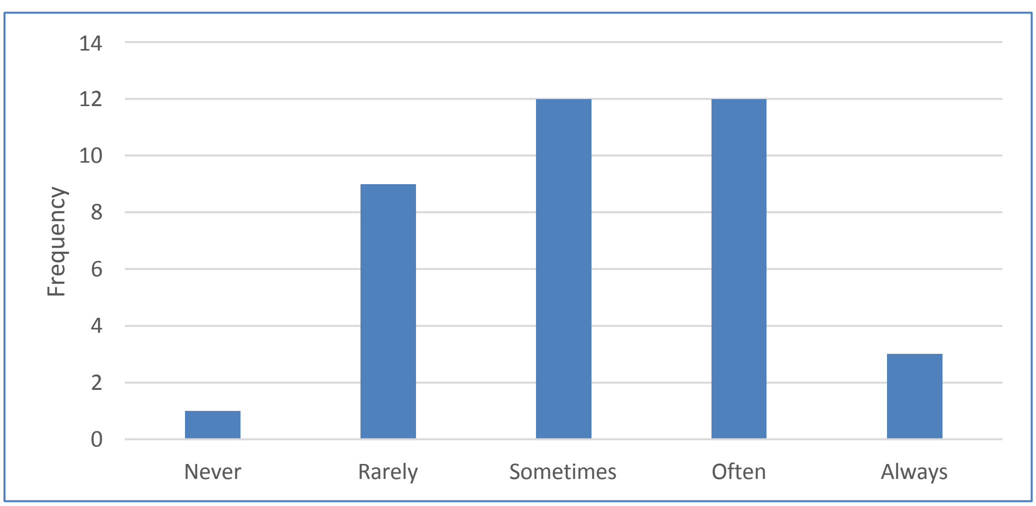


Figure 53. Perception of How Often a False Positive FCW Was Issued During the Study

Another possible scenario was that the driving situation posed a risk to the driver, but no FCW alert was issued (see Figure 54). The majority of participants (18) thought this never happened. Conversely, nearly one-third of the participants (11) believed this to rarely occur, 7 believed it occurred sometimes, and 1 participant believed it occurred often.

Participants elaborated on false positive alerts during the focus group. Several participants thought the FCW alerts were "inconsistent" and identified times when they thought an alert should have occurred, but did not. Similarly, there were instances when the alert occurred, but there was no perceived danger ahead.

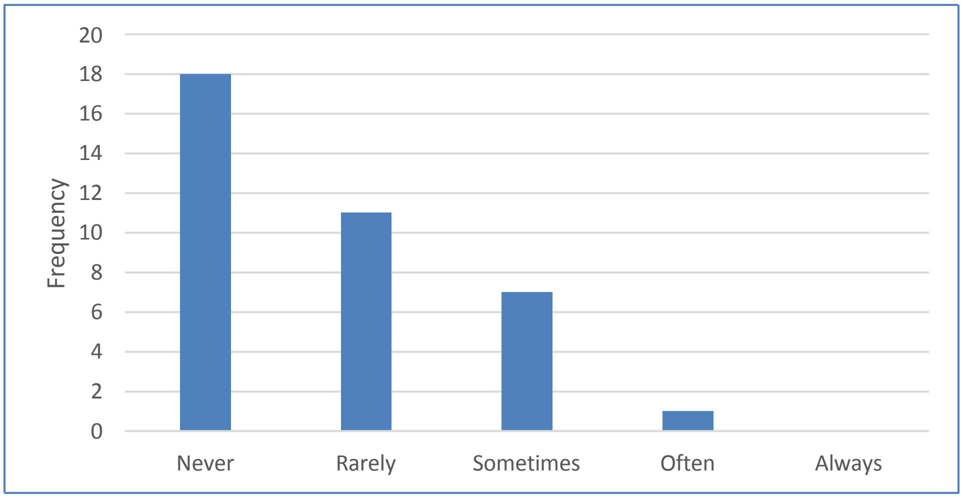


Figure 54. How Often an FCW Was Not Issued When the Driver Believed It Should Have Been

5.1.2 System Usefulness

The following subsections discuss drivers' perceptions of the usefulness of the forward collision warnings and automatic braking events.

5.1.2.1 Forward Collision Warnings

For the participants who completed the study the perceived usefulness of the FCW alerts changed between the background survey and the post-FOE survey. Prior to the study, participants viewed the usefulness of the FCW system as positive. In contrast, on the post-FOE survey, there were more negative views of the system than positive ones. During the focus group, drivers commented that the FCW alerts seemed inconsistent. This may explain the decrease in perceived usefulness over time. One participant noted that during "the last month or month-and-a-half it happened so frequently and there was not a lot of consistency to it so I could not rely on it. I could not trust it."

Thoughts on how to improve the usefulness of the FCW alerts differed across the participants. Some participants (5) commented that the interface could be improved through customizing the alert (e.g., change alert color). Four participants believed that if the system was more accurate, it would be more useful. One of these participants did state that having the ability to change the alert type would be useful. However, this capability currently exists in the research vehicle and participants did have access to this information through the driver's manual. Four drivers believed the system could be more useful if it could detect whether a driver was distracted (e.g., assess driver eye gaze) and only alert the driver during those instances. One participant wished that there was an additional far setting available when traveling at higher speeds, while another wanted a shorter gap setting. In contrast, 2 participants stated that the only way for the system to be more useful was for them to drive more distracted (e.g., texting while driving). These participants believed that the system was only useful if the driver was distracted. As such, increasing the amount of driver distraction seemed like the only solution for increasing usefulness.

5.1.2.2 Automatic Braking

Of those participants with an opinion, views of the automatic system were more positive than negative. Fifty percent of the participants (19) perceived the system to be useful to some degree, while only 13 percent (5) perceived the system to be useless to some degree. Thirteen of the participants were neutral in their perceptions of the usefulness of the automatic braking system.

Opinions on when automatic braking would be useful varied across participants. Generally, drivers described how automatic braking would be useful in a potential collision setting. Some participants also elaborated on which potential collision situations would be the best for this type of system. These included: sudden stops in traffic flow or congested roadways (12), distracted driving (11), to prevent a collision (5), when an object (e.g., vehicle, human, animal) enters the vehicle path unexpectedly (4), or in parking scenarios (2). One driver thought automatic braking would help to end illegal vehicle pursuits, and 1 thought it would be useful when driving in reverse.

Twenty-seven of the participants had no recommended change to the automatic braking system, felt their experiences did not lend themselves to giving advice about the feature, or made comments about the park assist system (which is not the system under investigation). Three of the participants wished that the system would provide feedback so the driver would know automatic braking occurred. Three participants wanted increased accuracy in the system and two wanted a distance or speed setting for when automatic braking would be disabled. One participant preferred the ability to disable the feature, one would like the feature to request feedback from the driver (e.g., "was the automatic braking event necessary?") so that the vehicle could "learn" the driver's driving style, and one participant preferred a larger braking distance. During the focus group, one participant who experienced the false automatic braking event discussed why the false event occurred: "I think it was the lighting from when I came out from underneath the bridge. It is hard to tell because I have been in the same scenario again and it did not happen. [It was] very unpredictable. I actually thought it was a very scary situation because it could have caused the car behind me to slam into me."

5.1.3 System Desirability

Based on the pre-FOE survey, about 62 percent (23) of the participants were willing to pay for automatic braking systems and about 22 percent (8) wanted automatic braking systems if they were standard features. Three participants did not want the feature. As shown in Figure 55 (which compares the desirability of the FCW alerts and automatic braking features to other popular commercially available systems) for those willing to pay for the systems, the median one-time cost participants would pay to install on their next vehicle was $500 (maximum = $30,000). If adding the system to their existing vehicle, participants were willing to pay a median one-time cost of $300 (maximum = $1,200).

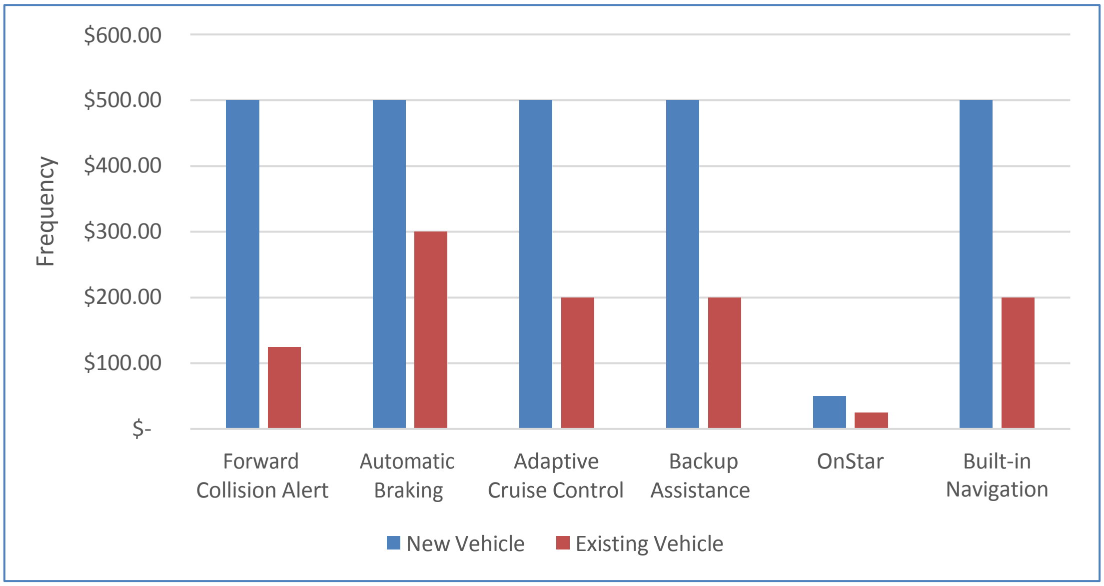


Figure 55. Median One-Time Cost to Add Various In-Vehicle Technologies to New and Existing Vehicles

When asked to imagine they were buying or leasing a new vehicle in the post-FOE survey, 61 percent of the participants (23) wanted the FCW and automatic braking system on the new vehicle. Of these individuals, 13 wanted the feature only if it were standard, 9 wanted the feature dependent on cost, and 1 wanted the feature regardless of cost. The 9 participants who wanted the feature dependent on cost were willing to pay an average of approximately $900 to have it on a new vehicle and an average of approximately $250 to add it to an existing vehicle. Eight of the participants did not care one way or the other for the feature and 6 participants did not want it on a new vehicle. During the focus group, some participants mentioned they would want the ability to turn the FCW and automatic braking system off if their vehicle was equipped with the technology.

When asked to imagine they were buying or leasing a new vehicle, 74 percent of the participants (28) wanted the automatic braking system on the new vehicle. Of these individuals, 17 wanted the feature only if it were standard, 10 wanted the feature dependent on cost, and 1 wanted the feature regardless of cost. These 10 drivers were willing to pay an average of $1,030 to have the feature on a new vehicle and an average of $485 to add the feature to an existing vehicle. Five of the participants did not care one way or the other for the automatic braking system and 5 did not want the feature on a new vehicle.

5.1.4 System-related Distraction

Participants rated how distracting they found the FCW and automatic braking system (see Figure 56). Overall, 65 percent of the participants (25) found the system to be distracting to some degree, while just less than half of these participants (11) believed the system was rarely distracting. Seven participants thought the system was sometimes distracting, 5 thought it was often distracting, and 1 thought it was always distracting.

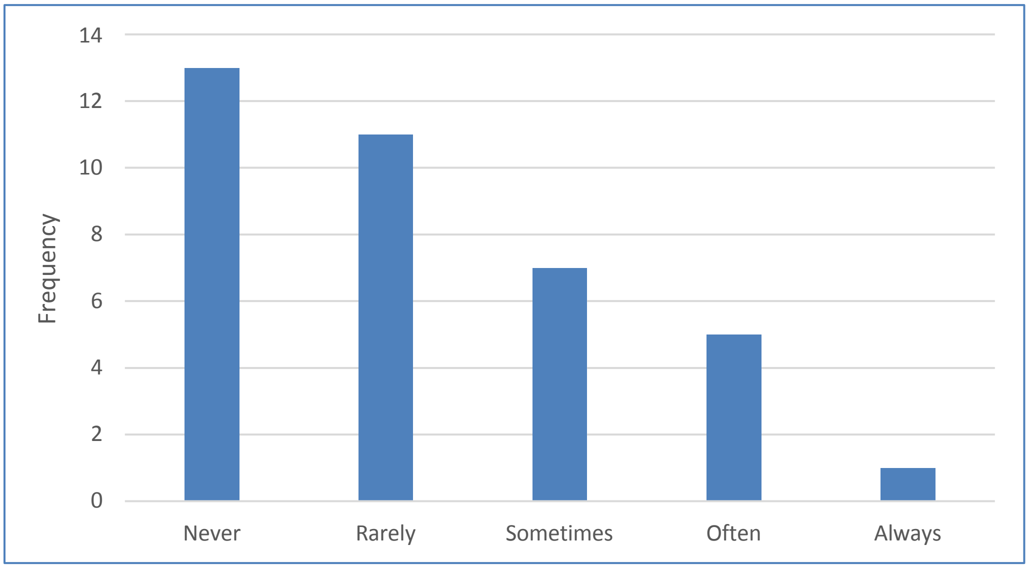


Figure 56. Perceived Level of Distraction of the FCW and Automatic Braking System

While the reasons for why the system was distracting varied across the participants, 13 of the 25 participants who stated why they believed the system was distracting said the system diverted the driver's attention away from the roadway. For example, one of these individuals stated that his gaze was drawn toward the flashing lights while merging into heavy traffic instead of toward the other vehicles in the roadway. This feeling was reiterated by the focus group. One participant said the alerts "make you focus 18 inches in front of you" rather than on the vehicles ahead, while a second noted "I almost focused more on the lights than the car I was going to hit." Two participants said that the alerts were distracting initially, but the distraction effect wore off over time as they became more accustomed to the system. Additional reasons for distraction from using the system were that the driver was already paying attention to the forward roadway (and thus the alert was unnecessary), the alerts were not necessary, the alerts were inconsistent in their occurrence, and the combination of the various types of alerts (visual and auditory or haptic) resulted in too much stimulation. The participants reiterated these comments during the focus group.

5.1.5 Impact on Driving Behavior

Eleven of the 37 participants who completed post-FOE surveys thought their behavior changed due to the inclusion of the FCW and automatic braking system on their vehicles. Of the 11 participants who provided additional details describing how their behavior changed, 6 believed that they were more aware of driving situations that could cause an alert, 2 believed that they were less attentive while driving due to the FCW and automatic braking system, 2 modified their driving behavior to prevent FCW warnings, and 1 was more cautious about forward collisions

5.2 Focus Groups

The following subsections summarize driver comprehension, exposure to and desirability of the FCW and automatic braking system, and driver behavior when driving with the system, based on the focus group sessions.

5.2.1 Forward Collision Warning System Comprehension

5.2.1.1 Forward Collision Alerts

A complete understanding of FCW system included several components: (a) a visual alert of red lights on the windshield, (b) a haptic or auditory signal providing an additional source of alert, (c) the ability to select between haptic or auditory alerts, and (d) the ability to adjust the gap associated with the alert (far, medium, or near).

While FCW was not always the first feature mentioned (ACC came to mind more readily), participants showed a high level of comprehension. All recognized that the purpose of the system was to warn of a potential collision with a forward vehicle. All understood that the alerts consisted of "flashing red lights" and "vibrating seats." Two participants noted that they were aware that the system could be adjusted to provide an auditory instead of haptic warning. Only one person reported trying this. All participants said that the auditory system would be overwhelming or annoying.

Participants had a difficult time explaining what triggered an alert. Most said it was the distance to a forward vehicle. Some participants even said that the FCW trigger would work better if the system accounted for vehicle speed (which it did). When asked for further details, some participants were able to explain that the system probably did consider their own speed or the speed of the vehicle ahead, but had trouble describing how this actually worked.

Only a few participants said that the far, medium, and near settings were able to affect the number of alerts the driver receives. Many understood that the setting could be adjusted but believed this was only associated with cruise control. It appears that these participants did not read the manual as advised during orientation in order to familiarize themselves with the systems and their options.

5.2.1.2 Automatic Emergency Braking

To understand the automatic braking feature, participants should recognize that (a) the vehicle will apply the brakes if there is an imminent risk of collision; and (b) that the car may apply the brakes in ACC or in parking situations.

When first asked about automatic braking, answers included situations on roadways and when parking. For the purposes of this study, further discussion focused on roadway situations. Most participants understood that the automatic braking feature was present, regardless of whether or not they had experienced a roadway automatic braking event. Three participants in the short-term exposure group were not aware of the automatic braking feature; this could be a result of their relative lack of familiarity or experience with the study vehicle.

Automatic braking was usually the last feature named when participants were asked about safety systems, but most knew that the feature was available and were able to describe it conceptually. They understood that if the collision risk was very great, the vehicle would apply the brakes for the driver. Some participants understood that automatic braking represented a progression in risk beyond FCW alone.

5.2.2 Personal Experience

Participants were asked to describe their experiences with FCW and automatic braking during the study. A series of questions looked at the number of events experienced (if any), whether the events were valid, whether an event helped to prevent a collision wholly or in part, and the degree to which false alarms or missed opportunities for alerts occurred.

The following sections describe participants' experiences for each aspect of the FCW and avoidance systems on the study vehicle.

5.2.2.1 Forward Collision Alerts

Participants were asked:

> *Did you experience this feature?*
>
> *Did it ever fail to go off (fail to give a warning or a miss) and you think it should have?*
>
> *Did it ever give you a false alarm (it went off and you don't know why)?*

The research team adapted the focus group protocol for group B2 (intermediate exposure) and group A (long exposure) by providing an estimation exercise. Participants were asked to estimate the maximum number of FCW alerts they received in a typical work week. Using this number they then were asked to graph the mean number of alerts received over their study participation.

In the later focus groups, participants were relatively accurate at estimating the number of alerts they received.

Participants were asked to indicate how the number of alerts changed over time by providing a visual estimation. About half of the participants (47%) said there were more alerts near the beginning of the study and a gradual decline over time. In some cases these declines were linear, and in others, the decline occurred after a fairly stable level of alerts early in the study. About a quarter of participants said there were a fairly level number of alerts over time. The remainder of participants said alerts were variable with no clear pattern over time.

All participants experienced multiple FCW alerts. Six participants felt that the system might have been a factor in preventing a collision. Only one of the participants (in the short-term exposure group) believed the system alerted him in such a way it prevent a collision when he was distracted. Receiving the alert led him to "slam on the brakes." The other 5 participants believed that the FCW occurred in a situation where a crash was very likely (i.e., they believed the situation was truly dangerous and believed the FCW was a helpful occurrence). However, they could not say with certainty that the FCW was the deciding factor in preventing a collision.

There was general agreement that not all alerts were necessary (i.e., participants were aware of the forward vehicle and were ready and able to brake appropriately). Participants were able to distinguish these "false alarms" from "faulty" FCWs. Three participants in the long-term exposure group experienced alarms associated with no discernable forward risk, such as when there were no other cars on the road. Some participants attributed these alarms to fog or glare at night.

5.2.2.2 Automatic Emergency Braking

Participants were asked to describe their experience with automatic braking events, if any:

> *If you observed the automatic braking in your driving, please explain the circumstances.*
>
> *Do you think the automatic braking was necessary in your situation? Did it help you by preventing a collision?*
>
> *Did it ever fail to go off (fail to give a warning or a miss) and you think it should have?*
>
> *Did it ever give you a false alarm (it went off and you don't know why)?*

When initially asked about automatic braking events, many participants reported experiences while backing up or parking. For the purposes of this report, only forward collision events on roadways were reported. Participants experienced the following automatic braking events:

1. Participant encountered a forward vehicle that was completely stopped on the Washington Beltway (I-495) and believed the automatic braking prevented a crash.
2. Participant believed that automatic braking prevented a collision.

3. Participant believed he experienced automatic braking in two situations. The first was a left-hand turn when he was cut off. The second was when he was distracted by the infotainment touchscreen. In both cases, he believed the system "helped" but he did not think the system prevented the collision.
4. Participant believed he experienced a false alarm while approaching an overpass in Loudoun County. The vehicle applied the brakes while there was no discernable target vehicle to target the automatic braking event.
5. Participant approached an intersection in Washington, DC and was aware (based on the pedestrian countdown signal) that his signal was about to change to amber and red. He anticipated the vehicle in front of him would go through the intersection but instead it braked suddenly, triggering an automatic braking event. However, he believed he would have been able to stop in time without automatic braking.
6. Participant reported an automatic braking event when he was on Fairfax County Parkway (at about 55 mph). He was aware of the car in front of him, but when that car started slowing down, it seemed that the automatic braking system would not let him accelerate.
7. Participant reported a possible automatic braking experience on I-95; she said that she wasn't sure if she stopped, the car stopped her, or both.
8. Participant reported two automatic braking events. In one situation, a vehicle pulled into his lane without looking. The second situation was on a winding country road where someone backed out of a driveway. In both cases, he believed that the vehicle applied the brakes at almost the same time that he did.
9. Participant discussed his experience where he was driving and unexpectedly came upon stopped traffic. The vehicle applied the brakes as did the participant. He did not think he would be able to come to a safe stop but was able to swerve into the adjacent lane.
10. Participant reported having a false alarm approaching a tunnel when there was no clear rationale for an automatic braking event.
11. Participant reported an automatic braking event when she was travelling at a high rate of speed on the Capital Beltway (I-495) and suddenly encountered traffic stopped at a closed HOV gate. The vehicle applied the brakes; she believed this prevented a serious collision.

5.2.3 System Desirability

Participants were asked about the utility and usability of the FCW and automatic braking system and how this affected its overall desirability.

All participants recognized that FCW and automatic braking events were not always necessary since the driver was already aware of the forward event. They had either negative or positive responses to these events. The positive response could be characterized as feeling as though the system alerted the driver adequately and that extraneous (unneeded) alerts could be ignored. These participants thought the alert was "startling" but in a good way, in that it would get a driver's attention, particularly if that driver was distracted. They often had the point of view that such systems did "more good than harm" and were more readily seemed able to "tune out" warnings perceived as redundant or extraneous.

The negative response could be characterized as perceiving the alerts as unnecessary and annoying. Participants were less able to tune them out and ended up being more frustrated when experiencing a warning. Several drivers reported talking back to the car in frustration. One participant reported saying "I got it, I got it…" when alerts occurred and she reported the alerts were "frustrating to me."

The majority of participants had a positive response to the system, but at least 4 participants indicated that they would prefer to not have this feature on the vehicle or would want the ability to turn off the feature under some driving conditions. However, while many participants indicated they wanted to have this system on their own vehicles, they questioned whether it would be wise for all drivers to have this. They worried that other drivers, especially novice drivers, would never learn good driving skills because of over-reliance on the technology.

Most drivers had a positive reaction to the automatic braking system, believing it served as a failsafe, and said it was better to have a system like this for when you really need it. Positive reactions to the automatic braking seemed more enthusiastic compared to the system, perhaps because the system couldn't "save" the driver in the same way the automatic braking could. However, there were concerns associated with the secondary effects of the automatic braking. Several participants felt that the automatic braking could do far more harm than good and worried that the automatic braking could cause secondary rear collisions when vehicles stopped abruptly. This was particularly troublesome in false alarm scenarios experienced by certain participants.

5.2.4 Secondary Task Behavior

While participants missed some comfort features of the vehicle, many noted that the infotainment console in the vehicle made them prone to distraction as the user interface required a large amount of looking away from the roadway.

Participants showed a desire to comply with real and imagined experimenter expectations to not use a handheld device while driving during the study. However, several participants in each group admitted to returning to their typical behavior within weeks of joining the study. Some drivers reported that the presence of Bluetooth technology in the study vehicle (as opposed to their own vehicle) made it more likely to multitask because it seemed easier and safer to do so hands-free.

Additionally, participants reported that the presence of FCW and automatic braking systems made them feel as if multitasking was less dangerous in some situations. Two participants in the long-term exposure group admitted that they felt as if they texted and made calls more frequently due to the presence of the various safety systems in the vehicle, including the FCW and automatic braking systems. One participant said checking her cell phone was "less daunting or scary." Another said the systems "made you feel like you have an extra second to look at your cell phone." However, they reported this was true only under certain circumstances, such as slow moving or stop-and-go traffic; it seems they felt that the FCW and automatic braking system added an extra layer of safety that could offer some protection to what they recognized as potentially risky behaviors.

5.2.5 Behavior Related to Study Participation

Participants were asked to describe how they were affected by the video cameras in the vehicle during the study. There was an even split in reporting a strong awareness of the cameras. About half said they were very wary of the cameras at first, while half said they weren't aware of them at all. However, for those participants who felt very aware of the cameras, they generally claimed that this feeling diminished over time ranging from 1 week to 2 months. Several people in the long-term exposure groups claimed that they never got used to the cameras (i.e., remained somewhat self-conscious), but realized the probability of the research team "watching every minute of tape was quite small."

6 Discussion and Conclusions

This driver adaptation FOE successfully quantified changes in driver exposure and response to high-risk driving scenarios over time, and as a result, changes in safety impact over time when driving with the FCW and automatic braking system. Driver safety at a given level of exposure (time or miles) was indexed both by conflicts and by the driver's response to those conflicts (average MinTTC, average PeakDx, MeanDx). The study also successfully quantified FCW and automatic braking system performance by the proportion of valid and false events. Driver acceptance was assessed in terms of effectiveness, usefulness, desirability, and distraction.

The following subsections contain key findings from the analyses of system performance, changes in safety impact, and driver acceptance; and discuss limitations to the study.

6.1 System Performance and Effects on Driver Responses

Overall, the accuracy of the FCW alerts was very high. Straight roads had a higher accuracy than curved roads, and moving targets had a higher accuracy than stopped targets. The majority of FCW alerts were issued for stopped targets:

- Ninety-eight percent of FCW alerts were true alerts (issued for in-path vehicles).
- FCW alert validity was slightly higher on straight roads compared to curved roads (99% true compared to 86% true).
- FCW alert validity was much higher for moving targets than for stopped targets (99% true compared to only 41% true); however, only 2 percent of alerts were issued for stopped targets.

By comparison, the accuracy of the automatic braking events was very low. Unlike the FCW alerts, the majority of automatic braking events were triggered by stopped targets, leading to many false activations. One rear-end crash did occur during the field test. While the automatic braking likely reduced the intensity of this crash, it did not help the driver avoid the crash completely.

- Overall, 26 percent of automatic braking events were valid (issued for in-path targets). In 12 cases (80% of the valid automatic braking events) drivers braked prior to the automatic braking event engaging. In 3 cases (20% of the valid automatic braking events) the automatic braking event engaged before the driver braked.
- Like FCW alerts, automatic braking events were more accurate on straight roads compared to curved roads (27% valid compared to 14% valid) and for moving targets compared to stopped targets (50% valid compared to 21% valid). The majority (83%) of automatic braking events were triggered by stopped targets.

The above results suggest one of two conclusions about drivers' response to the FCW alerts. Given the high accuracy of the FCW alerts, it is likely that drivers were able to create a mental model of the FCW alerts and anticipate when the system would—and would not—produce warnings. While high accuracy is a positive outcome, if a driver feels they can rely on system warnings to inform him or her of a risk, it creates the potential for negative adaptation [13]. Drivers may drive less safely (knowingly increasing their level of risk) when driving with a system they feel can be relied on to warn of unsafe situations. In turn, this reliance will keep the drivers' overall level of risk constant, diminishing the positive impacts of the safety system. This behavior is known as risk homeostasis theory [14] and drivers exhibiting the behavior are referred to as *risk constant*. Alternatively, a driver may decide that the alerts are worth avoiding, either because they warn the driver about situations which they find are inherently risky, or because the driver simply prefers not to receive them. In either case, the net result would be a positive adaptation, because the driver would avoid situations that triggered an alert. These drivers are referred to as *risk averse*. Section 6.2.2 discusses the effect of risk neutral and risk averse drivers on the change in conflicts and the response to conflict over increases in exposure.

The high accuracy and frequency of the FCW alerts, and low accuracy and frequency of the automatic braking events observed in this FOE mean that any observed behavior modifications are likely the result of adaptation to the FCW system, not to the automatic braking events.

6.2 Safety Impact

This subsection discusses results from analyzing overall driving and conflicts.

6.2.1 Overall Driving

The Volpe Center did not observe any changes in driver travel speed or headway keeping over time, but did observe reductions in FCW alert rates for specific groups:

- There were no changes in driver travel speed over time when driving with the FCW alerts and automatic braking.
- There were no changes in driver headway keeping over time when driving with the FCW alerts and automatic braking.
- Long-term drivers and long-term and medium-term drivers combined (all drivers except for short-term drivers) showed statistically-significant reductions in FCW alert rates over time. However, this reduction was due to drivers changing the alert setting to be less sensitive.
- Long-term and medium-term male drivers combined showed a statistically significant reduction in FCW alert rate over time (due to changing the alert setting to be less sensitive), while female drivers showed no change. On average, female drivers' FCW alert rate was about half the rate of male drivers.

These results bring up two important points. First, there are no studies that report how the FCW alert rate changes over time. There have been studies of alert rate changes between the baseline, treatment, and post-treatment periods for younger drivers who had and did not have a forward collision warning system installed in their vehicle [15]. However, this study did not measure the changes in alert rates during the treatment period among either group. The Volpe Center believes that this Driver Adaptation FOE study is the first time changes in alert rates have actually been measured during the treatment period.

Second, while driving with the FCW alerts and automatic braking did not have an impact on driver speed or headway keeping over time, drivers (specifically males) received fewer FCW alerts over time while in the study; however this change was due to drivers changing the FCW alert sensitivity setting. No changes were observed in alert rate when accounting for the FCW setting. Since male drivers on average received a fairly high rate of FCW alerts (around 4 alerts for every 100 miles they drove), they likely changed the sensitivity setting due to a desire to receive fewer alerts. Note that the failure to find a change in driver headway and the higher alert rates for males is consistent with the study by Jermakian, Bao, Buonarosa, and Sayer [15].

6.2.2 Conflict Analysis

The Volpe Center measured both the number of conflicts and the responses to conflicts across changes in exposure (1,000s of vehicle miles and months). There was a statistically significant decrease in the conflict rate when the conflict rate is normalized by miles or months between the initial and final conflict rates:

- The number of conflicts per mile decreased from a predicted 2.634 conflicts per 1,000 VMT during the first 1,000 miles to 0.615 conflicts per 1,000 VMT during the last 18,000 miles. This is a 76.6 percent decrease.

- The number of conflicts per month decreased from a predicted conflict rate pf 2.377 conflicts during the first month to 0.815 conflicts during the fourteenth month. This is a 65.7 percent decrease.

In addition, there was no change in any of the three different measures of responses to conflicts— average MinTTC, average PeakDX, MeanDX—using either miles or months as the measure of exposure. The trends were conflicting except for the change in the MeanDx. Over miles (and time) drivers' MeanDx decreased, though not significantly.

There are three findings of note. First, the Volpe Center believes this is the first study to show that conflict rates decrease with an increase in exposure. This study cannot determine the cause of this decrease in conflicts, but one possible explanation among several is the decrease in FCW alerts (discussed in Section 4.2.1.3). However, the results of the analysis by alert rate settings suggest that while alert rates did decrease over time, it was due to driver preference for less sensitive FCW settings, rather than a change in driver behavior. Regardless, the finding is consistent with the more general finding that FCW systems reduce property damage liability claims [16].

Second, the fact that there is no change in the response to conflicts when measured either as average MinTTC or as average PeakDx, indicates that drivers may have been truly surprised by the conflicts in which they are involved. Drivers are in fewer conflicts (as shown by the decrease in conflict rate), but conditional on a conflict occurring, they maintain the same level of PeakDx. This may make sense from a crash perspective. If drivers increased the PeakDx, they could cause a rear-end crash.

Finally, there is evidence of a increase in the MeanDx (it becomes less negative). However, it is slight and not significant. Again, this is consistent with drivers being surprised by the conflict, there being no evidencd of over time of a difference in the initial and final velocities of the vehicle during a conflict.

6.3 Driver Acceptance

The post-FOE survey results showed that drivers understood the FCW alerts, even after the first occurrence. Interestingly, the ratings of perceived usefulness of this system decreased from the pre-FOE survey to the post-FOE survey. Just under half of the participants rated the system as useful in the post-FOE survey. Comments received during the focus group discussions suggested that the alerts were, for the most part, either giving participants redundant information, since they had seen the vehicle ahead, or the system seemed to be inconsistent in issuing alerts.

However, while the usefulness of the system was relatively lower, 15 participants did report that they thought that the system had helped to avoid a total of approximately 30 collisions/incidents. And, even though the system was seen as inconsistent, approximately 84 percent of the drivers reported some degree of agreement (somewhat to strongly agree) with the statement that they trusted the system. There was a similar finding for the effectiveness of the alerts.

Approximately half of the participants rated the automatic braking events useful to some degree (though 13 percent indicated they found it useless). Focus group discussions indicated they thought it would be a useful system in crash situations and that it would be useful for distracted drivers. Many instances of automatic braking occurred in parking lots or backing up situations, and some of these instances frightened the drivers when they occurred. There were also false alerts when the system engaged for no apparent reason; in one instance, it occurred when a driver was under an overpass and it appeared to engage due to sun glare; in another, a driver was on a highway with essentially no traffic and it engaged (the driver believed it was because the system picked up a bridge abutment as an object). Two participants reported that the system did avert crashes by engaging correctly.

6.4 Limitations

There were five clear limitations to the study. First, this was a convenience sample. Drivers participated who chose to do so. The Volpe Center did not know whether drivers who chose to participate in an experiment like this differed in some fundamental way from drivers who did not choose to participate. Second, all of the drivers were 29 years old or younger. Studies have shown that drivers' responses to automation changes as a function of their age [17]. Third, there is a continuing controversy over the causes of crashes and near-crashes, with some researchers arguing that there is little relation between the causes of crashes and the causes of near-crashes [18], and others arguing that the relation is a strong one [19]. However, there is little argument that a measure of a particular near- crash (e.g., hard braking) can be predictive of a specific crash (e.g., rear-end), though not predictive of all crashes. As a corollary, the causes of a failure to brake appropriately can potentially help explain why drivers are involved in rear-end crashes. Fourth, there was no control group. Thus, the changes the Volpe Center observed in conflict rates across increases in exposure may have been observed in a group of drivers equipped with a new car and with no FCW alerts. Driver behavior improves over time; the changes that the Volpe Center believes can be attributed to driving with the FCW system may simply be due to drivers improving their ability to operate a new vehicle. Finally, the study was conducted using a 2013 production-level FCW and automatic braking system. There are many other similar systems available on the market; conducting the study using a different system may have produced different results. Additionally, given the current rate of technological advancement, improvements in collision avoidance technologies have likely occurred since the study was conducted that may impact driver response.

7 References

[1] Nodine, E., Lam, A., Stevens, S., Razo, M., & Najm, W. (2011). *Integrated Vehicle-Based Safety Systems (IVBSS) light vehicle field operational test independent evaluation* (Report No. DOT HS 811 516). Washington, DC: National Highway Traffic Safety Administration. Available at https://rosap.ntl.bts.gov/view/dot/9512/dot_9512_DS1.pdf?

[2] Sayer, J. R., Buonarosa, M. L., Bao, S., Bogard, S. E., Leblanc, D. J., Blankespoor, A. D., … Winkler, C. B. (2011, June). *Integrated Vehicle-Based Safey Systems light-vehicle field operational test methodology and results report* (Report No. DOT HS 811 482). Washington, DC: National Highway Traffic Safety Administration. Available at https://deepblue.lib.umich.edu/bitstream/handle/2027.42/84381/102750.pdf?sequence=1&isAllowed=y

[3] Najm, W. G., Stearns, M. D., Howarth, H., Koopman, J. & Hitz, J. (2006, January). *Evaluation of an automotive rear-end collision avoidance system* (Report No. DOT HS 810 569). Washington, DC: National Highway Traffic Safety Administration. Retrieved from www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2006/HS910569.pdf

[4] Kusank, K., Gabler, H., & Gorman, T. (2014). Fleetwide safety benefits of production forward collision and lane departure warning systems. *SAE International- Journal of Passenger Cars and Mechanical Systems*, *7*(2), pp. 514-527, 2014.

[5] Sullivan, J., Flanagan, M. J., Pradhan, M., & Bao, S. (2016, May). *Literature review of behavioral adaptation to advanced driver assistance systems* Washington, DC: AAA Foundation for Traffic Safety. Available at https://aaafoundation.org/wp-content/uploads/2017/12/BehavioralAdaptationADAS.pdf

[6] Johnson-Laird, P. (2006). *How we reason*. New York: Oxford University Press.

[7] Insurance Institute for Highway Safety. (2015, August 26). Stopping Power: IIHS Rates 20 New Models for Front Crash Prevention. Retrieved from www.iihs.org/iihs/sr/statusreport/article/50/7/1

[8] General Motors LCC. (2012). 2013 Cadillac SRX Owner Manual. Detroit: Author.

[9] Ayers, T., Li, L., Schleuning, D., & Young, D. (2001). Preferred time-headway of highway drivers In *IEEE Intelligent Transportation Systems Conference Porceedings*.

[10] Simons-Morton, B., Zhang, Z., Jackson, J., & Albert, P. (2012). Do elevated gravitational force elements while driving predict crashes and near crashes? *American Journal of Epidemiology, vol. 175*, pp. 1075-1079.

[11] National Highway Traffic Safety Administration. (2013, February). Forward Collision Warning System Confirmation Test (Unnumber report). Washington, DC: Author. Retrieved from www.safercar.gov/staticfiles/safercar/NCAP/FCW_NCAP_Test_-Procedure_2-7-2013.pdf

[12] Cohen, J. (1969). *Statistical power analysis for the behavioral sciences*, New York: Academic Press.

[13] Merton. (1936). The unanticipated consequences of purposive social action. *American Sociological Review*, vol. *1*, pp. 894-904.

[14] Wilde, G. (1982). The theory of risk homeostatis: implication for safety and health. *Risk Analysis*, vol. *2*, pp. 209-225.

[15] Jermakian, J., Bao, S., Buonarosa, M., & Sayer, J. (2015). Effects of an integrated collision warning system on teenage driver behavior. Retrieved from the IIHS web site at www.iihs.org/frontend/iihs/documents/masterfiledocs.ashx?id=2108 [No longer available online]. Also published in the *Journal of Safety Research, Volume 61*, June 2017, Pages 65-75. https://doi.org/10.1016/j.jsr.2017.02.013[16] Highway Loss Data Institute. (2011, December). Acura Collision Avoidance Features: Initial Results, *Highway Loss Data Institute Bulletin, vol. 28*, no. 21.

[17] Ho, G., Kiff, M., Plocher, T., & Haigh, K. (2005). A model of trust and reliance of automation technology for older users. In *Association for the Advancement of Artificial Intelligence Fall Symposium*.

[18] Knipling, R. (2015). Naturalistic Driving Events: No Harm, No Foul, No Validity. In *Proceedings of the Eighth International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*.

[19] Guo, F., Klauer, S., McGill, M., & Dingus, T. (2010, October). *Evaluating the relationship between near-crashes and crashes: Can near-crashes serve as a surrogate safety metric for crashes?* (Report No. DOT HS 811 382). Washington, DC: National Highway Traffic Safety Administration. Retrieved from www.nhtsa.gov/DOT/NHTSA/NVS/ Human Factors/Safety Problem Identification/DOT HS 811 382.pdf

[20] Golembiewski, G., Jackson, S., Jeffers, M. A., Miller, S., Armstrong, C., & Kehoe, N. (2016). Field Operational Experiment and Data Analysis of Driver Adaptation to Crash Warning and Avoidance Products. Cambridge, MA:The Volpe National Transportation Systems Center.

Appendix A: Screener Survey

Thank you for your interest in the *Field Study of Driving and Vehicle Systems*. The following questions will be used to learn about you and your qualifications to participate in the field study. This survey should take between 10 and 15 minutes to complete. You must complete this survey in one sitting (you may not save it and continue later). You must complete the entire survey by <date>, or your name will be removed from the pool of potential participants.

---

1. [Multiple Choice] Soon, SAIC will splitting into two new companies, Blue Company (Leidos) and White Company (the future SAIC). Please select the company you will belong to after the split.
   - Blue Company (Leidos)
   - White Company (SAIC)
   - I am not sure

2. [Multiple Choice using dropdown selection] Please select your date of birth.
   - [Month]
   - [Day]
   - [Year]

3. [Dichotomous Choice] Please select your gender.
   - Female
   - Male

4. [Dichotomous Choice] Do you have at least 3 years of driving experience within the United States?
   - Yes
   - No

5. [Multiple Choice] Because of the nature of this field study, each participant's driving record will be reviewed. In addition to reviewing your general driving history for the past 5 years, the research team will also consider any occurrences of moving violations such as Driving Under the Influence (DUI) convictions, reckless driving violations, and hit-and-run violations. Please read the following responses and select the one that reflects your willingness to have your driving record checked. Upon enrollment into the study, you will have to complete a formal driving history request authorization.
   - I understand my driving record will be reviewed, and I wish to continue the survey.
   - I prefer my driving record not be reviewed, and I decline to continue the survey. [Note: Respondents who decline to continue will be redirected to exit the survey.]

6. [Multiple Choice] Please read this short summary of the field study. Should you enroll in the field study, you will be provided with more detailed information and given an opportunity to ask questions.

   When you are done reading this summary, please indicate your willingness to continue with the eligibility survey.

You will be provided a 2013 Cadillac SRX to use during the duration of your participation that will last 3 months or more. After you receive the study vehicle, we ask that you use it as your primary vehicle for all trips. You will be required to care for the vehicle by having routine maintenance performed at an approved maintenance facility. However, you will not incur a personal expense for such routine care.

The vehicle will be equipped with a computer system used to record where and when you drive, as well as metrics like speed and braking. It will also be equipped with video cameras that will record your face, as well as views outside the vehicle (forward and to each side). A driver orientation session will describe these in more detail. During different periods of the study, some of the advanced systems in the vehicle will be turned on or turned off to meet the conditions of the study. However, you will always be made aware of this ahead of time. You will be required to attend appointments at approximately one-month intervals at the SAIC complex in Mclean, VA or at some mutually convenient location in order to have your vehicle equipment calibrated, data downloaded, or software updated (these appointments will be coordinated by the study team). At the conclusion of your participation, you will be required to complete at least 2 online surveys that will ask about your driving experience and reaction to the vehicle and its systems. The study team will also be conducting focus group meetings to further explore your opinions about your time in the study, and you will be encouraged to attend one of these meetings.

Vehicle insurance coverage will be provided by SAIC as long as the vehicle is used in compliance with the study requirements. As a participant, you agree that you will be the only person to operate the vehicle (although you may carry passengers) and will drive the car in a safe and legal manner, complying with all traffic laws. At the conclusion of the study, you will need to complete a short debrief by the study team and have the car inspected to ensure that you return it in the condition you received it (minus normal wear and tear, similar to the requirements for rental cars).

- I am interested in participating in the field study summarized above.
- I am no longer interested in participating in the field study.

7. [Multiple Choice using dropdown selection] Please consider the number of days each week that you expect to drive the field study vehicle (for at least one trip per day) and select the number below. Consider **all trips for work or other purposes** and keep in mind you will be the only person authorized to drive the vehicle.
    - [1 to 7]

8. [Multiple Choice using dropdown selection] Please consider the number of days each week that you expect to drive the field study vehicle **for work purposes only** and select the number below.
    - [1 to 7]

9. [Free Response restricted to accept zip codes] Please enter your home zip code in the box below.

10. [Multiple Choice] Consider your **work-related driving** in a typical week. Please select the one statement that best describes your work-related driving.
    - I drive to only one location 1-3 days per week.
    - I drive to only one location 4 or more days per week.
    - My job requires me to drive to multiple locations 1-3 days per week.
    - My job requires me to drive to multiple locations 4 or more days per week.
    - Other (please explain)

11. [Free Response restricted to accept zip codes; If respondent travels to a single location for work] Please enter your work zip code in the box below.

[Free Response: If respondent travels to multiple locations] Please enter the work zip codes of the locations you travel to in a typical week (separated by commas).

12. [Multiple Choice using dropdown selection] Consider the time of day that you most often leave **home** to go to work. Please select the time below.
    - [Hour]
    - [Minutes (on the hour and half-hour)]
    - [AM or PM]

13. [Multiple Choice using dropdown selection] Consider the time of day that you typically leave **work** to go home. Please select the time below.
    - [Hour]
    - [Minutes (on the hour and half-hour)]
    - [AM or PM]

14. [Free Response restricted to four digit whole numbers] Consider all trips for which you are the primary driver in a typical week. Include **both trips for work purposes and all non-work trips (e.g., shopping, recreation)**. Please enter the total number of miles driven in a typical week (rounded to the nearest mile).
    - **Back-up Assistance**: When the vehicle is in reverse, sensors or cameras alert the driver to the presence of objects to the rear.
    - **Forward Collision Avoidance**: These systems alert the driver when the vehicle is getting too close to one in front of it.
    - **Automatic Braking**: If the driver has not applied the brakes when a front crash is imminent, an emergency system applies the brakes for the driver. (Cruise Control does not need to be turned on for this to occur**.)**
    - **Adaptive Cruise Control**: When Cruise Control is turned on, this system maintains the following time/distance between your vehicle and a vehicle directly ahead.
    - **Adaptive Headlights:** These headlights help drivers see better on dark, curved roads by pivoting in the direction of travel based on steering wheel movement and sometimes the vehicle's speed to illuminate the road ahead.
    - **Antilock Brakes:** Antilock brakes prevent wheels from locking up and skidding during hard braking by monitoring the speed of each wheel and automatically pulsing the brake pressure on any wheels where skidding is detected.
    - **Lane Departure Warning**: These systems track the vehicle's position within the lane, alerting the driver if the vehicle is in danger of inadvertently straying across lane markings.
    - **Blind Spot Detection**: Vehicle sensors are used to monitor the side of the vehicle for vehicles approaching blind spots.
    - **OnStar®**: Subscribers have the ability to connect to the system and ask an Advisor to download a destination into the built-in navigation system or provide other information.
    - **Bluetooth® Voice Recognition**: This system allows for hands-free operation within navigation, audio, phone, and/or weather applications.
    - **Built-in Navigation System**: Map and routing information is integrated into the vehicle.
    - **Satellite Radio**: This service provides digital radio reception.

15. [Matrix Multiple Choice] Please think about any vehicles you have owned, leased, borrowed, or rented in the last 3 years. Also, please think about any vehicles you may have traveled in as a passenger in the last 3 years. Different vehicle features are listed above. Please read the list carefully, and for each feature, consider whether any of these vehicles were equipped with the feature (regardless of whether it was a standard feature or purchased as an option at an additional

cost). Have you traveled in (either as a driver or passenger) any vehicles in the last 3 years that were equipped with this feature?

- No.
- Yes, as a driver.
- Yes, as a passenger.
- Yes, as both a driver and a passenger.
- Not sure.

16. [Matrix Multiple Choice; Limit list to only those features for which the participant was a driver ("Yes, as a driver" or "Yes, as both a driver and a passenger")] For each feature listed below, please describe how long you **had access to** any equipped vehicle (and this feature) during the last 3 years. Select the response which most accurately reflects your experience. For example if you rented a car equipped with back-up assistance for 2 weeks last year, you would select "Less than 1 month."
    - Less than 1 month
    - 1-12 months
    - More than 1 year

17. [Matrix Scale; Limit list to only those features for which the participant was a driver ("Yes, as a driver" or "Yes, as both a driver and a passenger")] For each feature listed below, please describe how often you **used or otherwise engaged with** the feature. Select the response which most accurately reflects your experience. For example if you drove a vehicle equipped with back-up assistance but don't recall hearing a warning sound, you would select "Never."
    - Never
    - Once or twice
    - Sometimes
    - Very often

Appendix B: Background Driving Survey

Thank you for agreeing to participate in the *Field Study of Driving and Vehicle Systems*. The following questions will be used to learn more about you and your driving background. This survey should take between 15 and 20 minutes to complete. You must complete this survey in one sitting (you may not save it and continue later). Please complete the entire survey by <date>.

1. [Multiple Choice using dropdown selection] At what age did you obtain your first driver's license?
    - [Age (in years 15 to 26]

2. [Free Response] What is your occupation?

3. [Multiple Choice] What is your gross household income? In this case, gross household income refers to the income earned before taxes by an individual or an individual and spouse/domestic partner. Please do not consider income of roommates or parents in your household.
    - Less than $25,000
    - $25,000 to $49,999
    - $50,000 to $74,999
    - $75,000 to $99,999
    - $100,000 to $124,999
    - $125,000 or more

4. [Multiple Choice] What is the highest level of education you have completed?
    - Some high school
    - High school diploma
    - Some college
    - Associate's degree
    - Bachelor's degree
    - Some graduate school
    - Graduate degree (e.g., Master's, Doctorate)

5. [Multiple Choice] How many different vehicles do you currently drive on a regular basis (at least once per month)? Please consider vehicles you own, lease, or borrow on a regular basis.
    - 0
    - 1
    - 2
    - More than 2

6. [If respondent reported driving no vehicle, then no question will be asked about the type of vehicle]

    [Free Response with three fields; If respondent reported driving one vehicle] Please enter the year, make, and model of the vehicle you currently drive.
    - Year
    - Make
    - Model

[Free Response; If respondent reported driving two or more vehicles] Please enter the year, make, and model of the vehicle you currently drive most often (your **primary vehicle**).

- Year
- Make
- Model

[Free Response; If respondent reported driving two or more vehicles] Please enter the year, make, and model of the vehicle you drive as a **secondary vehicle**.

- Year
- Make
- Model

7. [Multiple Choice; For each vehicle reported] Approximately how many years have you driven this vehicle on a regular basis (at least once per month)?
    - Less than 1 year
    - 1-2 years
    - 3-4 years
    - More than 4 years

8. [Matrix Scale: List features for which respondents reported having "used or were otherwise engaged with" a feature at least "once or twice"(Screener Question 17)] On a previous questionnaire, you reported using several vehicle features in the past. For each of these features listed below, please indicate how **useful** you found the feature. Here, the word **useful** means that the feature made your driving experience better in some way, either making your trips more enjoyable, making it easier to get around, or improving safety and comfort.
    - Not at all useful
    - Not very useful
    - Somewhat useful
    - Very useful

9. [Matrix Scale; containing all possible features and not just those used by the respondent in the past] The following list includes vehicle features, some of which you may have used in the past and some of which you have not. Please imagine you are buying a new or used vehicle. Select the response that best indicates your desire to own a vehicle with each feature in the list below.
    - I don't care one way or the other.
    - I do not want this feature on my vehicle.
    - I want this feature, but only if it is standard and I do not have to pay additional money for it.
    - I want this feature, but it would depend on the cost of adding it as an option.
    - I want this feature and cost would not be an issue.

10. [Free Response; No forced response] Please use the following box to provide the field study team with any additional information you'd like to share.

Appendix C: Orientation Script

[Title Slide]

Good afternoon,

Thank you again for participating in this important project and for your patience throughout the development and selection process. At this orientation we will cover all the information you need for the study. We'll go over a description of the car and its basic operation as well as the driver assistance systems that are on the car. In addition, we'll cover the processes and procedures for the study (such as how we will download data), information regarding what to do in case of a crash or other incident (which we hope will be a rare occurrence), what to do in case you have any questions during the study, and a reminder of your responsibilities while you're in the study. As we go through this orientation, please feel free to ask any questions you may have.

My name is Gary Golembiewski. I'm the project manager –and we have a number of project members here. Nick Kehoe is our participant coordinator – he's the person who you've been calling/emailing over the past few months to confirm your information and coordinate all the activities. For the duration of the project, he'll be your main point of contact for all information on the project.

OVERVIEW OF THE PROJECT

As you might remember, from the initial ISSAIC announcement and from the screener survey, this is a field study of driving in different types of traffic and on different roadways. All of you here are participating in the same study but some of you will be driving for 3 months and some for 12 months. We at Leidos (SAIC) are working with the Volpe National Transportation Systems Center of the U.S. DOT. The National Highway Traffic Safety Administration (NHTSA) is the sponsoring agency. The overall goal of the study is to develop a data set that will contain driving data (your speed, brake use, lane position, etc.) and video recording inside the vehicle while you drive. This study is a naturalistic driving study, meaning that you are to drive the cars as you would normally drive outside of this project.

The study design and data security procedures have been reviewed and approved by an independent board that is responsible for reviewing research protocols involving human participants. Their review ensures that your rights as participants are protected and that information about you is kept confidential.

For the study, at the start, we expect that you will be getting used to how the vehicle handles, its different features, and the different systems. Therefore, the first three weeks are basically a period to for you to become familiar with the car.

And, the car is equipped with a number of driver assistance systems, not all of which will be activated during the first three weeks. We'll describe them in a moment. And, during these first three weeks, we'd like you to not change any of the settings for these systems.

At the end of week three, we will be scheduling the first of the video data downloads, which requires us to swap out the hard drive in the car. You will be contacted by Nick Kehoe to confirm where your car is located and a member of the study team will go to your car to swap out the drives. At that time, we will ensure that all driver assistance systems are activated.

Now, we'll discuss the systems and the study process in more detail now.

OVERVIEW OF THE CADILLAC SRX

For this project, we have leased 2013 Cadillac SRXs. The choice of this car was based on a number of factors, including our ability to access the on board computers to retrieve the data we need and the different systems that are included on the vehicles.

This orientation session will give you a good idea of how the vehicle and the driver assistance systems work, but it will not be an exhaustive training of the entire vehicle's operation. I strongly recommend that you read the manual as soon as possible to fully acquaint yourself with the car's features and systems. There are a lot of features, systems, and settings that you'll have control over. So, by reading the manual you'll know exactly how to navigate through the infotainment system, how to operate the radio and climate control, and you'll understand all the other functions and settings.

The *basic* operation of the vehicle is similar to any car; we will do a short "walk through" with a car in the parking lot after this presentation to acquaint you with the basic features so you'll be able to get on the road. Beyond the basic controls, there are other systems that we'll review.

Infotainment System [Picture]

The infotainment system has a home screen and options to adjust the climate control system, personalize audio features, obtain weather information, customize the settings for the driver assistance systems, provide navigation assistance, and other functions. Please familiarize yourself with this system. A separate Infotainment manual for this is included with the owner's manual.

OnStar [picture]

You will have the option to subscribe to the OnStar system for free while you are a participant. This is a comprehensive, in-vehicle system that can connect to a live advisor able to provide emergency, security, navigation, connection, and diagnostic services. Please see Section 14 of the driver's manual for information on how to activate the OnStar system. If you already have an OnStar subscription, you should contact them for procedures on how to transfer the subscription to the new vehicle.

DRIVER ASSISTANCE SYSTEMS

[List of the Systems]

The descriptions presented here are <u>very general overviews</u> of the systems' functions and displays. We're presenting them here since you may not be familiar with them in your current vehicles. This overview isn't intended to provide you with all the information you will need to understand how the systems work – I encourage you to read the owner's manual for more information.

Adaptive Cruise Control [picture]

Adaptive Cruise Control allows you to select the cruise control set speed and the following gap. The following gap is the following time between your vehicle and a vehicle detected directly ahead in your path moving in the same direction. If a vehicle is detected in your path (indicated by a green vehicle icon near the speedometer), adaptive cruise control can apply acceleration or limited, moderate braking to maintain the selected following gap. Essentially, this system maintains that gap between you and the car in front of you.

Forward Collision Alert [picture of car icon]

The Forward Collision Alert will alert you if you are closing in on a vehicle ahead too quickly and are at risk of rear ending it. In that case, the forward collision alert provides a flashing alert reflected onto the windshield and will pulse the driver's seat or issue an auditory beeping. The forward collision alert system only works if it detects that there is a vehicle ahead. Detection of a vehicle is indicated by a green-vehicle icon near the speedometer. This system also provides a visual alert when you follow another vehicle too closely—in that case, the green vehicle icon would turn yellow.

Lane Departure Warning [picture of alert]

The Lane Departure Warning provides an alert if your vehicle crosses into another lane without using a turn signal. This warning system is based on a camera sensor that detects the lane markings on the road. When the alert goes off, you will feel three pulses from the left or right side of the seat. The side of the seat from which the pulses emanate indicates the direction of your lane departure.

Park Assist and Rear Vision Camera [picture]

The car will provide feedback to you when you are parking, or when you are pulling forward or backing up at very low speeds. The feedback comes in the form of a visual indicator behind the steering wheel that tells you how close you are to nearby objects, and which warns you through seat pulses when you are getting too close.

The vehicle is also equipped with a Rear Vision Camera, which provides a camera view of the area behind the vehicle on the Infotainment screen when the vehicle is in reverse.

As part of the Park Assist system, the vehicle also provides Rear Cross Traffic Alerts, which assist you when you're reversing out of a parking spot or elsewhere by identifying objects or other cars that may be crossing behind your vehicle. These alerts are shown on the Infotainment screen with the RVC view and also by providing seat pulses.

Side Blind Zone Alert [picture of alert on side view mirror]

The Side Blind Zone Alert is a lane-changing aid that alerts you when another vehicle is present in your side blind zone (or spot) area. The side blind zone alert sensor covers a zone of approximately one lane over from your vehicle.

As you can see, there is a lot of information to digest. And these systems do have some limitations. For instance, the adaptive cruise control's performance may be limited in poor visibility conditions; and the lane departure warning system may not detect lane edges when the lane markings are faded.

You will have the option of personalizing a number of the system's features, such as the seat position, lighting level, language, type of displays for the system alerts, climate controls, etc. For all the driver assistance systems, the cars currently have the default settings selected—that is, a visual alert, such as a warning light or icon; and a haptic alert that provides seat pulses. Again, until the first hard drive swap, please do not change any of the settings on the driver assistance systems; and during this time, not all of these systems will be active.

DATA COLLECTION

[Data Collection Slide]

The data collection system consists of a computer, a hard drive, a cell card mounted in the glove compartment; and four cameras mounted in the cabin. When we do the vehicle "walk through" in the parking lot we'll point out where these all are. Since the data collection system is mounted in the glove compartment it will be locked and we ask that you not open the glove compartment. In addition, there is a cable on the floor to the left of the brake pedal that connects the car's computer to the data collection system. In order for the system to work properly, this cable must not be disconnected. It is labeled to alert any mechanics who may do maintenance on the car to re-connect it if they have disconnected it.

The data collection system is only activated when the car is running. And, you'll hear a few beeps from the system when the car is turned on and again when it's turned off.

Again, all the data that we collect are stored on secure servers that will only be accessible to members of the study team, including the teams from the Volpe Center and NHTSA.

We will be collecting three types of data:

First, the ***Vehicle Data***

The vehicle data that we collect will be uploaded to our secure server every morning at about 3 am. We will be monitoring the upload process to ensure that all required data are being transferred as planned. If we notice any issues with this process, Nick Kehoe will contact you to determine what the issue might be so that we can resolve the problem.

2nd, ***Video Data***

Video data is stored on a hard drive inside the glove compartment. Because of the large size of the data, not all information can be uploaded using the cell link. Instead, we will need to swap out these hard drives with empty new for you on a periodic basis.

This needs to be done about every four weeks. The first hard drive swap is scheduled about three weeks from now, during the week of August 12th. For these swaps, Nick Kehoe will contact you to confirm your car's location and the study team will perform the hard drive swap. We are not going to use the video data to assess your driving skills; our focus is on the car's technology and your interaction with them. And, we're only looking at specific situations with the video.

3rd, we will collect ***Survey and Focus Group Data***

You will be required to complete surveys at the beginning and at the end of your participation. These surveys will ask you a number of questions about your driving experience and should each not take more than 30 minutes to complete. Nick Kehoe will contact you with the information needed to complete them.

We will also conduct focus groups near the end of the study to get more in-depth information through discussion about your experiences. Again, Nick Kehoe will contact you regarding this.

We would also like you to keep a driving diary (show the example). Since there may be specific comments or opinions you have regarding your driving experience throughout the study, we would hate for you to forget them before you've had a chance to complete the survey. Please record these impression/opinions on a regular basis (perhaps weekly or bi-weekly) and we will collect the diaries when your participation has ended.

Finally, at the end of your participation, we will conduct a short de-brief when we meet you to get the keys to the car.

GENERAL RESPONSIBILITIES

[slide with a list, surveys, possible recording of participants, insurance, vehicle maintenance]

Surveys

As I'd mentioned earlier, there are two surveys to complete, the first one is about your driving background. Nick Kehoe will send you a link to access the survey site. Please complete this survey in the next five days. Additional information about the second survey and focus group meeting will come later in the study.

Possible Recording of Your Passengers

Because of the way the cameras are installed there is a possibility of recording passengers in your car. It is your responsibility to inform your passengers of this, but also inform them that the data are secure and that no one outside the study team, which includes the Volpe Center staff and the NHTSA staff, will have access to the data.

Cost To You

You are responsible for gas, tolls, parking tags (and any citations you may get). If you have an EZ-Pass account, EZ-Pass will allow you to change vehicles to your account, so please contact them to make this arrangement. In addition, we have the Velcro mounting strips if you need them.

Insurance

We will cover all insurance costs, including the deductible, with project funds. But remember, you are the only person who is to drive the car.

Vehicle Maintenance

Basic vehicle maintenance is covered under our leasing agreement. You can have the vehicle maintained at any service station you would like. When you have maintenance performed, please present the maintenance card to the service station staff so it can be billed correctly because each maintenance card is linked to a specific car and can only be used with that car. (The maintenance cards are in the center console storage).

<u>Oil Changes</u> – Required every 6,000 miles. Nick Kehoe will send a reminder message; in addition, a "Change Engine Oil" message will appear on the vehicle's display when the oil needs to be changed. Please see the owner's manual for more information.

<u>Tire Rotation</u> – Required and could be done at the same time as the oil changes, which may be more convenient; Nick Kehoe will send a reminder message when this needs to be done.

<u>Roadside Assistance</u> – The leasing agreement covers roadside assistance through AAA. Details for the coverage and contact information are on the maintenance cards that are in your vehicle.

<u>Virginia Safety Inspections</u> – The cars have their safety and emission inspections completed. If you are in the group driving for 12 months, you will need to have an inspection completed – please check the inspection sticker date to determine when it needs to be done. In addition, Nick Kehoe will send you a reminder message. You will be reimbursed for the cost of the inspection.

<u>General Care of the Vehicle</u> – You are required to return the vehicle in the same condition as it was delivered to you, except for normal wear and tear (please care for these vehicles as if they were your own).

[Slide with bullet list]

PROCEDURES FOR EMERGENCIES

If you are involved in a crash, your first priority is your safety and the safety of your passengers. If there are any injuries, seek immediate medical attention (if On-Star is activated, it will automatically connect to help in most crashes – again, please read the manual to acquaint yourself with the system).

Within 24 hours of the crash, you are required to complete the claim report form [**show picture of the form]** and call Nick Kehoe (his contact information is also in the owner's manual and on the form). Should you be in a crash which injures a third party or damages a third party's property, you are required to notify the police department immediately.

SUMMARY

Reminder of your responsibilities

1) Read the manual
2) Only you can drive the car
3) Drive as you normally would
4) Complete the driving background survey in the next five days
5) Remember to log any opinions/comments in the diary
6) Monthly data downloads will be required, starting the week of August 12th; (you will be reminded of the dates by Nick Kehoe)
7) Report any malfunctions you may notice to Nick Kehoe
8) Report any crashes/damage within 24 hours to Nick Kehoe; and you must fill out the claims form
9) Have regular, routine maintenance performed; this includes oil changes at approximately 6,000 miles (and the car will generate a message when the oil change is recommended) and tire rotation at the same time
10) You are responsible for paying for gas, tolls, and any fines/citations you may receive
11) The car is to be returned in the same condition it was when you took delivery

Documents/Materials

Except for the vehicle registration card (which is in the center console), you should have these materials in front of you:

Owner's manual
Maintenance card
Proof of insurance certificate
Insurance claim process instructions and form
Driver diary
Contact Information for Nick Kehoe and Kathleen Hudgins, his backup. Their cards are in the slots in the owner's manual.

Finally, please feel free to contact Nick Kehoe (or Kathleen Hudgins) if you have any questions regarding the car or your participation in the study. If needed, he will forward your questions to the members of the study team. You can contact Nick at any time, but please use email as your primary medium. For all non-emergency issues, he will get back to you during normal business hours.

Again, we would like to thank you for participating in this study. We hope you will enjoy the experience and your participation will give us valuable information on driving patterns.

Any questions?

Now, we'll go out to the cars and do a walk through

CAR DEMO/WALK THROUGH

All of your cars are parked in the lot outside the Enterprise building – you may have seen them on the way in.

[as we walk to the car, we will show the keyless entry system and then open all doors so everyone can see what we're discussing]

Will show the participants the following features/options:

Center console storage – where all the documents and the owner's manual is stored.

Mirror adjustment – the mirror control pad is located on the arm rest of the driver's seat; adjust by selecting each mirror (Left or Right) and use the arrow controls to move the mirror up/down/left/ right.

Seat adjustment – there are three controls on the left side of the driver's seat that allow you to move the seat forward or back; raise or lower the front part of the seat cushion; and raise or lower the entire seat.

Windshield wiper control – located on the right lever behind the steering wheel; there are three speeds (hi, lo, intermittent); this also controls the rear window wiper control.

Headlight settings – on the instrument panel on the left side of the steering column; we recommend keeping the headlights on the "automatic" position.

Infotainment system screens – start at "Home" and scroll through the different screens to explain how to navigate for climate control, the radio, safety settings, etc.

Explain the rear view camera and the haptic (seat pulse) alerts.

Appendix D: Participant Informed Consent

Study on Driving Patterns

In accordance with 45 C.F.R., Section 46.116, relating to the Protection of Human Subjects in Research, your informed consent for participation in the Leidos Study of Driving Patterns is required.

The following information reflects the data management and protection practices approved by the Leidos Institutional Review Board (IRB; #FWA0001115). The data, as discussed below, will be stored on secure, password-protected servers and will only be used for data analysis by the members of the study team. Leidos will retain data for three years, consistent with the policies of the Leidos Institutional Review Board.

Please consider the following information in reaching your decision whether or not to consent to participate. Your participation is completely voluntary. As a Leidos employee, your participation is not to be considered a direct project assignment. Your participation will have no impact on your employment status, performance review, or other aspects of your work life. As stated below, all data collected will be accessed only by the project team.

WHAT IS THE PURPOSE OF THIS RESEARCH?
In this study, we are collecting data on how people drive, especially in congested areas, such as the Washington, DC area. The information we collect will help illuminate the decisions drivers make, depending on the specific conditions they drive in, and how the car's equipment might impact those decisions.

WHAT SHOULD I KNOW BEFORE DECIDING TO PARTICIPATE?
To be eligible for this study, we must inspect your driving record. We will look only for information about Driving Under the Influence (DUI) convictions, reckless driving violations, hit-and-run violations, and other moving violations that occurred within the last three years. Our copy of your driving record and of the information used to obtain it will be destroyed if you do not participate in the study for whatever reason, or at the end of the study.

In order to participate in the study, we would like you to consider the items listed below.

1. You will be required to attend a Driver Orientation session, which will take about an hour and is where the study team will provide an overview of the vehicles and remind you of the study requirements. At least two sessions will be scheduled to allow for flexibility in attendance. We are planning to begin this study the first week of June, 2013.
2. You will be provided a 2013 Cadillac SRX to drive during the duration of your participation. After you receive the study vehicle, we ask that you use it as your primary vehicle for all trips. You will be required to care for the vehicle as you normally would, including having routine maintenance performed at an approved maintenance facility. If you use a facility approved under the lease agreement, regular service will not require

any out of pocket costs to you. When vehicles are assigned, you will be provided with a list of approved facilities.

3. The vehicle will be equipped with a computer system used to record where and when you drive as well as metrics like speed and braking. It is also equipped with video cameras which will record your face as well as views of the outside the vehicle (forward and backward). In addition, the camera views may capture images of your passengers – you are responsible for informing passengers of this possibility. Only members of the project team and the sponsoring U.S. DOT agency teams (The Volpe Transportation Systems Center and the National Highway Traffic Safety Administration) will have access to all collected the data (including all video data). The Driver Orientation session will describe this in more detail. Also, keep in mind that for some periods of the study, some of the advanced safety systems in the vehicle will be turned on or turned off, to meet the conditions of the study. However, you will always be made aware of this ahead of time. You will be required to have monthly appointments in order to have your vehicle equipment calibrated, data downloaded, or software updated (these appointments will be coordinated with the study's team). At the conclusion of your participation, you will be encouraged to complete an online survey that will ask about your driving experience and reaction to the vehicle and its systems. The study team will be conducting focus group meetings to further explore your opinions about your time in the study, and you are also encouraged to attend one of these meetings.

WHAT DO I HAVE TO DO IF I CHOOSE TO PARTICIPATE?

The project involves a data collection effort in which a data collection system containing sensors and cameras have been installed in the Cadillac SRXs. In order to participate, we ask that follow the following requirements:

1. You are the only driver of the vehicle.
2. Drive as you normally would, using the Cadillac as your primary vehicle.
3. Schedule an appointment with the study team liaison, Nick Kehoe, approximately every 4 weeks for data downloads.
4. Maintain the vehicle, including oil changes and tire rotation. The procedures will be explained at the orientation session.
5. Agree to be responsible for all tolls and any citations received.

WHAT HAPPENS WHEN THE PROJECT IS OVER?

At the conclusion of the study, you will need to complete a short debrief by the study team. You will also need to return the car to the study team and you are expected to return it in the condition you received it (minus normal wear and tear, similar to the requirements for rental cars).

WHAT ARE THE RISKS OF PARTICIPATING IN THIS PROJECT?

The risks of this study are minimal and similar to the risk you face when you operate your own vehicle normally. All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard or problem to you when you drive. The data collection system installed in the car will not affect the operating or the handling characteristics of the vehicle. There are non-driving risks associated with your participation. Four cameras have been placed in the vehicle. If you drive into an area where cameras are not allowed, including international border crossings, certain military and intelligence locations, and certain manufacturing plants, there is a risk you may be arrested or detained or that the vehicle may be impounded. For this reason, by signing this Informed Consent and thereby agreeing to participate in the project, you are also agreeing not to drive into any such areas while you are a participant.

Throughout the project, we will take all possible steps to protect your privacy and keep confidential your role in the project and the confidentiality of your personally identifying information.

WHAT DATA WILL BE COLLECTED?

The data to be collected on the on-board data acquisition system include driver/vehicle performance data and video data. The performance data includes a number of variables such as throttle, brake, and steering wheel positions as well as vehicle location, speed, and status of the forward collision warning system, and the automatic braking system. The video data includes a view of the driver's face, an over the shoulder view, and outside views of the vehicle on the back and front.

HOW WILL MY DATA BE KEPT CONFIDENTIAL AND SECURE? WHO WILL HAVE ACCESS TO MY DATA?

Any data collected during this project and personally identifies you or that could be used to personally identify you will be treated with confidentiality. As soon as you begin participating, your name and other identifying information will be separated from the raw data collected while you drive the vehicle and replaced with a number. That is, your raw data will not be attached to your name, but rather to a number (e.g., "Driver A1001"). The raw data collected while you drive the vehicle will be encrypted (i.e., made unreadable) and stored on secure central locations. Your name will also be separated from any data about you, either provided by you in response to questionnaires or gathered by researchers throughout the study and will be replaced by the same driver number (e.g., "Driver A1001").

Several types of information and data about you and the vehicle will be collected throughout the project period, including:

1. Contact Information – Including your name, address, email address, phone numbers, and similar information used to contact you when needed (such as to schedule data downloads). This information will be stored securely in electronic form during the course of the project and destroyed three years after the project is over (as required by our Institutional Review Board). This information will not be linked to or mingled with your study data, and will not be used in any research analysis.
2. Auxiliary Information – This includes your Social Security Number, driver's license number, driving record information, and similar data. This information will also be stored on a secure encrypted site during the course of the project and destroyed three years after the project is over. This information will not be linked to or mingled with your study data, and will not be used in any research analysis.
3. Driver Data – This includes your answers to questionnaires, the debriefing, and focus group discussion. These data will not contain your name or other identifying information and will be used in the analyses – separately, and in combination with the driving data. The data will be stored securely in electronic form during the course of the project.

4. Driving Data – This includes the data we collect from the vehicle while you are driving, including sensor and video data. This information will contain video of your face and GPS coordinates of your trips. These data will be encrypted and stored on a secure data storage site. These data will be used for analysis, both separately and in combination with the driver data. The data will be stored securely in electronic form during the course of the project.

Only authorized project personnel and authorized employees of the research sponsors will have access to project data that personally identify you or that could be used to personally identify you. As explained below, other qualified research partners may be given limited access to your driver data and driving data, solely for authorized research purposes and with the consent of the IRB. This limited access will be under the terms of a data sharing agreement or contract that, at a minimum, provides you with the same level of confidentiality and protection provided by this Consent Form. However even these qualified researchers will not be permitted to copy raw study data that identifies you, or that could be used to identify you, or to remove it from the secure facilities in which it is stored without your consent.

Project personnel, the project sponsors, and qualified, authorized research partners may show specific clips of video at research conferences. The project sponsors may show specific clips of video to the media, driver's education teachers and students, and others involved in efforts to improve highway and road safety.

It is anticipated that some of the data we capture throughout the course of the project will be a valuable source of data on how drivers respond to certain situations and how the roadway and the vehicle (and its systems) may impact driver safety.

WHAT ARE THE BENEFITS FROM PARTICIPATING IN THIS PROJECT?
While there are no direct benefits to you from this research, you may find this project interesting. No promise or guarantee of benefits is being made to encourage your participation. However, the project will help to improve the body of knowledge regarding highway safety, and participation may help us understand the impacts of vehicle design and roadway characteristics in future years.

WHAT ABOUT INSURANCE?
Vehicle insurance will be provided by Leidos. As a participant, you agree that you will be the only person to operate the vehicle and will drive the car in a safe and legal manner, complying with all traffic laws.

If you do experience any mechanical problems, crashes, or damage to the vehicle, you need to report that information within two days to the study team's participant liaison, Mr. Nick Kehoe (contact information for the study team will be included as part of the study packet you will receive at the orientation meeting).

AM I FREE TO WITHDRAW FROM THIS STUDY AT ANY TIME?
While we encourage you to participate for the full length of time you have agreed to, you are free to decline consent or to withdraw consent and discontinue participation in the study session at any time. The only requirement is the return of the vehicle.

HOW DO I PROVIDE MY CONSENT?

For Further Information:

If you have additional questions pertinent to this project, your rights as a participant, or any questions or issues you may have, please contact:

John Guglielmi, Project Manager
Volpe National Transportation Systems Center
Advanced Vehicle Technology Division, RVT-92
55 Broadway
Cambridge, MA 02142
(617) 494-3593

OR

Nicholas Owens, Human Protections Administrator
Transportation Solutions and Technology Applications Division
Leidos
11251 Roger Bacon Drive
Reston, Virginia 20190
(703) 318-4263

Privacy Act Statement (5 U.S.C. § 552a, as amended): AUTHORITY: Section 5306 of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, (P.L.109-59, Title V, 2005) authorizes DOT to conduct operational tests of intelligent vehicles as part of its intelligent transportation system research. PURPOSE(S): DOT will use the information provided to, determine participant eligibility, evaluate technologies used by drivers during the study, and identify driver behaviors, and for other purposes as described in the DOT Privacy Act Notice. ROUTINE USE(S): In accordance with DOT's system of records notice, DOT/RITA 001 – Vehicle and Driver Research, Test, and Evaluation Records, the information provided may be disclosed to, parties conducting research on behalf of DOT, government officials in order to determine the suitability of an individual to participate in the research activity, members of the DOT workforce including contractors, consultants and others performing work on behalf of the Department, and for other uses as described in the "Prefatory Statement of General routine Uses" (available at https://www.transportation.gov/privacy). DISCLOSURE: Provision of the requested information is voluntary; however failure to furnish the requested information may result in an inability of the Department to include you in the research activity.

The foregoing information has been presented and clearly understood by me, and I hereby voluntarily consent to participate in this project.

YES, I consent to participate in the study______NO, I do not consent to participate in the study____________

_________________________   _______________________   ____/___/___

Name (Print) Signature Date

_________________________________ ______________________________

Home Address

_________________________________ ______________________________

Work Address

(_____)________________________

Phone

Optional use of video images: I agree to permit the unrestricted use of the video recordings of my driving (continuous or single framed) to be used for scientific, educational, and outreach purposes. I am aware that these recordings will contain images of my face. I am aware that I may decline to permit the unrestricted use of the recordings without penalty or compromise to my participation in this study.

YES, I consent to allow unrestricted use of my video recordings_______NO, I do not consent to allow unrestricted use of my video recordings _____________

Signed: ____________________________________ Date: ____________________

Appendix E: Data Transfer and Processing

Trip Definition and Data Logging Setup

Power was supplied to the data acquisition system when the vehicle ignition was started. Data capture began when the vehicle traveled over 2 km/h, as measured by the GPS engine on the data acquisition system. Data capture ended when the vehicle ignition was turned off or if the vehicle sat idle for 600 seconds or more. These thresholds were set to prevent extensive logging of non-driving-related events. Each data capture event was referred to as a “trip.” For example, a trip would begin when a mother driving her children to soccer practice left the driveway and exceeded 2 km/h. The trip would continue until she turned the vehicle ignition off. However, after arriving at the practice fields, if she left the car running while she sat and watched practice, the trip would end after the vehicle remained stopped for 10 minutes. This would prevent extensive recording of vehicle and video data in the parking lot. The thresholds selected were intended to capture driving-related tasks, such as sitting in stop and go traffic, but prevent recording of parking lot or other idle-related vehicle tasks.

The data acquisition system setup file loaded on the system prior to the FOE start determined the thresholds described above, and other logging-related settings. This file specified various settings, such as trip start and stop, logging frequency, data element selection, video resolutions, etc. When an empty USB drive was installed on the data acquisition system, a folder named “media” was automatically created at the time that the first trip was saved to the USB drive. The file naming convention for the vehicle and video data files was determined by the logging settings. A vehicle ID (1-24) was created in the data acquisition system setup file so that the files saved for each trip were uniquely identifiable and contained a timestamp using the current time zone (Eastern) with daylight savings applied.

Other data acquisition system setup settings included the overlay of data elements on the four-quadrant video files. The four camera views were captured together in a single video file. The supporting data acquisition system software allowed data elements to be overlaid on the video when it was captured to support analysis. Note that the overlaid data elements needed to be set in advance and could not be changed or altered after data capture was completed. Figure 57 shows the four quadrant video overlay created for the FOE.

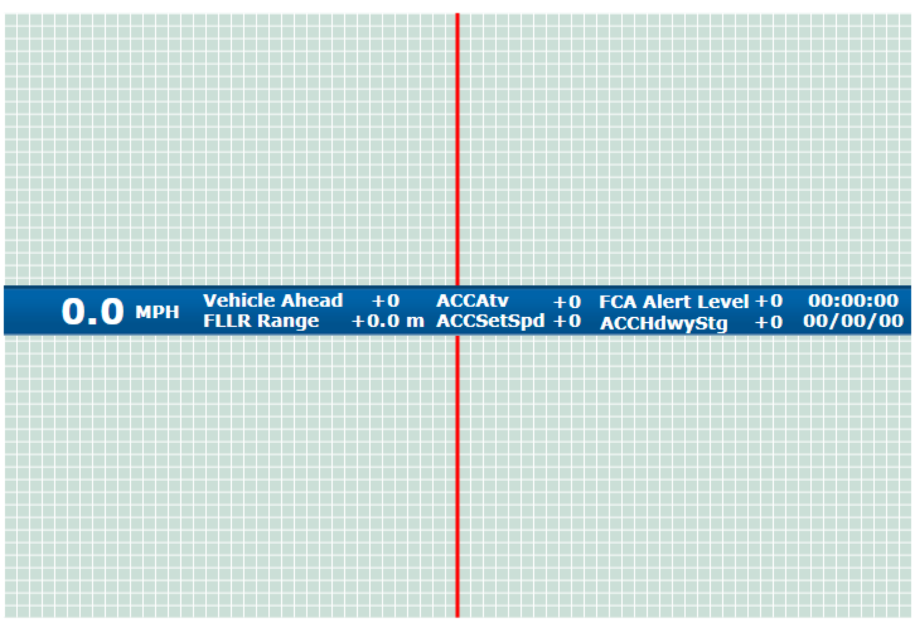


Figure 57. Four-Quadrant Video Overlay

The video and camera settings for the FOE included the format set to NTSC 720×480 and the video quality set to low. The four quadrant view was also set.

Data Monitoring and Transfer from Vehicle to Server

The data transfer approach combined the data accessibility and monitoring benefits of real-time data transfer via wireless communications with the data protection and cost-saving benefits of local storage on the vehicle. The FOE had a dedicated project server that handled all communication with vehicles for data monitoring and transfer, and processed incoming data into the FOE evaluation database.

The data acquisition system solution included a rugged Linux PC that supported access to all data on the vehicle within 24 hours of data capture. Figure 58 shows the data acquisition system architecture, where the "Computer" supported access to the "External' HDD (i.e., USB flash drive) and a cell antenna for wireless 3G communication. A 3G wireless card was installed in each vehicle with both an assigned cell phone number and a unique, static IP address. The project server used an e-mail text function to text message the cell number associated with each 3G wireless card. The "computer" remained in a standby state at all times until a text message was received by the onboard wireless card. When the message was received, an application developed for this study "woke up" the computer and established a secure connection with the project server via Secure Shell. For an additional layer of security the connection request from the vehicle also provided a unique key to access the server. The project server restricted access from all external connections, except for the approved list of static IP addresses.

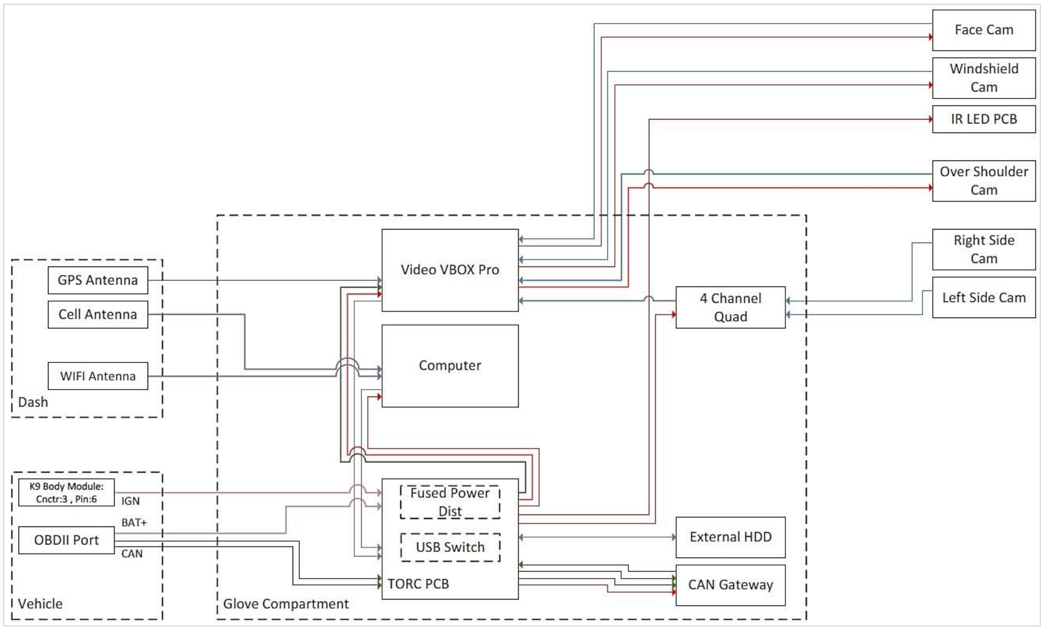


Figure 58. Data Acquisition System Architecture

Complete vehicle data files and screen captures of the video data files were transferred from the vehicle to the server each day. However, a copy of the vehicle data file remained on the vehicle's USB flash drive, along with the corresponding video data file. To collect and download the video data files from the vehicles, the research team performed hard drive swaps on each vehicle once a month. During this process, prior to the monthly hard drive swap, a team member dialed the vehicle manually to ensure the latest vehicle data was loaded to the server. A team member then unlocked each participant's vehicle using the available spare key, removed the USB flash drive from the data acquisition system, and replaced it with an empty USB flash drive to allow data collection to continue.

Data Reconciliation

The research team also developed a web application allowing researchers to log in and query the evaluation database. The web application synchronized numerical data with video data using video file timing offsets. These offsets allowed researchers to identify positions in streaming video data using data points (including timing information) generated from their database queries. The data acquisition system synchronized data obtained from the vehicle and GPS with video timing data using UTC time coordination.

Each data point was a row in a table and each row contained a control to play the selected data point as streaming video. Users were able to specify a lead-in time to the streaming video (e.g., 5 or 10 seconds before the start of the data point). Figure 59 provides a component overview for the data acquisition system and data transfer approach.

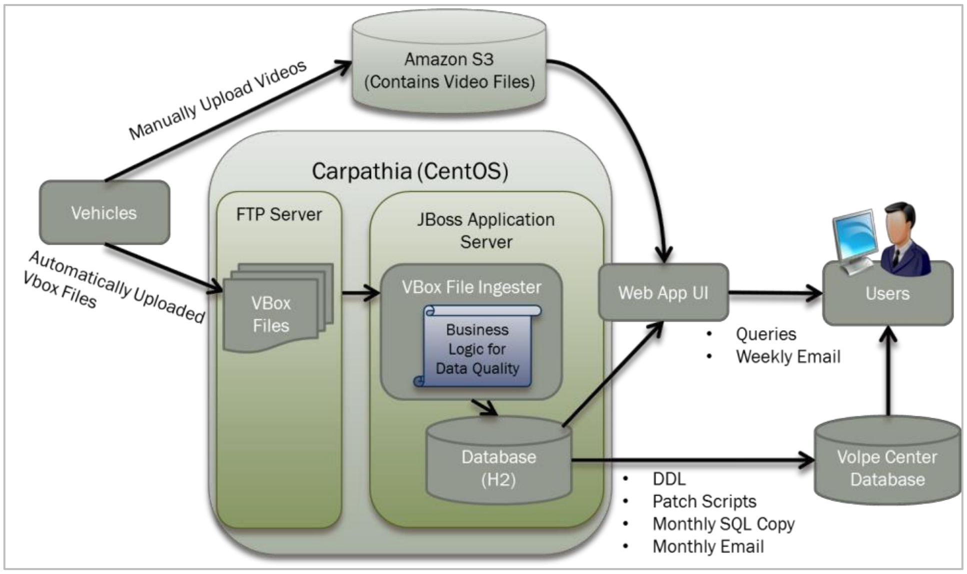


Figure 59. Component Overview

Figure 60 illustrates the system data flow and the data transfer and quality assurance process that was followed. “VBox” represents the vehicle data files generated by the data acquisition system. Each numbered box is described in the following list.

1. Vehicles generate data for Vbox.
2. VBox compiles data into VBox files and coordinated AVI video files.
3. VBox sends VBox files via FTP to Carpathia servers daily.
4. VBox File Ingester detects new files on Carpathia servers and parses.
5. VBox File Ingester performs data quality checks.
6. If data passes data quality checks it is added to the database.
7. If data fails data quality checks it is added to a quarantined database.
8. Quarantined data is inspected for issues and the Data Quality team creates an SQL script to remediate inconsistencies.
9. Every week Web App user UI users write queries to identify valid trips and trips with issues. These trips are included in a weekly email to the Volpe Center Contracting Officer Representative.
10. VBox video files are obtained manually from vehicles, compressed, and converted into M4V file format, and uploaded onto an Amazon S3 account.

11. After video data is uploaded, the video becomes accessible via streaming from the Web App UI after a user query to identify a data point they are interested in watching.

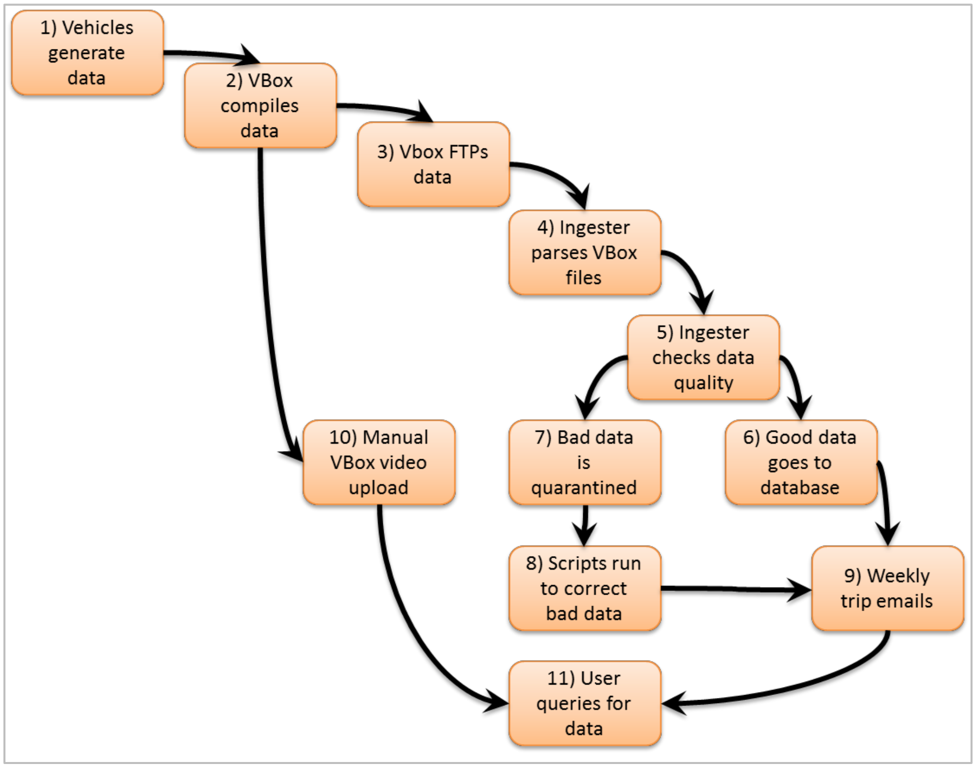


Figure 60. Flowchart of VBox Data Management

Prior to full equipment installation on all FOE vehicles, the research team conducted testing on one to two vehicles to confirm that data collection equipment functioned properly under a variety of conditions and was successfully collecting and transferring the necessary data elements. The primary focus of these activities relating to objective data elements was to confirm that:

- Data elements from the CAN bus were collected and decoded as expected;
- Camera positions and views were set up with minimal detection from drivers and minimal impact from conditions (i.e., usable video data was being captured during daytime, nighttime, and various weather conditions); and
- GPS data was logged effectively.

An understanding of the status of FCW and automatic braking system settings and how to record all events relating to both systems is essential to supporting data analysis for the FOE. To confirm that related data elements were captured, the research team conducted testing with a balloon vehicle, to safely trigger the crash warning and avoidance technologies on the vehicle without risk of an actual collision. Figure 61 shows photographs of the balloon car testing performed during May, June, and July 2013 with an FOE vehicle at the Federal Highway Administration’s Turner Fairbank Highway Research facility.

Figure 61. Balloon Car Testing Performed During May 2013

This testing allowed the research team to confirm the progression of alerts and the eventual triggering of brake preparation and automatic braking. The ability to capture the alerts and braking events triggered by the vehicle crash warning and avoidance systems, paired with objective driver performance and video data, provide powerful insight into driver response and adaptation to these systems.

Appendix F: Post-FOE Survey

Thank you for your participation in the *Field Study of Driving and Vehicle Systems*. The following questions will be used to learn about your experience and opinions during the field study. We ask that you keep the content of this survey confidential and not discuss it with anyone else who might be participating in the field study. This survey should take between 20 and 30 minutes to complete. You must complete this survey in one sitting (you may not save it and continue later). Please complete the entire survey by <date>.

1. [Matrix; Containing all possible features and not just those used by the respondent in the past] On a previous questionnaire, you reported using several vehicle features in the past. For each of these features listed below, please indicate how **useful** you found the feature. Here, the word **useful** means that the feature made your driving experience better in some way, either making
   - Not at all useful
   - Not very useful
   - Somewhat useful
   - Very useful

2. [Matrix; Containing all possible features and not just those used by the respondent in the past] The following list includes vehicle features, some of which you may have used in the past and some of which you have not. Please imagine you are buying a new or used vehicle. Select the response that best indicates your desire to own a vehicle with each feature in the list below.
   - I don't care one way or the other.
   - I do not want this feature on my vehicle.
   - I want this feature, but only if it is standard and I do not have to pay additional money for it.
   - I want this feature, but it would depend on the cost of adding it as an option.
   - I want this feature and cost would not be an issue.

The following questions are about situations in which **another vehicle is ahead of you** on the road.

The field study vehicle is equipped with a forward collision warning and avoidance system that provides various alerts regarding your position relative to a forward vehicle (the vehicle in front of you). Please think about **your personal experience** with this feature and how it operated as you drove the vehicle. There is no right or wrong answer. We are trying to learn how well this feature met **your** needs and how it might be better designed to assist you.

One aspect of the forward collision warning and avoidance system is the display on the dash which provides an indication of your following distance/time from the vehicle in front of you. The **vehicle-ahead indicator** displays a green vehicle icon when the system recognizes a vehicle in front of you. The system displays an amber vehicle icon when you are following a vehicle ahead much too closely. The two status icons as indicators are shown in the picture below, and the following questions refer to it. [The research team will insert a picture of the indicator.]

3. [Multiple Response] Please think about when you **first** noticed this vehicle-ahead indicator in the vehicle while you were driving, and select any of the statements your understanding of the indicator.
   - I am still not sure I fully understand the indicator.
   - I did not fully understand the indicator when I started driving the test vehicle and sought more information about it in the Owner's Manual and/or study team.

- I did not fully understand the indicator when I started driving the test vehicle, and I sought help from my friends or family.
- I did not fully understand it when I started driving the test vehicle, but I figured it out by simply driving more.
- The study team provided a good overview of the indicator, and it made sense when I started driving the test vehicle.

4. [Free Response; If respondent indicated they did not fully understand or does not understand] Please explain what information would have helped you to better understand how the indicator worked.

5. [Multiple Choice] The sensitivity of the vehicle-ahead indicator could be set to Far, Medium, and Near. How often did you change the sensitivity setting of the indicator during the entire field study?
   - I did not know you could change the sensitivity setting of the indicator.
   - I knew you could change the sensitivity setting but never did.
   - I changed the sensitivity setting at least once early in the field study (within first month) and then left it alone.
   - I changed the sensitivity setting occasionally throughout the field study depending on the driving situation.
   - I changed the sensitivity setting frequently throughout the field study depending on the driving situation.

6. [Free Response; If respondent changed the setting] Please explain your decision(s) to change the sensitivity setting (i.e., under what driving conditions did you change the setting).

   [Free Response; If respondent knew you could change the setting but did not] Please explain why you chose not to change the following distance.

7. [Multiple Choice; If participants reported knowing you could change the setting or actually did change the setting] What sensitivity setting did you prefer for most of your driving?
   - Far
   - Medium
   - Near
   - It depended on the situation.

8. [Free Response; If respondent selected Far, Medium, or Near] Why did you prefer this level of sensitivity?
   [Free Response; If respondent selected "It depended on the situation"] Please explain how you selected the sensitivity setting for the indicator. In what situations did you prefer Far, Medium, or Near?

9. [Multiple Choice] Please think about your **first month** driving in the field study. How often did you look at the vehicle-ahead indicator in a typical trip?
   - Never
   - At least once
   - Several times

10. [Multiple Choice] Please think about your **last month** driving in the field study. How often did you look at the vehicle-ahead indicator in a typical trip?

- Never
- At least once.
- Several times

11. [Multiple Choice] During your **last month** in the field study, how frequently did the vehicle-ahead indicator turn amber?
    - Not often enough
    - Just the right amount
    - Too often

12. [Multiple Choice] Did the frequency of amber indicators increase or decrease while you were driving in the field study? Consider the **first month and last month** you participated. Did the number of amber indicators increase, decrease, or stay about the same?
    - Decreased
    - Stayed about the same
    - Increased

13. [Multiple Choice] How useful did you find the vehicle-ahead indicator? Here, the word **useful** means that the indicator made your driving experience better in some way, either making your trips more enjoyable, making it easier to get around, or improving safety and comfort.
    - Not at all useful
    - Not very useful
    - Somewhat useful
    - Very useful

14. [Matrix; If respondents expressed that the indicator was useful] For any of the situations you experienced below, please select the response which indicates how useful you think the indicator was. Remember, the word **useful** means that the indicator made your driving experience better in some way, either making your trips more enjoyable, making it easier to get around, or improving safety and comfort.

Highway driving
Parking lots
When traffic was heavy
When I was tired
When I was distracted
Dark conditions
Roads with speed limits under 40 mph
Roads with speed limits over 40 mph
In light traffic
When fog was present
Roads with lots of intersections
Rural/country roads
Rainy conditions
Icy conditions
Unfamiliar roads
Roads I travel frequently
Other: [Free Response]
Other: [Free Response]
Other: [Free Response]

- Not at all useful
- Not very useful
- Somewhat useful
- Very useful
- No experience

[Note: These situation items were randomly ordered.]

15. [Free Response] Are there any ways in which you would change the vehicle-ahead indicator make it more useful? If so, please explain.

16. [Matrix] Please indicate how frequently you observed each of the following statements to be true.

The indicator unnecessarily distracted me from driving. The indicator kept me focused on driving and prevented me from being distracted. The indicator alerted me when I was not too close to the vehicle ahead of me. The indicator alerted me at the correct time that my vehicle was too close to the one in front. The indicator made me feel safer while driving.	• Never • Seldom • Sometimes • Often • Always

Another aspect of the forward collision warning and avoidance system is the **forward collision warning** that occurs if a crash is imminent unless the current speed is modified or the driver changes lanes. These warnings take three forms:

- Six red lights flashing on the windshield;
- Eight beeps played through the vehicle's sound system; and
- Five pulses of the driver's seat.
  [The research team will insert an image or images of this visual warning.]

Again, please think about **your personal experience** with this feature and how it operated as you drove the vehicle. There is no right or wrong answer. We are trying to learn about how well this feature met your needs and how it might be better designed to assist you.

17. [Multiple Choice] Think about the last month you have driven in this field study. How often did the forward collision alert provide you with warnings while you were driving?
    - I never received a warning
    - Less than once a month
    - Once a month
    - Several times per month
    - Several times per week
    - Daily

18. [Multiple Choice] Did the frequency of warnings increase or decrease while you were driving in the field study? Consider the first month and last month you participated. Did the number of warnings increase, decrease, or stay about the same?
    - Decreased
    - Stayed about the same
    - Increased

19. [Multiple Response] Please think about when you **first** received a warning in the vehicle while you were driving, and select any of the statements your understanding of what the warning meant.
    - I am still not sure I fully understand the why the warnings go off.
    - I did not fully understand the warning the first time I experienced it and sought more information about it in the Owner's Manual and/or study team.

- I did not fully understand the warning the first time I experienced it, and I sought help from my friends or family.
- I did not fully understand the warning the first time I experienced it, but I figured it out by simply driving more.
- The study team provided a good overview of the warning system, and it made sense when I first experienced it.

20. [Free Response; If respondent indicated they did not fully understand or does not understand] Please explain what information would have helped you to better understand how the warning system worked.

21. [Multiple Choice] How useful did you find the collision warnings? Here, the word **useful** means that the indicator made your driving experience better in some way; either making your trips more enjoyable, making it easier to get around, or improving safety and comfort.
    - Not at all useful
    - Not very useful
    - Somewhat useful
    - Very useful

22. [Matrix Scale; If respondent expressed that the warnings were useful] For any of the situations you experienced below, please select the response which indicates how useful you think the warnings were. Remember, the word **useful** means that the indicator made your driving experience better in some way; either making your trips more enjoyable, making it easier to get around, or improving safety and comfort.

Highway driving
Parking lots
When traffic was heavy
When I was tired
When I was distracted
Dark conditions
Roads with speed limits under 40 mph
Roads with speed limits over 40 mph
In light traffic
When fog was present
Roads with lots of intersections
Rural/country roads
Rainy conditions
Icy conditions
Unfamiliar roads
Roads I travel frequently
Other: [Free Response]
Other: [Free Response]
Other: [Free Response]

- Not at all useful
- Not very useful
- Somewhat useful
- Very useful
- No experience

[Note: These situation items were randomly ordered.]

23. [Free Response] Are there any ways in which you would change the warning system to make it more useful? If so, please explain.

24. [Multiple Choice; if respondent reported the warnings were useful] Which warning type was most useful in warning you about a possible collision with the vehicle ahead?
    - The visual warning (6 flashing red lights).
    - The auditory warning (8 beeps).
    - The seat warning (5 pulses).
    - A combination of the visual and auditory alerts.
    - A combination of the visual and seat alerts.
    - A combination of all three alert types (visual, auditory, and seat).

25. [Free Response] Please explain what you liked and disliked about the visual warning (6 flashing red lights)?

26. [Free Response] Please explain what you liked and disliked about the auditory warning (8 beeps)?

27. [Free Response] Please explain what you liked and disliked about the seat warning (5 pulses)?

28. [Matrix Scale] Please indicate how frequently you observed each of the following statements to be true.

The warnings unnecessarily distracted me from driving. The warnings prevented my distraction from causing a collision. The warnings alerted me when I was not too close to the vehicle ahead of me. The warnings alerted me at the correct time to keep me from colliding with a vehicle in front of me. The warning system made me feel safer while driving.	• Never • Seldom • Sometimes • Often • Always

The test vehicle was also equipped with an **automatic braking** feature that applies the brakes if the driver does not respond when a collision is imminent. Please keep in mind that this is an emergency braking system (not ABS or cruise control). This system would apply the brakes for you in any imminent collision situation.

Please think about **your personal experience** with this feature and how it operated as you drove the vehicle. There is no right or wrong answer. We are trying to learn about how well this feature met your needs and how it might be better designed to assist you.

29. [Multiple Choice] During your time driving the test vehicle, how often did automatic braking occur?
    - Never
    - Once or twice
    - Three or more times

30. [Multiple Free Response; For each time respondent reported that automatic braking occurred] Please describe in detail the conditions under which automatic braking occurred.
    a. On what kind of road were you driving? If you remember the roadway name, please include it in your description.
    b. What were the traffic conditions?
    c. What were the weather conditions
    d. About what time of day did the incident occur?
    e. What were you doing just prior to automatic application of the brakes?
    f. What did the vehicle ahead of you do?

31. [Multiple Choice; Regardless of whether the respondent experienced an automatic braking event] Even if you have never personally experienced automatic braking, how useful do you think the automatic braking system is? Here, the word **useful** means that the system makes your driving experience better in some way; either making your trips more enjoyable, making it easier to get around, or improving safety and comfort.
    - Not at all useful
    - Not very useful
    - Somewhat useful
    - Very useful

    [Matrix Scale; If respondent expressed that the automatic braking was useful] Please select the response which indicates how useful you think the automatic braking system might be in the different situations listed below. Remember, the word **useful** means that the automatic braking might make your driving experience better in some way; either making your trips more enjoyable, making it easier to get around, or improving safety and comfort.

    Highway driving
    Parking lots
    When traffic is heavy
    When I was tired
    When I was distracted
    Dark conditions
    Roads with speed limits under 40 mph
    Roads with speed limits over 40 mph
    In light traffic
    When fog was present
    Roads with lots of intersections
    Rural/country roads
    Rainy conditions
    Icy conditions
    Unfamiliar roads
    Roads I travel frequently
    Other: [Free Response]
    Other: [Free Response]
    Other: [Free Response]

    - Not at all useful
    - Not very useful
    - Somewhat useful
    - Very useful
    - No experience

    [Note: These situation items were randomly ordered.]

32. [Free Response] Are there any ways in which you would change the automatic braking system to make it more useful? If so, please explain.
    As you answer the following questions, please consider **the types of safety systems** described so far (the vehicle-ahead indicator, forward collision warnings, and automatic braking).

33. [Dichotomous Choice] True or False: I feel like I changed the way I follow other vehicles because of the collision warning and avoidance system.

34. [Free Response; if respondents answered "true"] How did you change the way you follow other vehicles because of the collision warning and avoidance system? How does your driving now differ from the beginning of the field test? Why?

35. [Dichotomous Choice] True or False: I feel like I collision warning and avoidance system helped prevent at least one crash while driving.

36. [Free Response; if respondents answered "true"] Please describe the circumstances in which you feel the system helped prevent a crash. How did the system help?

37. [Free Response; No forced response] Is there any additional information you would like to provide to the study team regarding your participation in this research?

Appendix G: Focus Group Protocol

Participants: TBD

Facilitator:

Date/Time: TBD/5:30 – 7:00

Note-taker:

Flip-board/Counts

Overview:

- Welcome/Introduction
- Overall reactions
- 1-Brainstorm and rank risky situations
- 2-Determine if/how car mitigated risk
- 3-Understanding of FCW feature
- 4-Understanding of automatic-braking feature
- 5-Adaptation
- Other questions/Closing

5:15-5:30 pm

Welcome (15 minutes)

- Reminder to study team to not interrupt unless invited.
- Study team, please help with counts and writing down voting.
- Participants will arrive, be greeted, and be seated. CHECK OFF NAMES
- Direct to refreshments.

5:30- 5:35pm

Introduction (5 minutes)

- Welcome and introduce study team in the room
- We'll be talking about the goals of the study tonight. The study is almost over, but there are a few more drivers left for us to talk to. Please don't discuss these goals/topics with others who still may be participating
- Inform them that we are **recording** the session (audio) and taking notes; won't be personally identifiable
- Location of bathrooms/food (feel free to get up during discussion).
- Mute cell phones.
- Introductions – first name, hometown, how long you've worked at SAIC/Leidos
- Ice breaker (e.g., car you drive now and dream car) (OPTIONAL)
- We are interested in your **personal experience** driving the Cadillac vehicle.
- There are no wrong opinions or ideas. We really want to get diverse feedback and we **do not need to reach consensus** as a group.

- For this reason, everyone needs to speak up and please indulge me if I call on you (gentle encouragement).
- As well, I may ask you to hold your point or otherwise move us along, so that we can stay on schedule

5:35-5:50

Overall reactions to the Cadillac (15 minutes)

- Car had a lot of special features, many of which you had not used before
- How do you feel now that you are driving a different vehicle than the Cadillac? Did you notice any changes in your driving as a result of being in the study and switching back? Explain.
- How long did this effect last?
- How do you think your behavior changed during study (something you did differently from beginning to end or as a result of an event while you were driving)?
- Focus of rest of our discussion today
    - The cars you drove during the study (Cadillac) had lots of features (as described in orientation). Some had to do with leaving the lane (lane departure warning) and some had to do with warning about objects in the blind spot (side blind zone warnings). And some others. We will talk about these later.
    - Now, we will focus on situations in which there is another vehicle ahead of you on the roadway.
    - Specifically, we are interested in situations where there is some risk of you colliding with something in front of you (regardless of through your own actions or that of another driver).
- Questions?

5:50-6:00

Topic 1 - Brainstorm and rank risky situations (10 minutes)

- Will move through this sort of quickly
- Don't focus on the car now. Think about driving in general
- What situations are risky (in the forward scene/involving a vehicle ahead of you on the road)?
- What do you worry about? Be specific about your position, the other car's position, the type of car/truck, etc. ahead, road type, surroundings. Ignore contributing factors now, like alcohol, distraction, weather.

  LIST THESE SITUATIONS

- Just think about driving in general. Maybe consider near misses or accidents in which you've been involved.
- Some examples to generate discussion
    - Stop and go traffic
    - Car ahead suddenly slows/stops or in traffic
    - Car ahead slows "too much" to turn

  - Car merges/changes lanes ahead
  - You merge/change lanes and there is a car ahead of you

- Which of these are the most risky in your opinion? ? Vote for the three risky situations – you can vote for 3 and only 3. Now vote for the one which is the most risky. Show of hands. COUNT
- Anything that contributes to these situations, makes them worse? Examples to generate discussion - distracted driving (you or other driver? Note everyone can get distracted, not just cell phone use, but just zoning out or talking to a passenger), sun in my eyes, fog, rain, ice, snow, night)

  LIST THESE CONTRIBUTING FACTORS

- Which of these are the most risky factors? Vote for the three risky situations – you can vote for 3 and only 3. Now vote for the one which is the most risky. Show of hands.

  COUNT

6:00-6:10pm

Topic 2 – Determine if/how car mitigated risk (10 minutes)

- Think about these situations we just discussed. What kind of systems/features did the study car (Cadillac) have that might in some way help with forward collisions? Specifically, warn you, prevent a collision or reduce severity. LIST **THESE** FEATURES
- Examples for discussion BRING UP IF NOT MENTIONED
  1. Tailgating alert/Vehicle-Ahead Indicator
  2. ACC
  3. FCW
  4. Automatic-braking
  5. (they may mention other systems, that's okay)
- Even if you didn't experience a feature, how do you think it worked? Describe how they function.
- For each, how do these work to prevent a forward collision? Describe (at a high level) when/how/under what circumstances? In what situation mentioned above?
- Please keep opinions to yourselves for now – just report how it works. We'll get to opinions later.

6:10-6:30pm

Topic 3 – Understanding of FCW feature (20 minutes)

- Recap how they defined FCW above
- If not included, discuss
  - How did you know you were getting a warning? Alert types (visual, auditory, haptic/seat vibration)
    - What was your preference?
    - Any you disliked?
  - What about the vehicle-ahead indicator (tailgating alert) Was that involved? Or related in some way?
  - What determined if you were too close to the vehicle ahead? Gap setting (far, medium, near)
    - What was your preference? Why?

- Did you experience this feature? (Raise hands)

COUNT

- EXERCISE 1:
    1. Please take a sticky note and a pen. Silent activity – don't discuss with your neighbor.
    2. Think back to your time driving the Cadillac. It's been a while – end of last summer, fall, winter, spring, and this summer.
    3. Think about the times that you got an FCW = warning with the red lights and vibration/sound. What is the most = greatest number of alerts you think you received in one day ever, in the entire 12 months?
    4. Write that on the note pad.

- EXERCISE 2:
    1. Hand out sheets and a pen.
    2. Write your name on the paper.
    3. Now write the number from the sticky note in the box on the top left.
    4. This is a chart, the axis on the left indicates the number of alerts you get <u>in one day</u>. The minimum is zero. The maximum is the number you just wrote.
    5. Now we are going to talk about averages or your typical experience with getting FCW alerts. Draw a line on this chart that shows the average or typical number of alerts you saw in one typical weekday.
    6. Examples= a constant amount? More in the winter? More early? More recently? Or all over the place?
    7. Let's see the charts. Why did you draw them this way?

- Think first about any <u>positive</u> aspects of the FCW feature. Did it help you in some way? (Pros to using)
    - Alert you
    - Prevent collision
- Did it hinder you in some way? Did you have a <u>negative</u> reaction? (Cons to using)
    - Distract you/surprise you
    - Cause you to react in a dangerous manner or cause different risk
- Did it ever fail to go off (<u>fail to give a warning</u> or a miss) and you think it should have?
- Did it ever give you a <u>false alarm</u> (it went off and you don't know why)?
- How many of you think that <u>all vehicles</u> should be equipped with this? (Raise hands) COUNT Why or why not?
- Ignoring cost for the moment, how many of you would want to have this feature on <u>your own car</u>? (Raise hands) COUNT Why or why not?
- If not your car, who should get it and why?

6:30-6:40pm

Topic 4 – Understanding of Automatic Braking feature (10 minutes)

- Recap how they defined automatic-braking above.
- Regardless of whether you experienced it or not, what do you think of this feature? Positives and negatives?
- If you observed the automatic braking in your driving, please explain the circumstances.
- Do you think the automatic braking was necessary in your situation? Did it help you by preventing a collision? (the collision would have occurred if not for this feature)
- Did it ever fail to go off (fail to give a warning or a miss) and you think it should have?
- Did it ever give you a false alarm (it went off and you don't know why)?
- How many of you think that all vehicles should be equipped with this? (Raise hands) COUNT Why or why not?
- Ignoring cost for the moment, how many of you would want to have this feature on your own car? (Raise hands) COUNT Why or why not?
- If not your car, who should get it and why?

6:40-6:50pm

Topic 5 – Adaptation (10 minutes)

- Thinking only about these two systems we just discussed – FCW and automatic braking
- Do you think that having them on the car and/or experiencing them, affected how you drove or reacted to some of the risky situations we discussed? Or how you thought about the driving task? How/why? Explain?
- How do you think that others might be affected by these systems if more widely available (i.e., change driving behavior)? (Drivers other than you, people you know, etc.)

6:50-7:00pm

Closing (10 minutes)

- Miscellaneous topics
  - Give me some feedback on the other driver assist systems not necessarily part of the forward collision situations (lane departure, blind zone, parking assist) – pros/cons and desirability (would you want this).
  - Study team, do you have any questions for the group?
- Any closing thoughts?
- Any questions? Feel free to stay around and talk to us for a few minutes or contact us later with thoughts, ideas, or comments.
- Thanks for coming.
- Please do not discuss the reasons/goals of the study with any people who are currently participating.

Appendix H: System Exposure Descriptive Statistics

Table 14. Vehicle Miles Traveled Descriptive Statistics by Test Group and Gender

Test Group/ Gender	Mean	sd	n	Max	Min
Long-term	11,034	2,491	11	15,772	6,379
Medium-term	8,509	3,584	14	17,658	4,067
Short-term	2,402	1,796	13	7,544	636
Female	6,292	3,607	20	2,362	636
Male	8,104	7,897	18	17,658	997

Table 15. Number of FCW Alerts Descriptive Statistics by Test Group and Gender

Test Group/ Gender	Mean	sd	n	Max	Min
Long-term	281.82	396.95	11	1446	36
Medium-term	181.50	229.01	14	748	18
Short-term	36.92	32.25	13	123	1
Female	78.15	316.00	20	310	12
Male	253.22	208.26	18	1446	1

Table 16. Number of Automatic Braking Events Descriptive Statistics by Test Group and Gender

Test Group/ Gender	Mean	sd	n	Max	Min
Long-term	2.18	1.89	11	6	0
Medium-term	1.93	1.69	14	5	0
Short-term	0.46	0.66	13	0	2
Female	1.15	1.23	20	4	0
Male	1.89	1.97	18	6	0

Appendix I: Video Coding Manual

This appendix lists all variables coded during the video analysis of safety application alerts and driving conflicts. The intent of the video analysis is to capture information that is not available in the numerical database or to validate the numerical data.

Introduction

This document defines the variables to be captured from the video recordings of the Field Operational Experiment and Analysis of Driver Adaptation to Crash Warning and Avoidance Products project. It also instructs on how to properly code the videos.

During both the baseline and testing phases, events are defined by any recorded instance of the forward collision warning system being activated. More specifically, an event consists of any time a forward collision alert is issued or when automatic braking occurs. Additionally, specific instances based on driver performance variables (e.g., time to collision, range, brake pedal activation, steering) during the baseline phase will serve as events because the forward collision warning system was turned off. Queries of the vehicle data database determined the onset of each event. Video is coded 10 s prior to the onset of each event and 5 s after. Thus, each segment of video will be 15 seconds in duration (150 frames based on the 10 Hz sampling rate of the data collection system).

Variable definitions and coding instructions are presented below. These have been developed using information contained in the *Safety Pilot Evaluation Light Vehicle Data Logger Attributes* document created by the Volpe National Transportation Systems Center.

Forward Target Location

Use the forward view to determine if a forward target is detected. Note whether or not the target is in the same lane or in the current path of the host vehicle at the time the alert was issued.

> *1. IN LANE:* Target vehicle is in the same lane as the host vehicle at the time the alert was issued. Target vehicle is considered to be in-lane if any part of the vehicle is in the host vehicle's lane at the time of the alert.
>
> *2. ONE LANE OVER:* Target vehicle was in the lane adjacent to the host vehicle. If the vehicle is between the adjacent lane and two lanes over, then code one lane over.
>
> *4. IN-PATH OBJECT:* Target is in-path, but is not a vehicle (e.g., object in roadway).
>
> *5. ROADSIDE/OOP OBJECT:* Target is a roadside object such as a sign post or Jersey barrier.
>
> *6. BRIDGE/OVERHEAD SIGN:* Target is a bridge overpass or overhead roadway sign.
>
> *3. OTHER:* All other scenarios that do not fit into the above categories. For example, if the target vehicle is in a parking lot. Describe details in the comment field.

Near Crash

Watch the full length of the video, paying particular attention to the driver's reaction to the alert. Use your judgment to determine if the scenario was a high-risk, close call scenario that required a driver response. For example, this would be the case if a driver swerved into on-coming traffic on a two-lane road in order to avoid a forward collision. If the scenario appears high risk but the driver does not respond in the video, then include a note in the comment section.

> *1. NO:* Scenario was not high risk and did not require a driver response (e.g., no target vehicle present, driving in a parking lot, target vehicle quickly moved out of lane, etc.)..
>
> *2. YES:* High-risk, close call scenario that required a driver response.

Pre-Crash Scenario

The pre-crash scenario describes the geometry and dynamics of the vehicles involved in the alert. If the scenario does not match any of the options, pick the best option and leave a comment regarding the decision in the comment section.

> *1. LEAD VEHICLE STOPPED:* Rear end crash scenario where the target vehicle is stopped. Select this code only if the vehicle is never seen moving in the video.
>
> *2. LEAD VEHICLE DECELERATING:* Rear end crash scenario where the target vehicle is decelerating (generally braking) or stopping.
>
> *3. LEAD VEHICLE CONSTANT SPEED:* Rear end crash scenario where the target vehicle is maintaining constant speed and the host vehicle is traveling faster than the target. Also code constant speed if the target vehicle is accelerating.
>
> *4. OTHER/UNSURE:* Pre-crash scenario description does not fit into one of the three above categories. If selecting this value, then include a note in the comments section.

Host Vehicle Maneuver

Record any intentional maneuver the driver performed immediately before the alert (1 second prior), or was performing during the time the alert was issued, based on the driver's actions and the front and side views.

> *1. GOING STRAIGHT:* Driver remains in only one lane, without making any maneuvers.
>
> *2. CHANGING LANES:* Driver executes a lane change to either the left or right on a multi-lane road just before the alert, is making a lane change at the time of the alert, or is showing intent to make a lane change (checking blind spot/mirrors). Blinker may or may not be used.
>
> *3. TURNING:* Driver is turning (either left or right) or bearing off from one road to another.
>
> *4. MERGING:* Driver is merging into moving traffic on another road or merging when a lane ends on the current road.
>
> *5. STOPPED:* Vehicle is stopped, not necessarily at a stop light (only select if vehicle does not move).
>
> *6. OTHER:* Any other movement that does not properly fit into the above categories.

Host Vehicle Position

Note the position of the host vehicle around the time of the alert (1 second prior).

> *1. STRAIGHT ROAD:* Vehicle is traveling on a straight road without any intersecting roads.
>
> *2. IN CURVE:* Vehicle is navigating a curve.
>
> *3. CURVE ENTRY:* Vehicle is approaching or just entering a curve.
>
> *4. CURVE EXIT:* Vehicle is exiting a curve or has just completed the negotiation of a curve.

Host Vehicle Lane Position at Time of Alert

Using the forward view, note the vehicle's location within the lane at the moment the alert was issued.

> *1. IN LANE:* Vehicle is maintaining travel in the lane or is initiating a lane change, but has not yet crossed the lane line.
>
> *2. BETWEEN LANES:* Vehicle is in the process of making a lane change maneuver or has drifted out of their lane.
>
> *3. IN ADJACENT LANE:* Vehicle has just completed a lane change maneuver and is completely in the adjacent lane.

Steering Response

Using the forward and cabin views, note whether the driver made any significant steering movements (larger than just minor corrections to remain on the current track) in response to the target vehicle (either before or after the alert).

1. NO: Driver did not make a significant steering movement in response to the target vehicle.

2. YES: Driver made a significant steering movement in response to the target vehicle.

Steering Response Time

If Steering Response was “YES” or “MAYBE,” then enter the video timestamp when the steering response was initiated.

Forward Target Maneuver

If a forward target is present, then note any maneuvers the vehicle is making within 1 second before or after the alert is issued.

1. NO FORWARD TARGET: No target vehicle could be detected.

2. MAINTAINING LANE: Target vehicle is traveling in its current lane without making any maneuvers. If the target vehicle is stopped, then code it as maintaining lane.

3. CUT IN: Target vehicle executes a lane change from an adjacent lane into the lane of travel of the host vehicle, or the target vehicle turns onto the roadway in front of the host vehicle (within approximately 5 seconds of the alert). Target vehicle may cut in from either direction.

4. CUT OUT: Target vehicle executes a lane change to an adjacent lane so that it is no longer in the same lane of travel of the host vehicle (within approximately 5 seconds of the alert). Target vehicle may cut out in either direction.

5. CUT IN AND OUT: Target vehicle executes a cut out immediately after a cut in (e.g., moves from one adjacent lane to the adjacent lane on the other side of the vehicle). Target vehicle may execute this in either direction.

6. TURNING OFF: Target vehicle is preparing to turn onto another road (is slowing) or is turning onto another road. Use blinker to help determine if the target vehicle intends to turn. Target vehicle may turn into either direction of travel.

Forward Target Road Position

Use the forward view to determine the characteristics of the road where the target vehicle is traveling at the time of the alert.

1. NO FORWARD TARGET: No target vehicle could be detected.

2. STRAIGHT ROAD: Target vehicle is traveling on a straight road without any intersecting roads.

3. IN CURVE Target vehicle is navigating a curve.

4. CURVE ENTRY: Target vehicle is entering or about to enter a curve.

5. CURVE EXIT: Target vehicle is completing the negotiation of a curve.

8. UNSURE: Target vehicle road position is uncertain.

Forward Target Brake Onset Time

If Forward Target Location is “IN LANE,” then record the video timestamp where the target vehicle’s brake lights first appeared in the video. If the target vehicle does not brake, then leave this field blank.

Forward Target Turn Signal

If Forward Target Location is "IN LANE," then record whether or not the target vehicle activated a turn signal within 5 seconds prior to the alert.

1. NO: Target vehicle did not use either turn signal.

2. LEFT: Target vehicle used left turn signal.

3. RIGHT: Target vehicle used right turn signal.

Eyes-Off-Driving Task (Due to Secondary Tasks)

Watch the face view and pay attention to the direction of the driver's gaze in the 5 seconds prior to the alert being issued. If the driver's eyes were focused away from the driving task (anywhere other than the forward scene, the driver's blind spot, or the rearview mirrors) for at least 1.5 continuous seconds, then the driver's eyes are considered to be off the driving task.

1. NO: Driver's eyes are not directed away from the driving task for at least 1.5 continuous seconds.

2. YES: Driver's eyes are directed away from the driving task for at least 1.5 continuous seconds.

3. MAYBE: Unclear or not possible to tell where the driver's gaze is directed, or where the driver's attention was directed (driving task or secondary task).

Secondary Tasks Related to Eyes-Off-Driving Task

If Eyes-Off-Driving Task was coded as "YES," then note the activity that drew the driver's attention away from the driving task. If the driver was engaging in multiple secondary tasks that lead to taking their eyes off the road, then select the task that had the greatest contribution to the distraction. Leave a comment for any behavior that is not clearly defined.

First complete Secondary Task Engagement coding for the "BY FRAME" coding scheme to determine the value of this variable.

1. NONE: Driver is not engaging in a secondary task.

2. GROOMING: Driver is applying makeup, using rearview mirror to look at him or herself, brushing hair, shaving, etc.

3. PASSENGER INTERACTION: Driver is engaged in conversation with passengers or looking at/distracted by passengers.

4. ACTIVE INTERACTION WITH ELECTRONIC HANDHELD DEVICE: Driver is actively interacting (pressing buttons) with a cell phone (e.g., dialing, texting, e-mailing, etc.), portable music player, GPS, etc.

5. PASSIVE INTERACTION WITH ELECTRONIC HANDHELD DEVICE: Driver is passively interacting (no button presses) with a cell phone (e.g., reading, hand-held phone conversation, holding phone in preparation to read, etc.), portable music player (e.g., listening through headphones, etc.), GPS, etc.

6. READING: Driver is reading something other than a cell phone (e.g., newspaper), where the reading material is in view and the driver is focusing his or her eyes toward the reading material.

7. INTERACTION WITH STEERING WHEEL: Driver is reaching toward buttons on steering wheel to adjust in-vehicle controls.

8. INTERACTION WITH INFOTAINMENT SYSTEM: Driver is reaching toward the infotainment system (center console) to adjust in-vehicle controls.

9. REACHING FOR OBJECT: Driver is reaching for an object somewhere in the vehicle (e.g., fallen object in passenger seat, reaching behind driver's seat, etc.).

10. SEARCHING INTERIOR: Driver is looking around the interior of the vehicle (either front or back seat) but not reaching for a particular object.

11. VERBALIZATION: Driver is verbally interacting with the vehicle's Bluetooth system (e.g., phone conversation, requesting song change, etc.), interacting with a hands-free device, singing, or whistling. Because no audio is being recorded, the method of verbalization may be unknown. However, if the method is known, then please include in the comments section.

12. LOOKING OUTSIDE: Driver is focused on something outside the car that does not appear to be related to the driving task.

13. YAWNING: Driver is yawning.

14. EYES CLOSED: Driver's eyes are visibly closed for more than 1 continuous second. A blink would not be included in this category.

15. SMOKING: A cigarette/cigar is visible and the driver is engaging in any smoking related behaviors (e.g., opening window, ashing, smoking, opening cigarette box, etc.).

16. OTHER: Any visible distraction that does not fit previous categories.

17. UNKNOWN: Secondary task cannot be determined.

Eyes-Off-Threat (Due to Driving Task)

If the driver's eyes were focused on the driving task, note whether the driver was looking away from the vehicle posing a threat (vehicle that triggered the alert) 1 second before the alert (e.g., if the driver was checking his or her blind spot and did not see a vehicle stopped in front of him or her).

1. NO: Driver was looking towards the threat at the time of the alert.

2. YES: Driver was looking away from the threat at the time of the alert.

3. UNSURE: Unable to determine if the driver was looking toward or away from the threat at the time of the alert.

Response to Automatic Braking Visible in Video

For automatic braking events indicate whether uncontrollable response is visible in the video (e.g., driver shifts forward, driver is jolted).

1. NO: No response is visible in the video.

2. YES: A response is visible in the video.

Roadway Lighting Level

Make note of the time of day based on the light conditions in the forward, side, and rear view videos.

1. DAY: Daylight is detected. Visor use, driving directly into the sun, and other environmental cues to detect daylight.

2. DUSK: Sun is actively setting and daylight is dimming.

3. NIGHT: No daylight can be detected.

Weather

Determine the current weather using the forward view and the activation of the windshield wipers.

1. CLEAR: No rain or snow is detected.

2. RAIN: Rain is detected.

3. SNOW: Snow is detected.

Traffic Congestion

Determine the level of traffic congestion on the roadway.

1. FREE FLOW: Traffic is in free flow conditions and constantly traveling at speeds near the speed limit.

2. SLOW DOWN: Traffic is neither in "FREE FLOW" or "STOP AND GO."

3. STOP AND GO: Traffic is in stop and go conditions. Brake lights are often seen in the video and travel speeds are low.

Appendix J: Overall Driving Technical Approach Details

Overall Driving Calculations

This appendix describes how the Volpe Center calculated each of the overall driving metrics.

For speed and headway, the Volpe Center's goal was to filter the FOE data and capture each driver's routine weekday driving behavior. This approach minimizes variability in overall driving metrics caused by external factors.

Speed

The following filter was used to select data to be included in the analysis of travel speed:

- FCW alerts and automatic braking are enabled (turned on).
- Includes only trips taken on weekdays (Monday – Friday). Drivers generally have predictable driving patterns and consistent driving routes on weekdays. Weekend trips were eliminated to remove variability.
- Includes only trips that were between 4-60 miles long (the most likely trip durations observed during the FOE. Longer trips are more likely to represent out-of-the-ordinary trips like vacations or special events. Shorter trips are more likely to be at lower speeds and require more stops and speed variability).
- Speed is greater than 35 mph (higher speeds are more likely to represent scenarios where the driver was selecting their speed, rather than stopping, starting, or navigating based on traffic flow).

For all driving that satisfied the above criteria, the Volpe Center calculated average speed within each week.

Headway

The following filter was used to select data to be included in the analysis of headway keeping:

- FCW alerts and automatic braking are enabled (turned on).
- Includes only trips taken on weekdays (Monday – Friday). Drivers generally have predictable driving patterns and consistent driving routes on weekdays. Weekend trips were eliminated to remove variability.
- Includes only trips that were between 4-60 miles long (the most likely trip durations observed during the FOE).
- Speed is greater than 35 mph.
- Host vehicle and lead vehicle are in a steady-state (constant speed) following scenario for at least one second.

For all driving that satisfied the above criteria, the Volpe Center calculated the average headway during following scenarios within each week.

Alert Rate

All driving data during the treatment period (FCW alerts and automatic braking enabled) were used to calculate alert rate. The equation for alert rate by week is as follows:

(Number of true alerts[20] experienced by Driver X in a given week/Total number of miles driven by a driver X in a given week)*1000

$$Alert\ Rate = \frac{Number\ of\ true\ alerts\ experienced\ by\ a\ given\ driver}{Total\ number\ of\ miles\ driven\ by\ a\ given\ driver} X\ 1000$$

[20] Alerts with an in-path target.

Appendix K: Group and Driver Level Analyses

Summary measures of the change over time in the number of conflicts per unit exposure could be computed in one of two ways. First, the Volpe Center could identify the best fitting model using the overall data and examine the parameters of that model (the summary measures) to determine whether there was a change over time in the number of conflicts per unit of exposure. This is referred to as analysis at the group level. Second, for each driver the Volpe Center could identify the best fitting model, compute the summary measures by taking the mean of the parameters of individual models, and then determine whether the computed summary measures indicate a change over time in the number conflicts per unit exposure. This is referred to as analysis at the driver level.

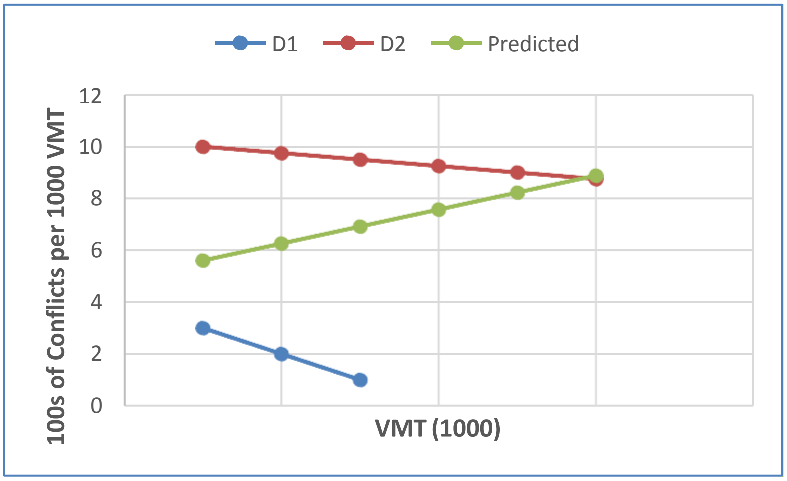
If all drivers had driven the vehicle for the same number of miles (or months), the two ways of computing the summary measure would be equivalent. However, as noted in Section 2.1.2, drivers had the car for either what were classified as a short, medium, or long term-period. The number of drivers were roughly spread evenly across the three groups. This can present a problem for analysis at the group level. The following example explains why this is the case.

Assume, for purposes of this example, that drivers in the long-term group had more conflicts per unit of exposure than drivers in the short-term group (the conflicts are inflated for illustrative purposes). Furthermore, assume that the number of conflicts per unit of exposure decreased across time for both groups. Finally, assume that there were only two drivers in each group, that the second driver drove twice as far as the first driver, and that the number of conflicts per unit of exposure decreased linearly in each driver across total exposure, as shown in Table 17.

Table 17. Analysis Plan (Simple Example: Two Drivers)

VMT (1,000)	Driver ID	Conflicts
1	1	300
2	1	200
3	1	100
1	2	1,000
2	2	975
3	2	950
4	2	925
5	2	900
6	2	875

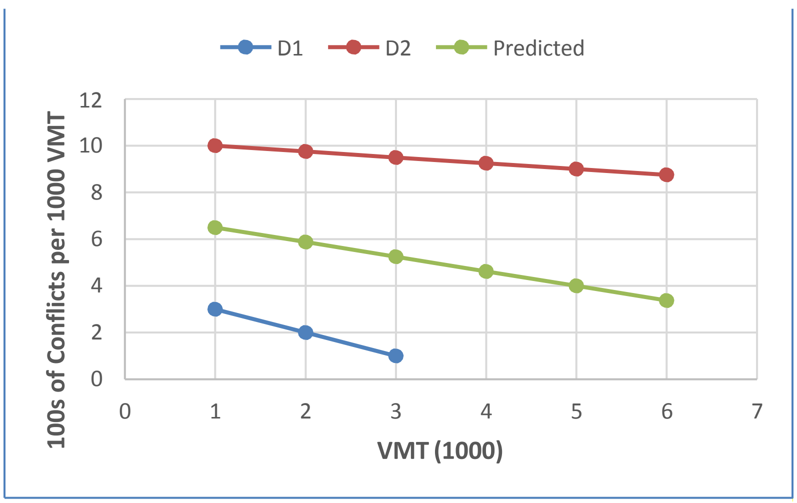
Since the number of conflicts per 1,000 VMT decreased for each driver, the Volpe Center would like to see any computed summary measures show a decrease across time in the number of conflicts per unit of exposure in the group. If a simple regression at the group level is used, there is instead an increase predicted in the number of conflicts per unit of exposure (Figure 62). The green line represents the best fitting line at each unit of exposure. The predicted number of conflicts per unit of exposure increases as exposure increases. However, observations for drivers D1 (red line) and D2 (blue line) in Figure 62 (and Table 17) are decreasing across increases in exposure.



(Analysis at the group level)

Figure 62. Change in Conflicts per Unit Exposure Across Increases in Exposure (Group Level)

Clearly this does not fit with the Volpe Center's perception of how the summary measures should behave. To resolve this problem data is analyzed at the individual driver level by computing summary measures. Parameters are identified that define the change in conflicts per unit of exposure for each driver. Only the slope is of interest; it is equal to -1.0 for the first driver and -0.25 for the second driver. Thus, the average slope is -.625, negative as expected, and the summary predictions better coincide with the Volpe Center's expectations (Figure 63). (Note that to obtain the predicted line the intercept was also computed as the average of two individual intercepts.)



(Analysis at the individual level)

Figure 63. Change in Conflicts per Unit Exposure Across Increases in Exposure (Individual Level)

Based on these findings, the Volpe Center recommends analyzing the data, first at the individual driver level, and then computing the summary measures by averaging across drivers the estimates obtained from the change in the number of conflicts per unit exposure from each driver.

Appendix L: Conflict Analysis Reference Tables

Table 18. Conflicts per 1,000 VMT by Driver

	Total Miles in 1,000s																	
Driver ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1	0	2	1	0	0	2	0	0	0	0	0	0	1	0	0	1	NA	NA
2	5	4	1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4	6	7	3	8	16	9	12	8	6	1	1	8	6	0	NA	NA	NA	NA
5	2	1	0	1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	6	1	3	0	3	1	2	4	1	0	0	NA	NA	NA	NA	NA	NA	NA
7	1	3	5	12	5	9	5	4	2	3	2	NA	NA	NA	NA	NA	NA	NA
8	2	1	2	1	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	7	14	6	13	13	6	5	5	3	0	NA	NA	NA	NA	NA	NA	NA	NA
10	1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
11	1	0	2	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
12	4	2	0	1	3	1	4	2	3	0	NA	NA	NA	NA	NA	NA	NA	NA
15	2	0	7	0	4	5	3	1	7	2	1	1	0	NA	NA	NA	NA	NA
16	0	2	2	0	1	1	3	0	0	0	3	0	NA	NA	NA	NA	NA	NA
18	1	3	3	1	0	2	3	1	0	1	NA	NA	NA	NA	NA	NA	NA	NA
20	7	3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
21	0	0	1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
22	7	8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
24	6	2	2	0	3	4	6	6	1	2	3	0	NA	NA	NA	NA	NA	NA
25	8	6	3	5	3	3	1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
26	11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
27	0	0	2	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
28	5	5	2	1	4	1	4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
29	2	2	1	1	2	1	0	0	2	2	3	NA	NA	NA	NA	NA	NA	NA
30	14	2	2	6	6	2	0	8	0	NA	NA	NA	NA	NA	NA	NA	NA	NA
31	3	2	5	6	8	1	4	1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
32	5	9	2	2	3	2	4	11	1	5	10	14	15	15	15	10	10	6
33	0	1	3	5	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
34	7	4	15	6	5	6	5	4	10	5	4	2	4	NA	NA	NA	NA	NA
35	2	7	3	5	6	5	5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
36	1	2	1	0	0	0	0	0	2	0	0	0	NA	NA	NA	NA	NA	NA
37	5	5	5	7	4	0	0	7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
38	1	1	7	1	5	1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
39	1	0	0	0	1	1	2	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
40	4	0	0	0	0	0	3	1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
41	0	0	0	1	1	1	0	1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 19. Slopes from Poisson Regression of Conflicts per 1,000 VMT on Total VMT (1,000s) by Driver

Driver ID	Total Miles	Intercepts	Slopes
1	16	-0.2181	-0.0794
2	3	2.3521	-0.6402
4	14	2.3056	-0.0620
5	4	0.9416	-0.4196
6	11	1.5073	-0.1657
7	11	1.7622	-0.0393
8	5	1.1147	-0.3508
9	10	2.7250	-0.1540
10	1		
11	4	0.0361	-0.1340
12	10	0.8881	-0.0364
15	13	1.2650	-0.0501
16	12	0.1339	-0.0210
18	10	0.8878	-0.0943
20	2	2.7932	-0.8473
21	3		
22	2	1.8124	0.1335
24	12	1.3773	-0.0494
25	7	2.2814	-0.2441
26	1		
27	4	-1.8496	0.4196
28	7	1.5366	-0.1032
29	11	0.2214	0.0250
30	9	2.2860	-0.1800
31	8	1.5170	-0.0445
32	18	1.2834	0.0727
33	5	-0.1447	0.2271
34	13	2.1913	-0.0628
35	7	1.3000	0.0608
36	12	0.3725	-0.1985
37	8	1.7780	-0.0843
38	6	0.7492	0.0645
39	8	-1.1300	0.1360
40	8	0.3097	-0.0718
41	8	-2.0018	0.2543

(Regression run separately for each driver. Total miles driven by each driver in the middle column)

Table 20. Conflicts per Month as a Function of Total Months of Participation by Driver

Driver	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	2	1	0	0	2	0	0	0	1	0	0	0	1
2	6	4												
4	3	8	10	16	3	9	11	4	8	4	6	9	0	
5	2	2	0											
6	4	3	0	2	1	0	3	1	1	4	1	1	0	
7	1	2	1	5	6	7	5	8	5	2	3	2	4	0
8	0	2	1	2	1	0								
9	7	10	10	4	8	15	3	4	5	4	2	0	0	0
10	0	1												
11	1	2												
12	2	2	0	2	0	1	2	1	1	4	3	2	0	0
15	2	5	4	2	5	2	1	5	3	2	1	0	1	0
16	0	1	1	2	0	2	3	0	0	0	0	3	0	
18	0	1	2	4	0	0	1	1	2	2	1	0	1	0
20	4	6												
21	0	1												
22	7	8												
24	6	3	1	2	5	7	5	1	0	0	2	3	0	
25	3	3	2	3	3	1	3	4	1	3	2	1		
26	6	5												
27	0	2												
28	8	3	2	0	4	2	3							
29	2	2	1	1	0	3	0	0	2	0	5			
30	11	7	0	0	2	4	8	0	6	2				
31	3	0	2	3	3	6	5	3	5	0	0			
32	13	4	4	11	6	11	22	7	27	20	14			
33	0	0	0	0	0	2	1	4	1	0	1			
34	14	15	6	7	8	11	4	2	6	4				
35	4	5	2	1	5	5	4	7	0					
36	1	2	1	0	0	0	0	0	1	1	0			
37	2	3	2	2	5	5	3	4	0	4	3			
38	1	1	2	2	4	0	4	2	0	0				
39	1	0	0	0	1	0	0	3	0					
40	4	0	0	0	3	1	0	0						
41	0	3	1	0										

(Months across the top row)

Table 21. Slopes from Poisson Regression of Conflicts per Month on Total Months of Participation by Driver

Driver ID	Total Months	Slopes	Intercepts
1	14	-0.0855	-0.1106
2	2	-0.4055	2.1972
4	13	-0.0474	2.2620
5	3	-0.8341	1.7362
6	13	-0.0796	0.9930
7	14	-0.0115	1.3777
8	6	-0.0573	0.1956
9	14	-0.1642	2.6590
10	2	22.3026	-44.6052
11	2	0.6931	-0.6931
12	14	-0.0062	0.4025
15	14	-0.1179	1.6311
16	13	-0.0119	0.0023
18	14	-0.0475	0.4072
20	2	0.4055	0.9808
21	2	22.3026	-44.6052
22	2	0.1335	1.8124
24	13	-0.1142	1.7002
25	12	-0.0421	1.1457
26	2	-0.1823	1.9741
27	2	22.9957	-45.2983
28	7	-0.1747	1.7838
29	11	0.0503	0.0606
30	10	-0.0954	1.8736
31	11	-0.0133	1.0824
32	11	0.1075	1.8346
33	11	0.2044	-1.6277
34	10	-0.1459	2.7572
35	9	-0.0091	1.3445
36	11	-0.1574	0.2174
37	11	0.0152	1.0065
38	10	-0.0533	0.7514
39	9	0.1549	-1.4407
40	8	-0.2840	1.0749
41	4	-0.2023	0.4803

(Regression run separately for each driver. Total months driven by each driver in the middle column.)

Table 22. Average Minimum TTC per 1,000 VMT as a Function of the Total Miles Traveled (1,000 VMT) by Driver

ID	1K	2K	3K	4K	5K	6K	7K	8K	9K	10K	11K	12K	13K	14K	15K	16K	17K	18K
1		2.14	1.59			1.72							1.40			1.74		
2	1.51	1.48	1.67															
4	1.55	1.33	1.67	1.61	1.52	1.18	1.59	1.27	1.82	2.39	1.34	1.45	1.38					
5	1.60	2.48		1.77														
6	1.62	1.69	1.46		1.90	1.60	1.76	1.94	1.03									
7	1.61	1.27	1.34	1.57	1.69	1.48	1.53	1.25	1.36	1.49	2.08							
8	1.34	2.15	1.52	1.54														
9	1.35	1.37	1.53	1.44	1.42	1.64	1.25	1.55	1.07									
10	1.45																	
11	2.07		1.15															
12	1.44	1.36		1.23	1.29	1.41	1.58	2.18	1.74									
15	1.42		1.58		1.36	1.68	1.51	1.34	1.76	1.19	2.53	1.48						
16		1.93	1.34		1.53	1.45	1.65				1.72							
18	2.07	1.64	1.80	1.36		1.53	1.27	2.90		1.66								
20	1.25	1.27																
21			2.15															
22	1.82	1.75																
24	1.38	1.61	1.59		1.41	1.81	1.52	1.53	1.00	1.73	1.44							
25	1.44	1.51	2.10	1.84	1.14	1.54	1.24											
26	1.41																	
27			1.46															
28	1.51	1.20	1.16	1.74	1.76	1.29	1.32											
29	1.80	1.48	1.64	0.73	1.33	2.34			1.72	1.59	1.47							
30	1.62	2.03	1.66	1.56	1.72	1.83		1.40										
31	1.21	2.05	1.27	1.19	1.50	1.80	1.17	1.18										
32	1.80	1.70	1.64	1.86	1.49	2.16	1.64	1.57	1.76	1.51	1.49	1.76	1.58	1.51	1.62	1.51	1.32	1.53
33		1.58	1.78	2.03														
34	1.66	1.72	1.70	1.64	1.56	1.40	1.46	1.90	1.64	1.50	1.58	0.90	1.22					
35	1.84	1.85	1.51	1.31	1.43	1.58	1.30											
36	1.59	1.74	1.64						1.62									
37	1.40	1.20	1.52	1.42	0.85		1.50	1.26										
38	1.27	2.45	1.57	1.56	1.67	1.70												
39	1.22				1.89	1.36	2.06											
40	1.84						1.66	1.35										
41				1.17	1.26	1.45		1.31										

Table 23. Slopes from Linear Regression of Average Minimum TTC per 1,000 VMT on total VMT (1,000s) in Exposure Units with a Conflict by Driver

Driver ID	Total Miles	Slopes	Intercepts
1	16	-0.021	1.887
2	3	0.079	1.393
4	14	0.007	1.497
5	4	-0.003	1.959
6	11	-0.017	1.712
7	11	0.022	1.384
8	5	-0.002	1.644
9	10	-0.015	1.479
10	1		
11	4	-0.462	2.537
12	10	0.071	1.154
15	13	0.032	1.353
16	12	0.004	1.585
18	10	0.017	1.693
20	2	0.026	1.220
21	3		
22	2	-0.066	1.884
24	12	-0.008	1.552
25	7	-0.054	1.760
26	1		
27	4		
28	7	0.007	1.396
29	11	0.009	1.514
30	9	-0.037	1.842
31	8	-0.032	1.564
32	18	-0.019	1.818
33	5	0.228	1.111
34	13	-0.038	1.796
35	7	-0.081	1.870
36	12	-0.003	1.659
37	8	-0.008	1.342
38	6	-0.007	1.728
39	8	0.108	1.120
40	8	-0.056	1.920
41	8	0.036	1.093

(Regression run separately for each driver. Total miles (1,000s) driven by each driver in the middle column.)

Table 24. Average Peak Deceleration per 1,000 VMT as a Function of the Total Miles Traveled (1,000 VMT) by Driver

ID	1K	2K	3K	4K	5K	6K	7K	8K	9K	10K	11K	12K	13K	14K	15K	16K	17K	18K
1		-4.27	-7.47			-2.55							-5.52					
2	-4.24	-5.12	-4.68															
4	-3.44	-2.56		-3.26	-3.27	-3.48	-4.00	-2.71	-3.08	-4.05	-4.23	-4.25	-3.71					
5	-3.63	-4.35																
6	-3.33		-5.80		-4.26		-4.23	-3.32	-6.21									
7	-2.52	-4.59	-4.33	-4.44	-3.76	-4.42	-4.25	-4.71	-3.46	-4.91	-4.79							
8	-4.53	-4.89	-3.91	-4.14														
9	-4.02	-4.01	-4.54	-3.82	-4.60	-5.08	-4.74	-4.87	-5.28									
10	-5.22																	
11	-4.89		-5.46															
12	-3.71	-4.80		-4.83	-3.11	-4.32	-4.07	-4.46	-4.66									
15	-5.04		-4.00		-5.21	-4.70	-2.81	-4.56	-4.94	-2.79	-5.01	-4.14						
16		-5.85	-4.33		-3.09	-2.79	-3.75				-4.27							
18	-4.77	-4.87	-5.90	-4.38		-2.70	-6.23	-5.37		-4.50								
20	-5.13	-6.28																
21			-8.31															
22	-4.88	-3.75																
24	-4.47	-4.13	-4.89		-4.55	-4.59	-4.78	-4.82	-2.25	-4.13	-5.89							
25	-4.98	-4.54	-5.12	-3.99	-5.24	-4.34	-5.31											
26	-4.25																	
27			-5.84															
28	-4.74	-4.72	-4.35	-5.46	-5.32	-4.74	-5.34											
29	-4.72	-4.26	-4.38		-4.62	-4.05			-4.80	-3.75	-4.06							
30	-4.37	-3.92	-4.08	-4.55	-4.60	-5.44		-4.73										
31	-5.30	-4.47	-5.92	-4.81	-4.87	-3.75	-4.80	-4.11										
32	-5.24	-4.80	-3.91	-5.30	-4.24	-5.63	-4.43	-4.36	-4.32	-4.62	-4.52	-4.69	-4.62	-4.50	-4.63	-5.21	-4.77	-4.63
33		-4.50	-5.33	-4.29														
34	-3.94	-3.45	-3.17	-2.00	-3.40	-3.98	-3.95	-1.82	-3.12	-3.53	-4.09	-3.34	-2.71					
35	-4.32	-4.46	-2.27	-4.90	-4.45	-3.90	-4.88											
36	-4.86	-6.57	-4.41						-4.34									
37	-3.57	-3.94	-3.77	-4.68	-7.56		-4.05	-5.13										
38		-4.89	-3.78	-4.29	-2.74	-4.71												
39	-4.41				-5.85	-4.89	-4.54											
40	-4.96						-4.39	-4.14										
41				-4.83	-4.26	-4.29		-4.20										

Table 25. Slopes from Linear Regression of Average Peak Deceleration per 1,000 VMT on Total VMT (1,000s) in Exposure Units with a Conflict by Driver

Driver ID	Total Miles	Slopes	Intercepts
1	16	0.012	-5.02429
2	3	-0.219	-4.241
4	14	-0.086	-2.8721
5	4	-0.720	-2.91
6	11	-0.100	-3.97326
7	11	-0.101	-3.59474
8	5	0.215	-4.905
9	10	-0.155	-3.77743
10	1	NA	NA
11	4	-0.285	-4.605
12	10	-0.035	-4.06017
15	13	0.058	-4.73635
16	12	0.124	-4.71698
18	10	0.014	-4.90995
20	2	-1.151	-3.98357
21	3	NA	NA
22	2	1.130	-6.01
24	12	-0.001	-4.4424
25	7	-0.026	-4.685
26	1	NA	NA
27	4	NA	NA
28	7	-0.100	-4.55229
29	11	0.044	-4.58656
30	9	-0.139	-3.94958
31	8	0.156	-5.45698
32	18	0.004	-4.72917
33	5	0.105	-5.02167
34	13	0.013	-3.35864
35	7	-0.097	-3.77776
36	12	0.140	-5.56742
37	8	-0.216	-3.74691
38	6	0.140	-4.63943
39	8	-0.061	-4.63446
40	8	0.109	-5.07738
41	8	0.129	-5.13429

(Regression run separately for each driver. Total miles (1,000s) driven by each driver in the middle column.)

Table 26. Mean Deceleration per 1,000 VMT as a Function of the Total Miles Traveled (1,000 VMT) by Driver

ID	1K	2K	3K	4K	5K	6K	7K	8K	9K	10K	11K	12K	13K	14K	15K	16K	17K	18K
1		-2.47	-5.46			-1.47							-3.64					
2	-1.77	-2.71	-2.50															
4	-1.50	-1.26		-1.55	-1.91	-2.15	-2.48	-1.60	-1.99	-2.38	-2.79	-2.29	-2.28					
5	-2.19	-1.53																
6	-1.99		-3.79		-2.35		-2.24	-1.75	-2.35									
7	-1.27	-2.36	-2.26	-2.19	-1.90	-2.36	-2.48	-2.80	-1.28	-2.57	-2.79							
8	-2.12	-2.56	-2.13	-2.07														
9	-2.14	-2.06	-2.49	-2.17	-2.19	-2.93	-2.78	-2.62	-2.25									
10	-2.46																	
11	-2.54		-2.50															
12	-2.00	-3.05		-1.60	-1.77	-2.03	-2.48	-2.99	-1.91									
15	-2.25		-2.15		-3.41	-2.53	-1.63	-3.16	-2.46	-1.71	-3.84	-2.55						
16		-2.07	-1.62		-2.23	-1.83	-2.57				-2.94							
18	-2.25	-1.95	-3.18	-2.91		-1.40	-4.07	-1.56		-1.91								
20	-3.01	-3.00																
21			-4.71															
22	-2.83	-2.22																
24	-2.53	-1.86	-2.07		-2.62	-3.03	-3.06	-2.70	-1.27	-2.44	-2.34							
25	-2.22	-2.42	-2.91	-2.23	-1.93	-2.38	-2.67											
26	-2.44																	
27			-3.63															
28	-2.70	-2.60	-3.18	-2.44	-2.13	-3.44	-3.01											
29	-2.43	-2.04	-2.65		-2.44	-2.85			-1.84	-2.33	-2.50							
30	-2.02	-2.03	-2.24	-2.73	-2.59	-1.79		-2.18										
31	-2.05	-2.10	-2.88	-2.73	-2.27	-1.43	-2.64	-2.33										
32	-3.15	-2.85	-1.92	-1.76	-2.57	-2.88	-2.69	-2.44	-2.21	-2.54	-2.44	-2.42	-2.94	-2.73	-2.71	-2.76	-2.66	-2.56
33		-2.59	-2.47	-2.41														
34	-1.86	-1.65	-1.65	-1.26	-1.31	-1.77	-2.11	-0.87	-1.25	-2.00	-2.22	-1.45	-1.31					
35	-2.57	-2.27	-1.48	-2.49	-2.48	-1.95	-2.03											
36	-3.12	-4.52	-2.60						-3.08									
37	-1.67	-2.49	-2.21	-2.27	-3.16		-2.75	-2.69										
38		-2.17	-2.26	-2.70	-1.49	-3.07												
39	-2.47				-2.75	-1.95	-2.49											
40	-3.44						-2.27	-1.92										
41				-2.26	-2.64	-2.86		-1.43										

Table 27. Slopes from Linear Regression of Mean Deceleration per 1,000 VMT on Total VMT (1,000s) in Exposure Units with a Conflict by Driver

Driver ID	Total Miles	Slopes	Intercepts
1	16	0.011	-3.32436
2	3	-0.362	-1.60355
4	14	-0.091	-1.34798
5	4	0.654	-2.83906
6	11	0.077	-2.83436
7	11	-0.067	-1.8061
8	5	0.057	-2.36105
9	10	-0.057	-2.11631
10	1		
11	4	0.020	-2.5558
12	10	-0.006	-2.19592
15	13	-0.042	-2.26642
16	12	-0.123	-1.51272
18	10	0.040	-2.60748
20	2	0.016	-3.03065
21	3		
22	2	0.612	-3.44369
24	12	-0.001	-2.38649
25	7	-0.010	-2.35459
26	1		
27	4		
28	7	-0.056	-2.56143
29	11	0.010	-2.44317
30	9	-0.010	-2.18554
31	8	0.003	-2.3165
32	18	-0.009	-2.47776
33	5	0.088	-2.75398
34	13	0.005	-1.62307
35	7	0.044	-2.35841
36	12	0.059	-3.55215
37	8	-0.127	-1.91682
38	6	-0.104	-1.91999
39	8	0.025	-2.53275
40	8	0.209	-3.65671
41	8	0.228	-3.60854

(Regression run separately for each driver. Total miles (1,000s) driven by each driver in the middle column.)

Table 28. Average Minimum TTC per Month as a Function of the Total Months of Participation by Driver

Driver	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1		2.1	1.6			1.7				1.4				1.7
2	1.5	1.5												
4	1.8	1.5	1.4	1.6	1.3	1.2	1.5	1.8	1.3	2.0	1.5	1.3		
5	1.6	2.1												
6	1.4	1.9		1.0	2.4		1.9	1.6	1.9	1.9	1.6	1.0		
7	1.6	1.3	1.2	1.3	1.6	1.7	1.5	1.5	1.5	1.3	1.1	1.8	1.7	
8		1.3	2.2	1.5	1.5									
9	1.3	1.3	1.5	1.6	1.3	1.5	1.7	1.3	1.3	1.5	1.1			
10		1.4												
11	2.1	1.2												
12	1.5	1.4		1.4		1.2	1.5	0.9	1.4	1.6	2.1	1.6		
15	1.4	1.5	1.6	1.4	1.7	1.5	1.6	1.9	1.4	1.2	2.5		1.5	
16		1.8	2.1	1.3		1.5	1.7					1.7		
18		2.1	1.7	1.7			1.4	1.3	1.6	1.2	2.9		1.7	
20	1.4	1.2												
21		2.2												
22	1.8	1.8												
24	1.4	1.7	1.4	1.6	1.7	1.6	1.5	1.0			1.7	1.4		
25	1.4	1.5	1.5	1.4	1.6	2.2	2.0	1.8	1.4	1.2	1.5	1.2		
26	1.4	1.4												
27		1.5												
28	1.4	1.1	1.6		1.8	1.1	1.5							
29	1.8	1.5	1.6	0.7		1.7			1.7		1.5			
30	1.6	1.8			1.6	1.5	1.7		1.4	1.3				
31	1.2		2.1	1.2	1.5	1.2	1.2	2.0	1.3					
32	1.8	1.6	1.6	1.6	1.7	1.4	1.7	1.5	1.6	1.5	1.5			
33						1.6	2.7	1.9	1.5		1.9			
34	1.7	1.6	1.5	1.5	1.6	1.6	1.7	1.4	1.4	1.2				
35	2.0	1.8	1.4	1.7	1.3	1.4	1.5	1.4						
36	1.6	1.7	1.6						1.6	1.6				
37	1.5	1.4	1.3	1.2	1.5	1.3	1.5	0.8		1.3	1.3			
38	1.3	2.5	1.6	1.5	1.6		1.7	1.5						
39	1.2				1.9			1.8						
40	1.8				1.7	1.4								
41		1.3	1.3											

Table 29. Slopes from Linear Regression of Average Minimum TTC per Month on Total Months of Participation by Driver

Driver ID	Total Months	Slopes	Intercepts
1	14	-0.0235	1.8834
2	2	0.0504	1.4416
4	13	-0.0007	1.5291
5	3	0.5223	1.0824
6	13	-0.0097	1.7356
7	14	0.0126	1.3824
8	6	-0.0024	1.6464
9	14	-0.0155	1.4923
10	2	NA	NA
11	2	-0.9246	2.9993
12	14	0.0307	1.2451
15	14	0.0265	1.4176
16	13	-0.0108	1.7410
18	14	0.0037	1.6944
20	2	-0.2068	1.5848
21	2	NA	NA
22	2	-0.0657	1.8843
24	13	-0.0027	1.5049
25	12	-0.0098	1.6280
26	2	0.0578	1.3242
27	2	NA	NA
28	7	0.0115	1.3595
29	11	0.0061	1.4760
30	10	-0.0340	1.7711
31	11	0.0099	1.3978
32	11	-0.0209	1.7130
33	11	-0.0365	2.2343
34	10	-0.0375	1.7396
35	9	-0.0655	1.8581
36	11	-0.0036	1.6616
37	11	-0.0161	1.3917
38	10	-0.0185	1.7463
39	9	0.0912	1.2196
40	8	-0.0834	1.9519
41	4	0.0156	1.2637

(Regression run separately for each driver. Total months driven by each driver in the middle column.)

Table 30. Average Peak Acceleration per Month as a Function of the Total Months of Participation by Driver

ID	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1		-4.27	-7.47			-2.55				-5.52		
2	2	-4.26	-5.20										
4	4	-5.46	-2.88	-3.28	-3.17	-4.35	-4.27	-3.99	-4.44	-2.25	-3.31	-4.88	-3.49
5	5	-3.63	-4.35										
6	6	-3.87	-2.52		-6.60	-4.20		-4.26			-3.55		-6.21
7	7	-2.52	-4.62	-4.53	-4.33	-4.37	-4.47	-3.79	-4.43	-4.25	-4.53	-4.17	-4.29
8	8		-4.53	-4.89	-3.91	-4.14							
9	9	-4.02	-4.04	-4.30	-3.41	-4.38	-4.27	-4.50	-5.51	-4.22	-5.00	-5.61	
10	10		-5.22										
11	11	-4.89	-5.46										
12	12	-2.82	-4.59		-4.80		-4.83	-4.35	-0.63	-4.32	-4.07	-4.46	-4.66
15	15	-5.04	-3.90	-4.82	-4.85	-4.70	-5.01	-0.60	-4.04	-6.99	-2.79	-5.01	
16	16		-5.85		-4.33		-2.94	-3.75					-4.27
18	18		-4.77	-4.68	-5.74			-4.38	-4.38	-2.52	-7.34	-5.37	
20	20	-5.54	-5.27										
21	21		-8.31										
22	22	-4.88	-3.75										
24	24	-4.47	-4.45	-4.68	-4.37	-4.66	-4.96	-4.58	-2.25			-4.13	-5.89
25	25	-3.58	-4.70	-7.50	-4.61	-4.46	-5.40	-4.05	-4.44	-4.74	-5.04	-4.44	-5.31
26	26	-4.11	-4.42										
27	27		-5.84										
28	28	-4.33	-5.61	-5.01		-5.32	-4.98	-5.38					
29	29	-4.72	-4.26	-4.38			-4.43			-4.80		-3.94	
30	30	-4.53	-3.92			-4.24	-4.71	-4.81		-4.86	-4.35		
31	31	-5.30		-4.47	-5.78	-6.12	-5.27	-5.15	-3.81	-4.75			
32	32	-5.00	-4.65	-4.24	-4.63	-4.32	-4.56	-4.62	-4.59	-4.61	-5.01	-4.51	
33	33						-4.50	-6.21	-4.64	-4.02		-4.14	
34	34	-3.37	-3.58	-2.06	-3.82	-3.96	-2.72	-5.07	-1.79	-3.84	-2.71		
35	35	-4.31	-4.53	-2.51	-1.80	-4.90	-4.53	-4.25	-5.03				
36	36	-4.86	-6.57	-4.41						-4.29	-4.38		
37	37	-3.16	-3.84	-4.44	-4.30	-3.46	-4.70	-4.52	-7.56		-5.10	-4.81	
38	38		-4.89	-4.14	-4.32	-3.80		-3.30	-3.17				
39	39	-4.41				-5.85			-4.66				
40	40	-4.96				-4.39	-4.14						
41	41		-4.46	-4.20									

Table 31. Slopes from Linear Regression of Average Peak Deceleration per Month on Total Months Participation by Driver

Driver ID	Total Months	Slopes	Intercepts
1	14	0.0663	-5.3018
2	2	-0.9375	-3.3225
4	13	0.0283	-3.9977
5	3	-0.7200	-2.9100
6	13	-0.1349	-3.6679
7	14	-0.0660	-3.7896
8	6	0.2145	-5.1195
9	14	-0.1444	-3.6106
10	2	NA	NA
11	2	-0.5700	-4.3200
12	14	-0.0280	-3.7570
15	14	0.0328	-4.5391
16	13	0.1220	-4.9853
18	14	-0.0062	-4.8061
20	2	0.2745	-5.8170
21	2	NA	NA
22	2	1.1300	-6.0100
24	13	-0.0156	-4.3508
25	12	0.0045	-4.8852
26	2	-0.3110	-3.7940
27	2	NA	NA
28	7	-0.0790	-4.7893
29	11	0.0251	-4.5555
30	10	-0.0469	-4.2216
31	11	0.1039	-5.6389
32	11	-0.0029	-4.5955
33	11	0.2346	-6.6265
34	10	0.0175	-3.3870
35	9	-0.1527	-3.2935
36	11	0.1273	-5.5384
37	11	-0.2127	-3.3772
38	10	0.2698	-5.2401
39	9	-0.0532	-4.7249
40	8	0.1573	-5.1251
41	4	0.2600	-4.9800

(Regression run separately for each driver. Total months driven by each driver in the middle column.)

Table 32. Mean Deceleration per Month as a Function of the Total Months of Participation by Driver

ID	1	2	3	4	5	6	7	8	9	10	11	12	13
1		-2.47	-5.46			-1.47				-3.64			
2	-1.94	-2.64											
4	-1.95	-1.35	-1.50	-1.74	-2.82	-2.64	-2.35	-2.70	-1.49	-1.84	-2.91	-1.91	
5	-2.19	-1.53											
6	-2.29	-1.55		-4.55	-2.27		-2.35			-1.87		-2.35	
7	-1.27	-2.03	-3.03	-2.26	-2.24	-2.21	-1.79	-2.39	-2.48	-2.62	-2.37	-2.20	-2.58
8		-2.12	-2.56	-2.13	-2.07								
9	-2.14	-2.02	-2.36	-1.89	-2.50	-2.03	-2.36	-3.28	-2.32	-2.75	-2.18		
10		-2.46											
11	-2.54	-2.50											
12	-1.60	-2.40		-3.05		-1.60	-2.39	-0.51	-2.03	-2.48	-2.99	-1.91	
15	-2.25	-2.13	-2.88	-2.99	-2.53	-2.66	-0.60	-2.25	-3.34	-1.71	-3.84		-2.55
16		-2.07		-1.62		-2.03	-2.57					-2.94	
18		-2.25	-1.92	-2.88			-2.91	-2.54	-1.23	-4.99	-1.56		-1.91
20	-3.30	-2.78											
21		-4.71											
22	-2.83	-2.22											
24	-2.53	-2.02	-1.80	-2.86	-2.85	-2.89	-2.87	-1.27			-2.44	-2.34	
25	-1.81	-2.34	-2.66	-2.11	-2.73	-3.64	-2.12	-2.47	-2.39	-1.88	-2.46	-2.67	
26	-2.13	-2.80											
27		-3.63											
28	-2.52	-3.00	-3.04		-2.13	-3.48	-2.83						
29	-2.43	-2.04	-2.65			-2.58			-1.84		-2.43		
30	-1.97	-2.15			-2.61	-2.80	-2.39		-2.10	-2.43			
31	-2.05		-2.10	-2.26	-3.81	-2.88	-2.40	-1.85	-2.39				
32	-2.95	-2.09	-2.44	-2.66	-2.36	-2.43	-2.47	-3.01	-2.86	-2.68	-2.52		
33						-2.43	-2.88	-2.40	-2.09		-2.67		
34	-1.63	-1.88	-1.03	-1.65	-1.90	-1.12	-2.50	-1.06	-1.96	-1.31			
35	-2.59	-2.13	-1.68	-1.07	-2.49	-2.61	-1.98	-2.22					
36	-3.12	-4.52	-2.60						-3.20	-2.97			
37	-1.44	-1.82	-1.97	-3.25	-2.04	-2.24	-2.35	-3.16		-2.78	-2.58		
38		-2.17	-2.44	-2.46	-2.30		-1.76	-2.01					
39	-2.47				-2.75			-2.31					
40	-3.44				-2.27	-1.92							
41		-2.59	-1.43										

Table 33. Slopes from Linear Regression of Mean Deceleration per Month on Total Months Participation by Driver

Driver ID	Total Months	Slopes	Intercepts
1	14	0.0497	-3.5213
2	2	-0.7025	-1.2372
4	13	-0.0495	-1.7786
5	3	0.6540	-2.8391
6	13	0.0264	-2.6149
7	14	-0.0430	-1.9650
8	6	0.0568	-2.4178
9	14	-0.0512	-2.0411
10	2	NA	NA
11	2	0.0403	-2.5760
12	14	-0.0086	-2.0367
15	14	-0.0302	-2.2783
16	13	-0.1135	-1.5423
18	14	-0.0020	-2.4521
20	2	0.5284	-3.8333
21	2	NA	NA
22	2	0.6124	-3.4437
24	13	0.0052	-2.4166
25	12	-0.0143	-2.3468
26	2	-0.6693	-1.4620
27	2	NA	NA
28	7	-0.0349	-2.6953
29	11	0.0157	-2.4126
30	10	-0.0304	-2.1762
31	11	-0.0141	-2.3929
32	11	-0.0206	-2.4635
33	11	0.0082	-2.5583
34	10	0.0022	-1.6164
35	9	-0.0107	-2.0479
36	11	0.0520	-3.5420
37	11	-0.1079	-1.7488
38	10	0.0785	-2.5690
39	9	0.0173	-2.5891
40	8	0.3001	-3.7425
41	4	1.1527	-4.8918

(Regression run separately for each driver. Total months driven by each driver in the middle column.)

DOT HS 812 611
May 2019

U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

NHTSA

13688-050919-v3d