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16. Abstract

Connected vehicle technology allows equipped vehicles to communicate their position and movement with other equipped vehicles, enabling the provision of safety warnings for a variety of potential collision scenarios. CV devices can be installed as original equipment in new vehicles, but they can also be installed in existing vehicles as aftermarket safety devices (ASDs). ASDs can help to accelerate the rate of CV technology adoption, which is important for CV functionality, but they also raise distinct questions about interface considerations and the potential need for access to vehicle onboard data. This study addressed these questions through a series of research tasks. An information search and review found that ASD development is still in an early stage and there is little consensus regarding what ASDs are likely to look like when they become available to the public. There is also disagreement regarding the need for access to onboard CAN bus data and professional installation. An analytical task was conducted to identify the data elements that might not be available to an ASD without a data connection to the vehicle itself. Results showed that lack of access to vehicle data could limit the data available toASDs in a number of ways, and that two elements required for all CV devices (transmission state and steering wheel angle) are not inherently available to an ASD without a vehicle data connection. Following the analytical review, researchers developed three mock prototype ASD systems representing a range of design approaches for use in subsequent experiments. Level 1 was auditory only. Level 2 had an auditory warning with a small visual display device located on the vehicle dashboard that indicted threat direction. Level 3 represented a vehicle-integrated system with light bars located around the perimeter of the vehicles that flashed to indicate threat direction. A driving simulator experiment focused on driver response to collision warnings found that participants generally responded quickly to ASD warnings, and in some collision scenarios, the Level 3 interface led to faster responding than the other two interfaces.

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List of Acronyms

AAM: Alliance of Automobile Manufactures

ASD: Aftermarket safety device

BSM: Basic safety message

BSW: Blind spot warning

CCC: Car Connectivity Consortium

CV: Connected Vehicle

CVRIA: Connected Vehicle Reference Implementation Architecture

DNPW: Do not pass warning

DSRC: Dedicated short range communication

DVI: Driver-vehicle interface

EEBL: Emergency electronic brake light

FCW: Forward collision warning

HFCV: Human Factors for Connected Vehicles

HUD: Head up display

IMA: Intersection movement assist

LCW: Lane change warning

LTA: Left turn assist

NHTSA: National Highway Traffic Safety Administration

OBU: On board unit

OEM: Original equipment manufacturer

RSD: Retrofit safety device

TEOD: Time eyes on display

USDOT: United States Department of Transportation

V2I: Vehicle to infrastructure

V2V: Vehicle to vehicle

V2X: Vehicle to everything

VAD: Vehicle awareness devices

Executive Summary

Introduction

Connected Vehicle (CV) technology enables rapid wireless communications among individual vehicles, the transportation infrastructure, and other entities. A key application of CV technology is the communication of safety messages to drivers when potential conflicts between vehicles are emerging. CV technology removes the limitations of being able to detect emerging threat situations solely from onboard sensors and can detect potential conflicts without direct line-of-sight between vehicles. CV technology has great potential to reduce the types of collisions that cause the most deaths on U.S. highways (Harding et al., 2014), but certain implementation factors are necessary to ensure successful deployment. First, because vehicle-to-vehicle (V2V) communication requires both vehicles to be CV-equipped, a substantial number of CV devices must be deployed. Without substantial fleet penetration, it will be rare that potentially conflicting vehicles will both be CV-equipped and able to communicate to one another. Second, the CV interface must provide accurate and timely information that helps drives to take appropriate action to avoid collisions.

CV devices use dedicated short-range communication (DSRC) technology to provide short- to medium-range communication between vehicles and other road entities. The core data set communicated via DSRC for safety functions is known as the basic safety message (BSM), and is specified in SAE J2735. The BSM contains two parts. Part 1 consists of variables related to vehicle position (longitude, latitude, etc.), vehicle motion (speed, heading, acceleration, etc.), and vehicle size (length width). Part 2 consists of vehicle safety flags (ABS activation, wiper status, hard braing, etc.) All CV devices must include all Part 1 elements, but Part 2 elements may vary by vehicle model.

While the above issues are applicable to CV technology in general, they are especially relevant to aftermarket safety devices (ASDs). ASDs are CV devices that are installed in vehicles that do not include CV as original equipment. ASDs can help to enhance the efficacy of CV communications by increasing the rate of CV technology adoption and fleet penetration to higher levels than can be achieved by the sale of new vehicles alone.

Harding et al. (2014) define three types of aftermarket CV devices:

1. *Vehicle awareness devices (VAD)* are stand-alone devices that connect to the vehicle only for power. They do not have a user interface; they only provide the BSM to other vehicles.
2. *Self-contained ASDs* are like VADs, but also receive BSMs from other vehicles to support safety applications for the driver of the equipped vehicle.
3. *Retrofit safety devices* (RSD) are similar to self-contained ASDs, but require a connection to the vehicle's data bus to incorporate onboard vehicle data.

Self-contained ASDs (heretofore referred to simply as ASDs) are the focus of this project. While ASDs are likely to be an important part of the initial rollout of CV technology, they also have some distinct issues that must be addressed. For example, ASDs have limited access to onboard vehicle data relative to original equipment manufacturer (OEM) CV systems and retrofit systems, and the lack of vehicle data might influence the functionality of ASDs. ASDs might also have different interface characteristics and capabilities than an integrated OEM system.

Ultimately, ASDs will provide the greatest safety benefit if they are plentiful, function reliably for a wide range of V2V safety applications, and use driver-vehicle interfaces (DVIs) that promote rapid and proper responses to warnings without causing distraction, confusion, or frustration.

The purpose of this project was to increase understanding of ASD human factors issues, including identifying limitations and gauging the effectiveness of the ASD driver vehicle interface. The objectives as stated in the contract Statement of Work were:

- Support the Human Factors Connected Vehicle (HFCV) research program by conducting research that will examine the ASD DVI in the areas of human factors, systems design, and system performance. Some of the research results will feed into the next generation HFCV Principles, which is the primary product of the HFCV Program.
- Increase understanding of human factors issues, including identifying limitations and gauging the effectiveness of the ASD DVI.
- Obtain data and results to support NHTSA's HFCV program.

In order to achieve the project objectives, the following sequence of project activities was implemented.

- Focused review of literature related to DVI, with particular interest in aftermarket products
- Identification and description of available and planned product information, from manufacturer web sites and others sources
- Interviews with industry experts
- Analytic assessment of potential functional impact if certain data elements are not available to an ASD (i.e., no connection to vehicle data bus).
- Development of research plans to address key issues identified in the review and analysis
- Implementation and conduct of simulator experiment

Information Search and Review

This project included a range of tasks to investigate issues related to ASD interfaces. The initial research task was an information search and review that included a review of literature, products, and ASD design concepts. This task also included contacts with experts and technology developers working on ASD hardware and interfaces. The review found that ASDs are still early in development, and the few systems that have been developed are in experimental or prototype form. The review of literature, products, and industry expert contacts indicated that there was no clear trend or consensus in terms of expectations for future development of ASDs. Experts also disagreed regarding whether or not ASDs would require professional installation and connection to the vehicle's onboard data for adequate functionality and performance.

Relation to Onboard Data Sources

As noted above, there is a debate among CV developers and researchers regarding whether an ASD can perform adequately if installed as a stand-alone device, without access to the vehicle's onboard data via the CAN bus. The research team conducted an analytic task to determine the types of data that might or might not be available to an ASD, depending on the implementation model, and the potential implications of these data types' availability or unavailability. The objective of this task was to identify the various types of data that may or may not be available to an ASD from the device itself or from the vehicle, then determine the potential effects of a lack or impairment of that data type on ASD capability or performance, or driver behavior. The full set of CV data elements specified in SAE J2735 was used as a starting point. The high-level categories of onboard information type were Vehicle State, Roadway/Environment State, Driver State, Driver Intention, and External Object Detection. For each data element, the research team considered the potential effect of its unavailability on ASD capability or performance. The categories of potential ASD performance decrement were Resolution and Precision, System Redundancy/Complement, Predict Conflict/Hazard, Adapt Warning Algorithm, Adapt Warning Display, and Message Priority. This analytic task specifically considered the effects of data element availability on intersection movement assist (IMA) and left turn assist (LTA). Both of these applications help to predict conflicts and potential collisions in potentially complex scenarios. Therefore, they serve as good case studies of the potential detrimental effects of unavailable data elements.

Seven members of the project team reviewed the matrix of data elements and potential performance decrement categories and indicated for each cell whether ASD performance or driver behavior might be adversely affected if the variable is not available. Results showed that lack of ASD access to vehicle CAN bus data could potentially have detrimental effects on ASD performance and driver behavior across a wide range of variables. It is also important to note that two required components of the BSM Part 1 (transmission state and steering wheel angle) are not available to an ASD without access to vehicle status information.

Research Plan and Prototype ASDs

Following the information search and review, the research team developed a research plan for a simulator experiment focused on driver response to imminent vehicle threats. This experiment compared prototype ASD systems that differ in interface and integration characteristics. The three levels of ASD system were designed based on information gathered in the search and review task. Level 1 was an auditory-only ASD based on systems used in the Ann Arbor Safety Pilot (Gilbert, 2012). Level 2 included the same auditory signal as Level 1, but with the additional of a small visual display atop the center console that indicated the direction of a potential conflict. Level 3 represented a retrofit system that used light bars around the perimeter of the vehicle to indicate the direction of a vehicle threat. Level 3 had the same auditory signal as the other two systems, but the sound was played through the vehicle speakers with sound either coming from the left speakers, right speakers, or all speakers to provide an additional cue to the direction of the threat. In the simulator experiment, the Level 3 system also simulated access to vehicle CAN bus data to allow warnings algorithms to be adapted based on current vehicle dynamics (e.g., warnings could be suppressed if driver is already taking an evasive maneuver).

The experiment compared the three ASD systems for various CV applications across a set of driving scenarios. The experiment emphasized intersection-related applications (intersection movement assist, left turn assist), but included other applications as well (emergency electronic brake light, blind spot/lane change warning).

Driving Simulator Experiment

The driving simulator experiment used a between-subjects design with the independent variables: three CV applications (Intersection Movement Assist, Left Turn Assist, Emergency Electronic Brake Light) in appropriate potential collision situations, three levels of ASD interface (audio only, audio-visual, integrated), and access to onboard vehicle information present or not present to allow CV alert suppression if the driver was already responding to the collision situation. The simulator experiment placed drivers in potential crash situations that were not possible in an on-road study. Dependent measures included driver response measures: accelerator pedal release time from incursion vehicle visible, brake response time from incursion vehicle visible, steering response time from incursion vehicle visible, accelerator pedal application time from incursion vehicle visible; the outcome measure collisions; as well as driver comprehension and perceived benefits and acceptability. One-hundred and eight participants in good general health between the ages of 25 and 55 years old, balanced by gender across experimental conditions, completed the study procedures. Each participant experienced only one crash scenario ensuring an unprimed response to the alert and event. In order to collect uninfluenced data on participants' comprehension of the alert, no training on the warning systems was provided. The NADS ¼ cab miniSim was used for data collection.

The focus of this effort was to determine whether the types of displays expected in aftermarket systems elicit different responses from driver than OEM-installed systems. The audio only and audio-visual represent the potential aftermarket display types, while the integrated display represents an OEM-installed system. A no-alert condition was not included, as comparison to the integrated display is of interest rather than comparison to a no-alert baseline.

Driver response time varied with the three ASD interfaces and the three CV applications. The integrated display performed best in the IMA event. In the EEBL event the audio-visual and integrated displays performed best. Audio only and integrated displays performed best in the LTA event. The performance of the integrated display for the IMA and EEBL applications suggests ASDs may be less effective than OEM installed systems in certain events. For event outcome (crashes), when the direction of threat was clear and no driving maneuver was in progress at time of alert such as EEBL events, there was neither a benefit nor dis-benefit associated with any of the displays. Yet when direction of threat was unclear and no maneuver was in progress (IMA), there was a benefit associated with the integrated display, which included threat direction information. However, when a maneuver was in progress and threat direction was unclear (LTA), there was a dis-benefit associated with the integrated display. The EEBL event was the only CV application for which participants responded they understood to what the warning was alerting them, that the warning was easily and quickly understood, and useful.

No instances of alert suppression occurred during this study meaning that no drivers were responding to the potential collision at the time of alert from the CV application. This finding suggests that the designed crash threat scenarios allowed the ASDs to warn the participants before they were aware of potential collisions and thus provided them the chance to respond to the threat. This finding also suggests, however, that a wider range of collision threat scenarios, and perhaps more naturalistic, longitudinal research would be necessary to study the impact of nuisance warnings and investigate the potential benefits of warning adaptation and suppression. These potential benefits and the impact of nuisance warnings may only emerge after extended use of a CV system under normal driving conditions.

Conclusions

ASDs are still in the early stages of development and there is no consensus regarding what final products will look like once they are available to consumers. Experts also disagree about the fundamental requirements of ASDs, including whether access to vehicle onboard data is required for adequate functionality and whether professional installation of devices will be necessary.

The experiment described here addressed critical issues regarding ASD interface and vehicle integration, using three prototype interfaces based on existing concepts. Results show that there were some differences in response times between interfaces, but these differences were dependent on collision scenario and some analyses lacked adequate cell counts to make statistical comparisons.

1. Introduction

1.1 Background

This report describes the activities and findings of the National Highway Traffic Safety Administration (NHTSA) project "Aftermarket Safety Device Driver Vehicle Interface Guidance Development." It addresses human factors considerations for the driver-vehicle interface (DVI) associated with potential aftermarket safety device (ASD) products for Connected Vehicle (CV) applications.

CV technology enables networked wireless communications among individual vehicles, the transportation infrastructure, and other entities, such as pedestrians or passenger personal communication devices. Vehicles equipped with CV capabilities would be aware of the locations and trajectories of other equipped vehicles in the vicinity. Drivers could therefore be notified of potential dangerous conflict situations, such as someone about to run a red light as they near an intersection. The CV concept provides a potentially very significant increment in crash avoidance technology. It removes the limitations of being able to detect emerging threat situations solely from onboard sensors and provides a means of projecting the actions of a range of other roadway users in the vicinity of the driver's vehicle, without line-of-sight requirements. The U.S. Department of Transportation has been conducting research on this concept for over a decade and the technology has matured substantially. The Connected Vehicle Safety Pilot Model Deployment demonstrated the relatively successful ability of vehicles to transmit and receive appropriate information. However, while the ability to transmit, receive, and process signals from other vehicles (V2V), as well as from infrastructure (V2I) or other roadway users and elements (V2X), is advanced, this is not sufficient for insuring that the driver will be capable of *using* this information so that drivers can respond more rapidly, appropriately, and consistently. Furthermore, the system must not introduce problems due to distraction, workload, or confusion.

In projecting the benefits of V2V safety applications, one needs to consider both the effectiveness of the safety applications and the extent of fleet penetration (C_i, communication rate) of the communication technology (Harding et al., 2014). The effectiveness of a V2V-based safety application measures the direct and immediate benefit to a driver in terms of detection and avoidance of imminent threats by that application. However, fleet penetration must reach critical levels before the application can achieve a high enough C_i to make the system effective. Aftermarket device such as those communicating a Basic Safety Message (BSM) "here I am" may be use for accelerating C_i. Other low cost, low capability ASD use not only can accelerating C_i but also provide safety benefit.

Given this, it is essential to develop an understanding of the requirements for the DVI for CV devices. The displays (auditory, visual, haptic) must be adequately perceived and comprehended and the systems of which they are components (set of functions, suite of displays, range of messages, system operational concept) must promote appropriate responding. NHTSA has been active in research dealing with CV interface features and operational concepts. However, most research implicitly assumes an original equipment manufacturer (OEM) system, or at least a fully-integrated device, which is the ideal. Practically, however, aftermarket products are not likely to offer the same range of displays and operational features. In discussing the readiness of V2V technology for application (Harding et al., 2014), NHTSA recognized the difficulty of predicting the range of potential aftermarket equipment and drew a parallel with how other functions that may be provided by the OEM (e.g., navigation) have become available in dedicated aftermarket devices (e.g., navigation devices) and intelligent personal devices (e.g., smart phones, tablets). Such products may have inherent limitations associated with the driver interface, such as message content, display modalities, display characteristics, and ability to adapt algorithms to current vehicle status and driver actions.

Ideally, CV functionality would be fully integrated with existing vehicle safety and information systems. This would allow use of OEM-provided display capabilities and avoid problems of multiple alerts, message inconsistencies, and so forth. It would also allow full use of driver and vehicle status information available from onboard sensors. Vehicle manufacturers are developing such fully integrated CV capability. However, the potential benefits and problems with potential ASDs that have more limited capabilities than OEM systems are not well understood. For example, ASDs do not have inherent access to many vehicle-based data elements, including elements of the BSM (e.g., transmission state, steering wheel angle, vehicle safety flags such as ASD activation and wiper state). These limitations could potentially impair ASD capabilities or performance. ASDs may also have different interfaces, such as a single auditory alert. A better understanding of driver response to potential aftermarket products may provide support for the acceptability of, and requirements or design features of, DVIs for ASDs across a range of possible capabilities.

1.2 Objectives

This project included a sequence of activities in order to provide a better understanding of the relationship of ASD CV DVI features with driver behavior and safety. The objectives as stated in the contract Statement of Work were:

- Support the Human Factors Connected Vehicle (HFCV) research program by conducting research that will examine the ASD DVI in the areas of human factors, systems design, and system performance. Some of the research results will feed into the next generation HFCV Principles, which is the primary product of the HFCV Program.
- Increase understanding of human factors issues, including identifying limitations and gauging the effectiveness of the ASD DVI.
- Obtain data and results to support NHTSA's HFCV program.

In order to achieve the project objectives, the following sequence of project activities was implemented.

- Focused review of literature related to DVI, with particular interest in aftermarket products
- Identification and description of available and planned product information, from manufacturer web sites and others sources
- Interviews with industry experts
- Analytic assessment of potential functional impact of onboard data sources
- Development of research plans to address key issues identified in the review and analysis
- Implementation and conduct of simulator experiment

The subsequent sections of this report describe the technical work and findings of the project.

2. Information Search and Review

The information search was comprised of a literature review, an analysis of current products, and interviews with experts in industry and relevant CV research. The intent was to derive a picture of current product status and industry trends, identify key issues for aftermarket device interfaces, and highlight important challenges and knowledge gaps.

In accordance with the goals of this project, the scope of this search and review primarily focused on the convergence of aftermarket devices, V2V functions, safety information, and DVI. Given that there is little information available in literature or practice that addresses all four of these topics together, the review also drew from these topics individually where appropriate. Although focused on V2V safety functions, other V2X features and non-safety messages were considered because of the limited number of examples of V2V safety systems and because V2V safety must be considered within a broader system context that includes a wide range of CV applications and messages. The review did not focus on the technological underpinnings of CV and CV devices, though technology was addressed to the extent that it affects device interface and capabilities.

The methods and key findings of the search and review are summarized here. Full documentation of the review effort is provided in an interim project report (Levi, Yahoodik, Singer, Lerner, and Marshall, 2016).

2.1 Overview of Connected Vehicle Approaches Considered in Review

It is possible to envision a range of integration strategies for CV products that are not provided by the vehicle manufacturer as original equipment. At one extreme, a product could be entirely stand-alone, providing its own communications and data processing capabilities and conveying messages to the driver using its own displays. Some may not even provide a display but rather make use of displays such as smartphone screens or sounds. At the other extreme, products might be OEM-approved and dealer-installed to ensure consistent installation parameters and to allow connection with vehicle power, antenna, and data sources. Harding et al. (2014) first distinguish V2V OEM devices from V2V aftermarket devices. The OEM device is:

> *"an electronic device built or integrated into a vehicle during vehicle production. An integrated V2V system is connected to proprietary data busses and can provide highly accurate information using in-vehicle information to generate the Basic Safety Message* (BSM). *The integrated system both broadcasts and receives BSMs. In addition, it can process the content of received messages to provide advisories and/or warnings to the driver of the vehicle in which it is installed. Because the device is fully integrated into the vehicle at the time of manufacture, vehicles with Integrated Safety Systems could potentially provide haptic warnings to alert the driver (such as tightening the seat belt or vibrating the driver's seat) in addition to audio and visual warnings provided by the aftermarket safety devices. It is expected that the equipment required for an integrated OEM V2V system would consist of a general purpose processor and associated memory, a radio transmitter and transceiver, antennas, interfaces to the vehicle's sensors, and a GPS receiver. Such integrated systems are capable of being reasonably combined with other vehicle-resident crash avoidance systems to exploit the functionality of both types of systems."*

Such an OEM device provides a standard against which aftermarket devices may be compared. An aftermarket V2V device is one that provides:

> *"advisories and warnings to the driver of a vehicle similar to those provided by an OEM-installed V2V device. These devices, however, may not be as fully integrated into the vehicle as an OEM device, and the level of connection to the vehicle can vary based on the type of aftermarket device itself. For example, a "self-contained" V2V aftermarket safety device could only connect to a power source, and otherwise would operate independently from the systems in the vehicle. Aftermarket V2V devices can be added to a vehicle at a vehicle dealership, as well as by authorized dealers or installers of automotive equipment. Some aftermarket V2V devices (e.g., cell phones with apps) are portable and can be standalone units carried by the operator, the passenger, or pedestrians."*

Harding et al. then further define three subcategories of aftermarket devices: vehicle awareness devices (VAD), ASD, and retrofit safety devices (RSD).

- A VAD simply transmits a BSM to other vehicles. It does not provide any messages to a driver and has no driver interface. Therefore, VADs are not relevant to this project.
- An ASD has the ability to both receive and transmit data to nearby vehicles. It also contains safety applications that can provide advisories or warnings to the driver. Example applications might include, for example, forward collision warning (FCW) or emergency electronic brake light (EEBL).
- Harding et al. describe the RSD as more fully integrated than the ASD: it connects to the vehicle and receives information from the vehicle's data bus to support operation of various applications on the device…The advantage of RSDs, as compared to the other types of aftermarket devices, is that they can potentially perform different or enhanced safety applications or execute more sophisticated applications because they can access a richer set of data (i.e., data from the vehicle CAN bus). For example, having information on the turn signal status from the vehicle provides the device and application an indication of possible driver intent to make a turn, which can help inform the Left Turn Assist (LTA), Do Not Pass Warning (DNPW), Blind Spot/Lane Change Warning (BSW/LCW) safety applications. Therefore, the RSD is the closest of all of the aftermarket devices to a V2V device integrated into a new vehicle.

Using the Harding et al. (2014) categories, the systems types addressed in the present project are ASD and RSD. However, within these subcategories there are still a range of approaches and degrees of integration. OEM devices are not the direct focus of interest, but are relevant in providing a benchmark against which aftermarket devices may be compared. Table 1, taken from the Harding et al. report, summarizes the definition of categories as well as considerations of installation and functionality. Note that Harding et al. indicate that all three aftermarket CV device types require some degree of professional installation to ensure proper placement of the DSRC antenna and system security, as well as an installer for the vehicle data connection, if applicable.

Table 1. Aftermarket device types (from Harding et al., 2014)

Device Type	Definition	Method of Installation	Functionality
Vehicle Awareness Device	Device is able to be connected to the vehicle for power source. Device provides Basic Safety Message for surrounding vehicles.	Device would need to be installed by a certified installer on vehicles not equipped with V2V technology to ensure correct antenna placement and security. In the future, VADs might be mobile devices or stand-alone key fobs.	• Transmits BSM
Aftermarket Safety Devices (i.e., Self-contained)	Device is connected to the vehicle for power source, Device transmits BSM and receives BSMs to support safety applications for the driver of the vehicle in which it is installed.	This device only receives power from the vehicle; however, a certified installer would need to ensure correct antenna placement and security.	• V2V Safety applications • Receives and Transmits BSM • Driver-Vehicle Interface
Retrofit Safety Devices	Device is connected to the vehicle's data bus that provides BSM and safety applications for the driver of the vehicle in which it is installed.	This device needs to be connected to the vehicle's data bus, therefore would require an installer that can access this for the particular make of vehicle. Also, a certified installer would need to ensure correct antenna placement and security.	• V2V Safety applications • Receives and Transmits BSM • Driver Vehicle Interface • Integration into the vehicle data bus

The CV device definitions provided by Harding et al. also point to a potential dilemma for ASDs. SAE J2735 specifies the data elements that comprise the BSM. The BSM Part 1 elements are required. An ASD that has no connection to the vehicle's CAN bus can provide most of those Part 1 elements, but cannot inherently provide two required elements: steering wheel angle and transmission state. Unless an ASD can provide those data elements, it is not clear that an ASD can meet the data requirements to participate in the CV environment. Section 3 of this report addresses in greater detail the data elements that may or may not be available in an ASD, and the potential effects that this might have on system capabilities, functionality, and driver behavior.

2.2 Methods for Search and Review

The information search was comprised of three activities:

- a literature search for articles on CV driver interface, with particular interest in aftermarket products;
- identification of available product information, from manufacturer web sites and other sources;
- phone interviews with industry experts.

Findings from these three sources were then integrated in order to identify key issues and knowledge gaps.

The keyword-based literature search focused on driver interface aspects of CV technologies. Although there was particular interest in aftermarket products, we anticipated that there would be little in the way of formal published research or analysis of aftermarket devices. Therefore, the search also encompassed a review of major secondary source materials that dealt more generally with the DVI for CV.

A systematic search was conducted on Google Scholar, Transportation Research Information Services and IEEE Xplore as well in the general Google search engine. A variety of materials were gathered including articles in peer-reviewed journals, presentations at conferences and workshops, articles in popular magazines, and materials from company websites. In addition, existing DVI guidelines and recommendations were compiled as reference materials.

Over 30 keywords were utilized in the literature search, which encompassed the following major topics: CVs, ASDs, interface design, and warnings. The search primarily focused on materials that included combinations of these keywords, as single keywords often generated irrelevant literature. In addition, researchers searched for well-known CV pilot projects in the U.S. and abroad. Over 100 documents were initially reviewed, and approximately 60 documents, some of which were still in press or confidential, were deemed to have relevance to the current project and were compiled in a catalog including details on the topics covered by each literature source.

The search for available CV product information was conducted via general searches on the Google search engine as well as reviews of relevant company websites identified through other sources. A matrix was compiled to assist in gathering detailed product information; ultimately, it was evident that as there is limited information available on the details of the interface design. The information gathered in the internet search was supplemented by further details provided by conversations with industry experts.

Telephone interviews were conducted with knowledgeable representatives of companies active in the CV market, trade organizations, and major research groups. An interview guide developed by the research team was used to help ensure comprehensive exploration of key aspects, including current and forthcoming products, differences among OEM and aftermarket products, driver interface aspects, operational and functional aspects, guidelines or standards used in interface design, and perceptions regarding key knowledge gaps and research needs. Per agreement with the interviewees, in the treatment of the interview findings, there was no attribution of comments to individuals.

A list was compiled of potential contacts based on the literature review and internet search. This list was further supplemented by suggestions from NHTSA as well as by early interviewees. Although a few of the targeted sources were not able to be contacted, industry cooperation, in general, was high and supportive of this effort. Ultimately, interviews or relevant correspondence were completed with 8 companies and 6 organizations in addition to various NHTSA staff. The organizations contacted are listed below.

Companies:

- Autotalks
- Cohda Wireless
- Denso
- Kapsch TrafficCom, Inc.
- Panasonic

- Q-Free
- Qualcomm
- Savari

Trade and research organizations:

- Alliance of Automobile Manufacturers (AAM)
- CAMP Consortium
- Connected Vehicle Trade Association
- SAE Representatives:
- DSRC Technical Committee
- Standard - Onboard Minimum Performance Requirements for V2V Safety Communications
- University of Michigan Transportation Research Institute
- Virginia Tech Transportation Institute

2.3 Aftermarket Device Products and Features

The review of ASD products in development or production occurred in November and December of 2015. In review of product descriptions on company websites and in conversations with industry representatives, information was gathered about both general features of ASD as well specific products that have been or are in the process of development. A wide range of products are being developed for ASD, with several different interfaces. A variety of technical guidelines apply to : IEEE 802.11p -2010; IEEE 1609.2-2013; IEEE 1609.3-2010; IEEE 1609.4-2010; SAE J2735; and SAE J2945.

There are a variety of ASD product designs. A review of information publicly available and conversations with industry contacts point to different DVIs such as dashboard mounted displays, modified rear-view mirrors that display LED warnings, infotainment-integrated displays, head-up displays (HUD) auditory-only devices, and smartphone applications.

Complete details regarding the user interface of these aftermarket devices was usually not available. Even when manufactures present demonstration videos to illustrate the capabilities of their devices, the interface shown may function as a basic exemplar, not a final design. Some of the industry contacts indicated that the designs are not final. According to some experts, the interface is the domain of individual OEMs or Tier 1 suppliers. Because of the emphasis on personalization, these details are often proprietary. Developers use DVI guidelines such as the NHTSA Visual-Manual Driver Distraction Guidelines for In-Vehicle Electronic Devices (NHTSA, 2013) as voluntary, if at all.

Based on internet search and interviews with industry contacts, the following systems were identified:

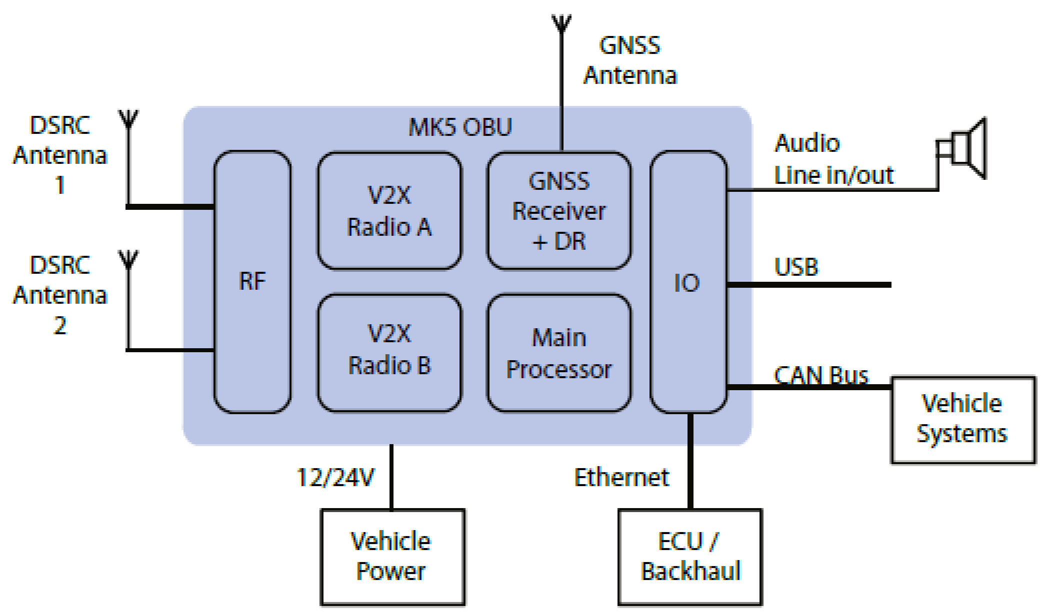
- Arada Systems
    - LocoMate Dual DSRC Classic On Board Unit
    - LocoMate mini 2 DSRC with External GPS and DSRC Antenna
    - LocoMate Mirror Rearview Mirror for DSRC V2X Connected Car
- Cohda Wireless
    - MK5-OBU
    - MK4a-OBU

- Kapsch
    - TS3306 OBU
- Qualcomm
    - Qualcomm's Snapdragon
- Savari
    - MobiWAVE

Details about each of these systems, including specific safety applications, are provided in an interim project report (Levi, Yahoodik, Singer, Lerner, and Marshall, 2016). Review of this range of products and associated industry comment revealed information about typical system components, development maturity, safety features, and the installation process.

Aftermarket devices generally consist of an onboard unit (OBU) and antennae. The OBU is the piece of hardware that contains the chipset and processor. This unit connects to the Dedicated Short Range Communications (DSRC) antenna(s) and the DVI. The device may also incorporate GPS, Bluetooth, cellular data, and Wi-Fi. In general, the OBU and the DSRC antennas are separate so that the antenna can be placed in a spot to optimize range. Figure 1, taken from Cohda Wireless (2015), illustrates the different components likely to be included in an ASD. However, some proposed designs, like Arada's rear-view mirror product, combine the antenna and OBU into one unit.

Figure 1. Illustration of ASD components (from Cohda Wireless, 2015)



A few companies have fully developed V2V DSRC technology, advertised as ready for use or deployment. However, this statement does not mean that the product is ready to market. The hardware and software may be developed, but for many companies, the DVI is not in a final state. Some organizations indicated that they themselves do not plan to develop the DVI, but instead are leaving those decisions to the OEMs or Tier 1 suppliers to which they are marketing their technologies for vehicle integration.

Overall, advertised safety features were generally consistent among brands and products. Listed below are the most common safety warnings for ASD and RSD devices:

- EEBL warning
- Forward collision warning
- Intersection movement assist (IMA) warning
- BSW
- LCW
- DNPW
- Control loss warning
- Pedestrian/bicycle alerts
- Curve speed warning

However, just because a hardware device has the capability of a safety feature does not mean that the product will have the safety feature or that the DVI already presents that feature. Experts emphasized that the safety features that will be present in the released products are largely dependent on what the OEMs or DVI developers want to include. Safety features such as collision avoidance, headlamp control, collision-imminent-automatic-braking, and adaptive cruise control require input into the CAN bus to override an action. Therefore, these features will likely not be feasible for an aftermarket device.

Because there are currently no fully developed aftermarket CV devices available on the market, the installation process and the equipment needed for installation for the general public is not yet mature. Businesses that were likely to install aftermarket systems generally did not distinguish CV systems from other types of systems they install. This is likely due to extremely low market penetration of the CV systems. In general, the businesses indicated that the primary guideline for installation of any type of aftermarket device is the instructions provided by the manufacturers and that these often vary between companies. The businesses are primarily familiar with installation of the following aftermarket equipment: back-up cameras, proximity sensors, and FCW systems (University of Iowa, 2015).

Several industry experts predicted that the DSRC antenna would have to be installed externally for ASDs to ensure optimal accuracy, range, and signal quality. For some experts, there was concern that the installation process and the cables needed to install the antennae would be costly. During the University of Michigan Safety Pilot Model Deployment, GPS antennas were installed on the top of the exterior of the car, with the DSRC antennas mounted either on the package shelf in sedans or by using an interior glass mount unit for vans and crossovers (Gilbert, 2012). However, not all planned products use external antennas. For example, the Arada LocoMate V2X Rearview Mirror incorporates a DSRC antenna into the rearview mirror itself.

2.4 Connected Vehicle DVI Research and Design

There has been limited formal research on ASD DVIs for CV applications. However, industry experts are able to offer important insights regarding issues and potential limitations. Furthermore, there is more substantial research on CV DVI needs in general. In this section, we describe research and industry insight regarding ASDs, as well as more general CV DVI issues, as relevant.

2.4.1 ASD DVIs

In the Safety Pilot Model Deployment in Ann Arbor Michigan, each ASD that was installed in vehicles only provided an audible master warning to drivers with no visual or haptic feedback (Gilbert, 2012). A special speaker was installed under the driver side knee bolster in the Safety Pilot light vehicles equipped with [prototype] ASDs. The readiness of the DVI utilized in the Safety Pilot was reviewed in a United States Department of Transpiration (USDOT) study by Battelle that was conducted for each of the participating devices. The ASDs utilized in the Safety Pilot did have some type of display, however it was determined by the research team that none of them were ready for a model deployment. As presented in the Test Conductor Team Report: "*Most required some type of driver input, were high-theft items, or the display did not dim and was too bright at night. In the end, the test conductor opted for a speaker-only DVI*" (Bezzina and Sayer, 2015).

In an in-vehicle, on-road study to compare driver performance across different types of CV displays, three DVIs were presented to participants. The three types of displays were an integrated display in the center console, a display fixed to the windshield, and an unmounted mobile phone; the researchers indicate that these were selected to simulate the integrated, retrofit and aftermarket systems that are likely to be offered by manufacturers to supported CV (Holmes et al., 2014). These displays were not specifically designed for CV purposes; rather, available devices emulated the future range of displays. Participants received similar applications on all three displays as well as distraction tasks based on the scenarios utilized in a previous study (Cooperative Intersection Collision Avoidance System to Prevent Violations (CICAS-V) Project). The applications included a variety of categories such as imminent safety, non-imminent safety, mobility, and weather. The presentation modes included both visual icons and auditory warnings. The study review did not report whether there were differences in the volume or intelligibility in the different displays. The research team found that the mobile [phone] display yielded lower compliance ratings for the imminent safety alert as compared to the integrated and fixed displays. However, analysis of the time eyes on display (TEOD) metric pointed to significantly lower TEOD for the mobile [phone] display as compared to the fixed or integrated display. Finally, memory recall in a post-trial questionnaire was lower for the information presented on the mobile [phone] display as compared to the fixed and integrated display. The research team suggests that the outcome of the study points to more effective function of the integrated and fixed devices for the simple, emulated CV system applications in the study as compared to an unfixed, mobile [phone] device (Holmes et al., 2014). Based on our discussions with industry experts an ASD DVI may be more likely to have a fixed or mounted position, rather than an unmounted device.

While CV technology may eventually be offered as standard equipment on new vehicle models, ASDs will only be added to vehicles if consumers acquire and install them. Consumer demand and acceptance will be important factors to ensure rapid adoption of CV. As reported in Harding et al. (2014), the Safety Pilot Model Deployment experience shows mixed findings in terms of consumer acceptance. While individuals who experienced CV demos in a clinic setting generally praised the CV technology as useful, intuitive, and desirable, individuals who drove CV vehicles longer-term during the model deployment had more mixed opinions. More than 40 percent of these participants said that their least favorite aspect of the CV system was alerts that they perceived to be incorrect, particularly for FCW, and these experiences negatively affected desire to own a vehicle with CV technology. These findings clearly show that while CV technology is desirable in general, the details of the implementation are critical to success. While there are many aspects involved in minimizing incorrect or nuisance warnings, one that could be particularly important is real-time adjustment of warning algorithms based on current driver, vehicle, and roadway conditions. For example, an FCW may need to be issued earlier if the driver is visually distracted in rainy conditions than if the driver is attentive in dry conditions. While it may be possible to dynamically integrate many variables into OEM or retrofit ASD CV systems, stand-alone ASDs could have limited access to such data. This could have repercussions for the perceived appropriateness of warnings, and in turn, the acceptance and desirability of ASD products. It should be noted that the Safety Pilot consumer acceptance assessment was focused on safety systems, but it remains to be determined to what extent consumers will like and want other features (i.e., mobility and sustainability applications).

A number of feasibility issues related to ASDs were raised by industry contacts. These relate to issues of accuracy, functionality and acceptability. Regarding the accuracy of data due to the fact that ASDs are not directly connected to the vehicle CAN bus, there are likely to be limitations in the type of data utilized by the system to provide warnings to the driver. Without a CAN bus connection, an ASD will not have direct access to two required BSM Part 1 data elements – transmission state and steering wheel angle. Access to vehicle event flags in BSM Part 2 (e.g., ABS activation, headlamp status) will also be limited. In addition, an ASD may have more limited information regarding the footprint and dimensions of the vehicle which is also likely to affect the accuracy of the data. Antennae installation is likely to have an impact on the accuracy of the data as well, and there were industry contacts that discussed the costs and complexity of installing additional equipment including DSRC antennae on behalf of the ASDs. These issues also affect the driver acceptability and interest in purchasing an ASD.

A number of industry contacts pointed to the difficulty of providing safety warnings and messages in an effective DVI platform within an ASD. Some of the issues raised specifically regarding the DVI were the difficulty in prioritizing messages as well as difficulty in making sure the message is “heard” in a setting which may have conflicting information attracting the attention of the driver. Experts point to the potential distraction from the driving task or overload of DVI interaction demands on the driver. Similarly, the research team at Battelle points to the difficulty of integrating aftermarket or nomadic systems. They indicate that, at this time, there is no acknowledged protocol for integrating aftermarket or nomadic systems. In particular, there is an issue with prioritization of messages that may be unreliable or undefined within an aftermarket system (Campbell et al., 2016).

The functionality of the DVI for ASDs is also limited due to the modality capabilities in provision of safety warnings. A number of different possible alert modalities for ASDs emerged during conversations with V2V industry experts, however the design is limited somewhat by what may be presented in an aftermarket setting. Auditory signals, including speech and tonal warnings, are the simplest and arguably the easiest to implement (either coming from a standalone device or fed into a car’s infotainment system). Simple, directional LED alerts can offer a slightly more sophisticated warning system, allowing to driver to recognize what direction the risk is coming from. Simple symbols displayed either on the dashboard or through a secondary display, are another modality of warnings. These symbols would be able to offer context regarding the imminent risk, allowing the driver to better understand the warning and react to the risk. Haptic components are less likely to be included in an ASD, however there are some exceptions, such as a haptic aftermarket steering wheel component (AT&T Steering

Wheel). The type of warning presented may also be influenced by the platform selected options presented by industry contacts include mounted display via cellphone or tablet, rearview mirror with an ASD component, Head Up Display in the windshield, or solely the use of auditory speakers.

In developing CV applications in a smartphone setting, the DVI may be limited to current existing commercial kits such as OSGi standard interface, a modular system and service platform for Java programming utilized in applications such as mobile phones. In addition, the auditory feedback is limited and may not be optimized because it is based on the existing platform. That said, industry contacts indicated that there are currently tests underway that may result in better optimization and allow for more differentiation within a cellular platform. In addition, a smartphone application is viewed by some contacts as a reasonable method to provide safety information to drivers due to the rapid and ongoing improvements in cellular technology and capabilities.

As indicated earlier, one of the issues related to the development of CV is the potential increase in distraction for drivers due in part to the wealth of information that may be provided as a result of the new systems. In considering the development of DVIs for CV, in particular for ASDs, there is a conflict between the interest in allowing innovation so that systems will provide more useful information, but it is vital that these same systems will not overload the driver. In addition, as industry contacts pointed out, if there is too much differentiation in the DVI across systems, it may lead to increased confusion for users when they drive in different vehicles.

Despite these issues, a number of contacts indicated that a variety of ASDs are in development or early stages of production for both the U.S. and European markets. In addition, several contacts pointed to the potential for improved safety even with a less then optimum CV platform. Some developers of ASDs indicated an interest in development of more suitable guidelines that will promote safer DVI for these systems.

CV ASDs have the potential to reduce the number of crashes and increase safety. However, safety itself may not be enough of a “selling point” to induce drivers to willingly buy and install ASDs. According to several experts, one option to increase the attractiveness and value of ASDs would be to combine the safety features with other useful applications. The Connected Vehicle Reference Implementation Architecture (CVRIA) allows for a wide variety of applications including those related to environment and sustainability (that are encouraged in the European setting) as well as applications associated with mobility. Parking locators would be a benefit to users, especially those who drive in urban areas. With the growing emphasis on sustainability and reduction of carbon emissions, an application that would track these statistics could encourage drivers to invest in ASDs. One of the industry contacts pointed out that an ASD may provide services to passengers as well as to the driver, since certain applications in the CVRIA may be directed to the passenger.

Combining these features with safety could help increase market saturation and acceptability however, these additional elements are likely to influence the DVI as they will require inclusion of additional information and warnings for the driver. These additional applications may also result in greater differentiation across developers. Other methods raised as potential for increased sales of ASDs include discounts provided by insurance companies as well as the promotion of new regulations in the U.S., which will encourage rapid penetration of the V2V technology in order to generate those benefits that are dependent on inclusion of the technology in a minimum percent of the fleet.

2.4.2 General DVI Considerations for CV

CV ASDs are still in the early stages of development and no design guidance yet exists to specifically address CV ASD interfaces. However, interface design considerations and guidance may be drawn from other sources that more generally address CV interfaces or aftermarket devices.

One of the strengths of CV is its potential to provide a great range of messages to the driver regarding safety, mobility, and sustainability. The CVRIA currently lists 98 CV applications, 27 of which are V2V or V2I safety. The potential for a large number of messages about a range of topics poses challenges for DVI design. These challenges are discussed below.

2.4.2.1 Message specificity and modality

Given the broad range of potential CV warning applications, it may not be feasible to provide a unique warning for each warning application. For example, Campbell et al. (2016) suggest that "If simple tones are used, no more than four distinct tones are used to discriminate between warnings. If more than four warning applications exist in a vehicle, warnings would either need to be provided in alternative ways (e.g., speech, visual) or multiple warning applications would have to share the same auditory signal." One limitation of using multiple warning signals is that imminent crash warnings are typically rare events, and therefore drivers would not experience the alerts often enough that they would learn to quickly interpret the meanings of tonal sounds. While speech warnings can provide unambiguous context, these warnings may not be adequately intelligible in loud environments and must be very brief to be heard in time to respond to an imminent threat.

As an alternative to multiple auditory alerts, a single master warning signal could be used for all warning applications. A master warning has the advantage of simplifying warning presentation, but the meaning of the warning and the appropriate response might not be clear, especially if the threat is not visually confirmable. This is possible since CV warning systems have the ability to present warnings for imminent threats that may not be visually detectable by drivers at the time of the warning. Examples might include EEBL, IMA, and DNPWs. Warnings of these sorts differ from other warnings in that they must elicit an appropriate response in the absence of direct visual cues to the nature of the threat. Drivers generally to not initiate a vehicle action in response to a warning until they visually confirm its presence. In this case, a general warning tone might not allow the driver to immediately identify the threat, but should prime faster responding through elicitation of safety-relevant responses such as visual search and covering the brake pedal.

Jenness et al. (in press) investigated driver responses to EEBL warnings in two on-road driving experiments. In this experiment, there were three types of warning: 1) vehicle immediately ahead brakes (FCW), vehicle two ahead brakes visible to driver (seen EEBL) and vehicle two ahead brakes not visible to driver (unseen EEBL). In these scenarios, the "braking" vehicles' brake lights illuminated, but the vehicle did not actually decelerate for safety reasons. This experiment showed that among the event scenarios, participants in the unseen EEBL scenario had the least speed reduction and the slowest brake responses. This study also revealed a concerning finding –

many participants who experienced the unseen EEBL scenario responded to the warning by looking away from the forward roadway, often to a display inside the vehicle. However, drivers who had received training about the EEBL warning system before driving had more rapid braking response and more appropriate visual scanning behaviors. These findings suggest that driver response to visually unverifiable threats may be less rapid and less appropriate than for seen threats, but that training and experience can improve performance.

While auditory signals are common for safety warnings, visual displays and haptic displays may also be used. Haptic feedback such as seat belt pretensioning is also promising for use as an imminent crash warning (Forkenbrock et al., 2011). HUDs have also been used in OEM warning systems in combination with auditory signals. While such implementations are feasible in OEM CV systems, they may not be feasible to implement, or may be challenging or costly to implement, for ASDs.

2.4.2.2 Urgency coding

CV systems can provide information ranging from non-urgent convenience notifications to urgent crash warnings. It is important that drivers quickly distinguish urgent warnings that require immediate attention from less critical notifications. Campbell et al. provide guidance on the topic of distinctiveness of warning messages:

The best available research on this topic suggests that this design goal can be met when:

- Auditory warnings use distinctive sounds that are easily distinguished from other auditory signals.
- Vehicles that are equipped with more than one CWS [crash warning system] use auditory signals that are distinguishable among CWS alerts, and are not confused with non-alert sounds
- Auditory cautionary warning signals are distinctive from imminent warnings (although the auditory modality is discouraged for cautionary warnings).
- If simple tones are used, no more than four distinct tones are used to discriminate between warnings.
- Too many distinctive warnings are avoided, as this may confuse drivers. Strategies such as functionally-grouped warnings may help minimize delayed reactions and driver confusion.

2.4.2.3 System integration (sensor and DVI)

In a vehicle with CV capabilities, messages provided to the driver could originate from the CV system, onboard OEM systems, portable aftermarket devices, or some combination of these. As vehicle information environments become increasingly crowded with additional systems and features, it is important to ensure that these systems and features are complementary rather than conflicting, and helpful rather than distracting.

An experiment conducted by Lerner et al. (2014) investigated drivers' responses to various integration strategies of OEM and aftermarket devices in a "Wizard of Oz" procedure conducted during closed course driving. The between-groups design compared OEM device only, aftermarket device only, and three different system integration and message prioritization strategies. Results showed that participants responded to warnings most quickly when only one device was active, but that when both devices were active, greater levels of system integration and message prioritization tended to lead to faster responding.

An experiment by Fitch, Bowman, & Llaneras (2014) investigated distracted drivers' responses to multiple alerts in a multiple-conflict event scenario during closed course driving. An event was staged in which participants needed to swerve to avoid an object on the road ahead (FCW) and then avoid a confederate vehicle during the swerve maneuver (LCW). Results indicated that participants who received both warnings responded more quickly to the lateral threat than did participant who only received the FCW. This suggests that closely proximal warnings for different threats may not cause undue driver confusion or impair responses in complex harard scenarios.

Campbell et al. (2016) describe an HFCV Integration Architecture developed by Doerzaph, Sullivan, Bowman, & Angell (2013) that "governs delivery of information to the driver so that safety-relevant messages are presented in a timely and effective manner." The three processing stages of this architecture are 1) synthesize inputs, 2) manage messages, and 3) present information. The central component of the architecture is a "dynamic integrator" that functions as a brain that controls delivery of CV messages, and possibly other messages, to the driver in a prioritized way to ensure that the most urgent messages receive priority and to avoid overloading the driver with too much information. Ideally, the dynamic integrator would also have information about driver state and roadway environment to be able to adapt message delivery to current conditions (e.g., provide warning earlier to visually distracted driver, withhold non-time critical information during a complex driving maneuver).

Given the potential complexity of the CV information environment, it is important to have a logical message prioritization scheme. The SAE J2395 Recommended Practice provides criteria to determine message priority for presentation to the driver. Tutorial 2 in Campbell et al. (2016) provides the evaluation criteria and subcategories for prioritization:

- "Safety Relevance: The degree to which the information affects the safe operation of the vehicle."
  - Directly Relevant
  - Indirectly/Somewhat Relevant
  - Not Relevant
- "Operational Relevance: The degree to which the information increases the ease and convenience of the driving task, for example, by decreasing travel time and the stress associated with driving."
  - Highly Relevant
  - Moderately Relevant
  - Little or No Relevance/ Significance
- "Time Frame: The degree to which the information is time sensitive, that is, the immediacy with which the information is required."
  - Emergency: 0-3s
  - Immediate: 3-10s
  - Near Term: 10-20s
  - Preparatory: 20-120s
  - Discretionary: >120s

SAE J2395, however, does not directly address the technical challenges in prioritizing non-integrated systems such as ASDs. In addition to the technical challenges of integrating and prioritizing messages from more than one sensor/information source, ASDs will raise challenges in terms of how to present and potentially suppress temporally proximal messages of equivalent priority from multiple systems.

2.4.2.4 Guidelines, standards, and performance assessment

While DVI design guidance specifically for CV systems is limited, performance guidelines for in-vehicle systems can be applied to CV systems. NHTSA's Visual-Manual Driver Distraction Guidelines for In-Vehicle Electronic Devices (NHTSA, 2013) provides guidance for developers of OEM systems regarding device interface, location, and performance (NHTSA, 2012). The fundamental principles that serve as the basis for these voluntary guidelines include issues such as:

- the driver's eyes should usually be looking at the road ahead;
- the driver should be able to keep at least one hand on the steering wheel while performing a secondary task;
- the distraction induced by any secondary task performed while driving should not exceed that associated with a baseline reference task (manual radio tuning);
- and the displays should be easy for the driver to see and content presented should be easily discernible.

In addition, the guidelines propose that tasks or devices that are not suitable for use while driving should be locked out. The protocols proposed by NHTSA for testing devices include use of a driving simulator with eye glance measurement and occlusion tests (NHTSA 2012).

The AAM developed Driver Distraction Guidelines in 2002 together with driver distraction experts, with the purpose of limiting driver distraction that is associated with the use of different types of telematics devices. The current working version was issued in 2006 (Driver Focus-Telematics Working Group, 2006). Alliance members and other companies have tested products against the AAM guidelines and complied with them since. Key metrics used to test products include:

1. "Single glance durations generally should not exceed 2 seconds"; and
2. "Task completion should require no more than 20 seconds of total glance time to the task display(s) and controls."

As an alternative to the glance metrics the benchmark manual radio tuning task is utilized. The document addresses installation, information presentation, interaction with displays and controls, system behavior, and provision of information about the system. The AAM has indicated that their guidelines are utilized by most members and that the guidelines allow for DVI differentiation.

While some standards have been developed for CV hardware, no standards currently exist for CV DVI other than the general requirement for an auditory or visual warning interface provided in the National ITS Architecture version 7.1: "The vehicle shall present information to the driver in audible or visual forms without impairing the driver's ability to control the vehicle in a safe manner." One of the challenges for CV standards development is the number of standards organizations involved in CV. The CVRIA is a framework that spans all standards development and helps to ensure consistency and thoroughness in CV standards development. To date, the existing CV standards have not addressed human factors aspects of DVI.

ASD developers and OEMs referenced various guidelines that they refer to when designing interfaces. Developers, however, may not necessarily abide completely by any particular set of guidelines both because they are non-binding and in some cases there are disparate views regarding the proposed criteria. One set of guidelines referenced by industry contacts is the NHTSA Visual-Manual Driver Distraction Guidelines for In-Vehicle Electronic Devices (NHTSA, 2013), which include guidance on visual-manual tasks for embedded in-vehicle devices. As indicated earlier, key performance goals recommended by NHTSA include minimizing total task performance time, minimizing long glances, minimizing total glance time, and minimizing task performance errors. The NHTSA guidelines are intended to be applied to non-driving related tasks, such as infotainment and navigation system interactions, and therefore do not directly apply to driving- and safety-related systems and warnings.

The AAM guidelines which were designed to minimize the potential for distraction during visual-manual interaction with in-vehicle systems are intended to apply to portable aftermarket devices as well as to embedded devices, to all systems or functions that are designed for use in a motor vehicle (Driver Focus-Telematics Working Group, 2006). The AAM has voiced a concern that there are currently more restrictive guidelines for OEMs, and this may lead to use of portable aftermarket devices by drivers in the vehicle. At this time portable devices are not subject to any federal guidelines, however it is important to note that with the publication of the upcoming NHTSA guidelines for portable devices (Phase II) this issue may be resolved.

Another group that has developed driver distraction guidelines is the Car Connectivity Consortium (CCC), which formed in 2011 and has 94 members representing OEMs as well as telematics companies and other interested parties. The CCC promotes Mirrorlink, which is a display protocol that allows drivers to mirror their smartphone interfaces on approved in-vehicle displays. The concepts promoted by the CCC include:

- once the phone is connected, there is no need to touch or look at the phone
- vehicle controls allow the use of certified smartphone apps

The consortium guidelines are only available to members, and it is unclear how these guidelines correlate with guidance from other sources (Young & Zhang, 2015). Since the CCC supports the use of portable devices, it is feasible that their guidelines may be relevant to the development of ASDs as well.

The NHTSA document *Human Factors Guidance for Driver Vehicle Interfaces* (Campbell et al., 2016) provides detailed human factors design assistance. There are specific sections in the document that are relevant for developers of ASDs, including a section on system integration which provides guidance to developers on how information and messages from multiple sources may be provided to the driver in such a way that the distraction is minimal and safety-relevant messages are delivered in a beneficial manner. One of the relevant resources on system integration is the SAE standard J2395 (*Recommended Practice for prioritizing messages and information presented to the driver)* which focuses on the methods and scheme to present higher priority messages to the driver. In addition, the document presents a tutorial on the HFCV Integration Architecture model, which may also serve to be useful for ASD developers. This is a model for an integrated system which governs the delivery of different types of information to the driver, including both safety and non-safety messages via a message manager component, so that the information is presented in the most effective manner. Expert contacts indicated that this type of software, including a threat detection engine that reviews incoming messages from neighboring vehicles and translates the messages into the appropriate warning for the vehicle, is a key component in CV platforms.

2.5 Aftermarket Safety Device Industry Trends

There are many opinions regarding the future trends for ASDs. Harding et al. (2014) point out that it is difficult to predict the future range of ASDs, but the devices that may be made available on the market are likely to span a variety of forms and functions similar to the developments in navigation devices and applications. A number of industry contacts indicated that one method to increase the share of vehicles with CV technology is by increasing sales of ASDs so that the V2V devices will be effective earlier on. This is largely due to the need for expanded penetration of V2V technology in the fleet in order to accrue the potential benefits, once regulations are in place. Therefore, if regulation requires CV deployment to take place in a short time frame, it will be important for the OEMs to accommodate consumers quickly and this may encourage the development of both retrofit devices and ASDs in order to realize benefits of the V2V technology. Alternatively, there were industry contacts that indicated that ASDs are not likely to develop further due to limitations, including antennae and accuracy requirements, the type of information ASDs will be capable of providing, and the difficulty marketing ASDs. In addition, the role of Tier 1 Suppliers and OEMs in developing CV technologies is progressing rapidly and may result in further limiting the market share for ASDs.

One major question is whether smartphones will be deemed viable as CV ASD interfaces. Most drivers already own smartphones, and the devices include an array of technologies that can be put to use for sensor and warning purposes (e.g., speaker, visual display, vibration, GPS, cameras, and more). If drivers were able to use their smartphones as ASD interfaces, they might be more willing to adopt the technology due to substantially decreased cost, ease of acquisition, and familiarity with their own device. Some CV technology developers are already creating CV applications that can be run on smartphones. It is still undetermined, however, whether smartphones have adequate data security and interface characteristics for CV applications.

There are several issues related to deployment of ASDs that are unknown and are likely to affect viability according to Bishop (2012):

- Vendor willingness to sell
- Customer willingness to buy
- Point of sale - traditional retail outlets or new models
- Potential and model for retrofit equipment

In focus groups, to provide information and recommendations for garnering consumer interest to purchase ASDs, a number of issues were raised by participants (Chan, 2012). The participants recommended that ASD platforms allow for tailored product features that would meet customer needs (e.g., inclusion of comfort and convenience functions along with safety functions). Participants pointed to the need for lower costs, therefore a package that includes both the safety functions and the convenience and comfort features would be ideal. Participants also indicated that distribution channels that allow for easy access to both purchase and installation is important, preferably through current aftermarket retail channels. Finally, the focus group participants indicated that insurance incentives are a positive catalyst for rapid deployment of ASDs and can help counterbalance the desire to limit expenses.

A variety of industry representatives will have a role in promoting and supplying CV technology. In speaking to industry contacts, it is clear that many companies offer services to multiple clients and that there is competition between them. OEM and Tier 1 suppliers are progressing in developing CV technologies. In some cases, V2V technology is already available (e.g., 2017 Cadillac CTS) while other industry contacts indicated that the pace is slower with a focus on developing a new DVI that will suit the more complex information that will be provided to drivers in CV. In addition to these traditional players, there are a variety of companies that are providing software and hardware to support V2V technology. There is overlap in roles, with some companies providing similar products to various markets – for example, there may be a single company that provides software to an OEM, Tier 1 supplier, and to ASD manufacturers. Similarly companies may be involved in development of more than one of the types of aftermarket categories, including VAD, RSDs, and ASDs. These companies range in size, scope and previous experience in the realm of vehicle safety. There were industry contacts that made it clear that some decisions on DVI and production of CV technology, including ASDs, is on hold until NHTSA provides further guidance and the regulatory path is clearly understood.

2.6 Challenges and Knowledge Gaps

One objective of the review was to identify the gaps in knowledge and research regarding ASDs for V2V applications. The review began with the knowledge that ASDs for V2V are a relatively new concept and that there is little direct research or practical experience with these devices to serve as a basis for design assistance or guidance for their development. Despite limited implementation experience, it is clear that ASDs have a variety of inherent or potential differences relative to OEM systems. There are also numerous strategies to implement ASDs, which can affect available applications, modalities, algorithms, and other aspects of user experience. The implementation considerations, challenges, and knowledge gaps related to ASDs for V2V applications are described below. While some of these general issues are relevant to OEM DVIs or other applications, there are aspects that may be of particular concern for ASDs. These issues are organized under the topics of display, alert modality, system integration and functionality, and user acceptability.

2.6.1 Display

- *Interface Approach:* In the past, new features have tended to be added to vehicles slowly over many years, and the evolution of in-vehicle displays and interfaces has tended to be gradual and iterative. The addition of CV to vehicles with the dozens of applications available provides an opportunity for interface developers to “start from scratch” and develop new interfaces suited to the CV environment. This approach could potentially be more easily adopted by ASD developers who are already starting from scratch, as they develop new devices and interfaces, than by OEMs and their suppliers who are beginning with existing cockpit interfaces as a starting point. OEMs may also be constrained by the need for compatibility with other vehicle systems and by a development pipeline that is often looking years into the future.
- *Device location*: The potential location of ASDs in the vehicle may be limited by the availability of free space. Many vehicles have little space available where a device brought into the vehicle would not obscure or interfere with another vehicle device or

airbag. Many States have laws forbidding the placement of devices on windshields. Some display locations might be subject to sun glare. The ASD would also need to be secured in a place in the vehicle that is considered safe in the event of a crash. After these considerations, there may not be many options for placement where the device would be relatively close to the driver's forward field of view. This is less of a concern for devices that have no visual or manual-interactive component. Given the differences between various vehicle makes and models, no single prescriptive installation instruction would work for all vehicles. Unless the device is professionally installed, the driver would have the responsibility to place the device in an appropriate location.

- *System status indication:* Drivers should be aware of the status of warning systems in their vehicles. They should know whether the feature is on and whether it is active. In a laboratory experiment reported in Lerner, Jenness, Robinson, Brown, Baldwin, & Llaneras (2011), results showed that in vehicles with onboard safety systems such as FCW, LDW, and BSW, participants were often unable to tell whether these safety features were currently turned on and operating properly. ASD systems may pose particular challenges. For instance, portable ASDs may require physical connections for data and/or power, or may require a wireless connection such as Bluetooth or Wi-Fi. If these connections are not made, systems may not work as expected. In some instances, a battery-powered device might run on battery power, but shut down when the battery dies. In some cases, users might have the ability to customize which features are active, but might not remember their most recent settings. Therefore, it may be important to consider system status indication as part of the interface when developing DVIs for ASDs.

2.6.2 Alert Modalities

- *Visual*: ASDs face some challenges when designing visual displays. For example, some ASDs may be unable to present certain types of visual displays such as HUDs, or may be unable to present visual information in more than one location (e.g., to present directional indicators). While these features are not impossible to implement, they are more challenging for ASDs than for OEM devices. Ideally, a visual display would be designed in consideration of its exact installation location, but that might not be the case for ASDs that have no single intended location. One potential advantage of visual displays for ASDs is that they can provide information that might not be easily conveyed in other modes, which could be particularly useful for messages other than imminent warnings.
- *Auditory*: While ASDs have the potential to make use of a vehicle's sound system via an AUX cable, Bluetooth connection, or other means, this connection is not guaranteed. Not all existing vehicles provide a means to connect an external device to the sound system. Without this connection, an ASD would likely be limited to a single, relatively low fidelity and low volume speaker. This limitation would preclude the ability to present directional sound indications. The ASD would also not have the capability to mute the radio to present alerts. The loudness and quality of the sound would also be at least somewhat dependent on the location of the device/speaker. Under these conditions, voice messages could potentially suffer from poor intelligibility.
- *Haptic*: Haptic messages have shown promise for the communication of in-vehicle messages. Examples include seat pan vibration, seat belt pretensioning, steering wheel vibration, pedal vibration, and pedal force feedback. Implementing particular forms of haptic feedback in ASDs may be challenging, if not impossible, depending on the device

and the installation method. A professionally installed system with access to OEM vehicle data could theoretically take advantage of existing in-vehicle haptic features, but in vehicles without these features, or without professional installation, ASDs would have to provide their own tactile stimuli For example, while steering wheel vibration may be possible in an aftermarket device, it is also likely to be expensive and complicated to install.

- *Multimodal displays:* Given the potentially complex information environment in a DSRC-equipped vehicle, multimodal displays may prove to have benefits in the provision of redundant or complementary information. Research on display modality should consider multimodal approaches.
- *Warning differentiation:* When determining whether to provide differentiation between warnings, the solution can fall between two extremes: provide a single master warning for all imminent threats or provide a unique warning for each threat. In the middle of the spectrum, other options could include multiple "classes" of warning (e.g., one for forward threats, one for lateral threats, etc.), or a single auditory alarm paired with a more specific visual display. ASDs have some unique considerations when making this decision. First, the warning approach should minimize confusions with other vehicle warnings and systems. Second, ASDs could potentially have fewer options for warning than OEM systems (e.g., no haptic or visual interface, only a single speaker).

2.6.3 System Integration and Functionality

- *Access to CAN bus data*: Whether or not an ASD has access to CAN bus data can have an important influence on how the device operates. The CAN bus is essentially the "brain" of the vehicle in lieu of a host computer, incorporating data from a wide variety of vehicle systems. ASD access to CAN bus data can enable an ASD to become a part of a central message prioritization scheme. It can also provide a substantial amount of supplementary information to influence the approach to warnings. For example, warning algorithms could be adjusted depending on whether the driver is already braking, if roads are wet, if the turn signal is on, and so forth. Given that warnings that are perceived to be unnecessary are a major impediment to consumer demand for vehicle warning systems, the ability to adjust warning algorithms in real time based on current conditions could significantly improve driver perceptions. Of course, implementing CAN bus data properly to maximize safety and the perceived accuracy of warnings is itself a challenge. Even if an ASD does not have access to CAN bus data, however, it is not necessarily "blind" to relevant information that could be used to supplement warning algorithms. ASDs potentially can include GPS, accelerometers, driver face cameras, microphones, and other sensors that can provide some indication of driver and vehicle state. Unless the ASD is using an existing device such as a smartphone that contains these features, adding extra sensors is likely to increase device cost, which could have implications for rate of adoption.
- *ASD retrofit installation*: In practical terms, an ASD is only likely to have access to CAN bus data if the device is approved by an OEM and installed by the dealership or other certified installer. This itself is a challenge because the OEM would have to provide the device with CAN bus codes, which are typically confidential. This might lead to a scenario in which the only ASDs with access to CAN codes are developed by OEMs and their suppliers for retrofit installation. Given that CAN codes differ between vehicle

models, and even some trim levels within a given model year, each ASD would need to be configured for the specific vehicle it which it will be installed. Another implication of this is that retrofit ASDs might not be transferrable between vehicles on either a short term or permanent basis. In other words, the hardware, software, and/or firmware associated with a given ASD might not be compatible with any other vehicle make or model.

- *ASD portable installation*: Portable installations of ASDs represent a tradeoff. While they do not have access to the CAN bus and the data therein, they do have some advantages. First, they do not need to be developed by or in cooperation with OEMs, which could potentially provide more choice to the consumer in terms of which ASD they would want to buy. Portable ASDs would not require a professional installation, which would save consumers money and time. Portable ASDs could also potentially be moved between vehicles on a temporary or permanent basis (though there could be challenges in achieving adequate antenna reception in temporary installations, as described below). Even in a portable ASD, however, some customization is required to identify the host vehicle and, importantly, its external dimensions and the location of the antenna. If a user does not accurately identify their vehicle, there could potentially be negative safety implications, as well as the impression that the ASD is not working correctly.
- *Prioritization*: CV technology will drastically increase the amount of information potentially available to drivers for a variety of functions including safety, mobility, and convenience. While this creates challenges in message prioritization in general, ASDs have their own challenges. While retrofit ASDs that connect to vehicle data systems can theoretically provide message prioritization in the same way that an OEM CV system could, ASDs without that data connection would not have any direct way to be a part of any vehicle-wide prioritization scheme. This could lead to potential issues where multiple safety alerts are presented simultaneously from the vehicle and the ASD (if the vehicle has onboard safety systems). This is just one of many potential scenarios in which lack of prioritization could lead to messages presented to the driver in a less than ideal way. It will be important to understand the scenarios in which less than ideal prioritization may occur and how those influence safety and driver opinions about the systems. There may also be some ways to customize systems to minimize the likelihood of message conflicts, such as turning off one of two redundant warnings (OEM warning or ASD warning).
- *Antenna accuracy*: Antennas (both GPS and DSRC) will need to be installed for ASDs, either inside or outside the vehicle. For V2V applications, a location accuracy of approximately 18 inches is required. While DSRC antennas may be able to achieve that level of accuracy with an antenna on the vehicle exterior, antennas located inside the vehicle (e.g., between the windshield and the rear view mirror) may not meet this accuracy requirement. Among the experts interviewed for this project, there was no consensus on whether an antenna in the vehicle interior would meet the accuracy requirement or not. It will be important to better understand consumers' real world expectations of ASDs, how such installation requirements will affect their interest in ASDs, and whether or not consumers are capable of installing antennas on their own or if professional installation (perhaps including drilling and wiring through the vehicle roof) might be necessary and acceptable to consumers.
- *Power*: While OEM systems receive uninterrupted power directly from the vehicle, aftermarket devices need to be plugged into a vehicle power source and/or powered by

their own internal batteries. Failing to plug in a device, or allowing a battery to drain could result in a non-functional ASD. In addition, if a driver needs to plug in their ASD every time they drive, they may be less likely to use it. Research on real-world use of ASDs and similar devices could provide evidence of whether drivers keep their devices powered, and whether requirements for ASD connections to power and data influence how likely drivers are to use the ASD.

2.6.4 User Acceptability

- *Willingness to pay for device*: Unlike OEM systems, which in the future could be required in the development of new cars, consumers must voluntarily opt into purchasing ASDs. Harding et al. (2014) suggests that consumers are currently not willing to pay much for CV technologies. However, real-world experience with CV is very limited, and high-profile news stories about the potential safety concerns of CV could affect current opinions. Consumer opinion could potentially change as public knowledge and real-world use expands. In order for aftermarket devices to help V2V integration reach a critical mass, the device must offer good value for money. Public information campaigns could potentially help to better inform the public about the benefits of CV, and ASDs in particular. Research on current consumer knowledge and opinions about ASDs, as well as exploratory research about features that consumers want and do not want could aid in the design of public information about ASDs, as well as the designs of these products.
- *Perceived system accuracy*: Harding et al. (2014) provided a revealing finding regarding consumer acceptance. They report that in the Ann Arbor Safety Pilot, drivers who experienced a demo of the V2V safety functions under ideal circumstances had generally very positive opinions of V2V. However, drivers who experienced V2V safety systems in the actual Safety Pilot over a longer period of time had more mixed opinions, largely due to warnings that were perceived to be unnecessary. This highlights the potential gap between ideal and real-world perceptions of CV, as well as the critical need to meet driver expectations as far as warning algorithms and minimization of perceived unnecessary warnings. It would be useful to have a better understanding of what constitutes an unnecessary warning in the minds of drivers, and the correlation between perceived unnecessary warnings and system acceptance. Special consideration should be given to warning scenarios where threats are not visually confirmable (e.g., EEBL) to determine whether drivers mistakenly interpret these warnings as false alarms. Some evidence of this outcome was found by Jenness et al. (in press), though for safety reasons these experiments did not include an actual hard braking event, so such participant attributions are worthy of further investigation.
- *Additional features*: Other non-safety features added to aftermarket devices may increase the attractiveness and perceived value of ASDs to consumers. Identifying which features (parking assistance, ecological monitoring, insurance discounts) are most likely to convince a consumer to buy an ASD could help improve adoption. These additional features, however, also potentially bring with them new challenges for prioritization, distraction, and workload management.
- *Customization*: For ASDs, some degree of customization will be required to identify the dimensions of the subject vehicle and the location of the antenna. However, drivers could potentially be given the ability to customize a variety of system features, including which

warnings/features are active, warning algorithms (e.g., warn earlier or later), and even aspects of the auditory and visual interface. Customization could potentially improve consumer satisfaction, but could also lead to inconsistencies between devices or performance that is not in compliance with best practices. Research on consumer preferences could help to identify where customization would be desirable to drivers, and empirical research could help to determine the parameters or boundaries within which customization should be allowed.

3. Relation to Onboard Data Sources

As noted earlier, ASDs may differ from OEM-provided CV systems in that they may lack access to onboard vehicle data. ASD concepts differ in the degree to which they may integrate with the host vehicle and are able to share in onboard information as well as in-vehicle interface components. OEM CV systems themselves may make use of different sorts of information for adapting algorithms that trigger warnings, message content, or vehicle-initiated control actions. An analytic effort provided some preliminary indication of the kinds of onboard data that may be integrated into warning algorithms and the potential consequences of not having access to such data.

3.1 Key Onboard Variables

As a basis for identifying potential benefits and problems associated with a specific onboard data source, a systematic approach for mapping onboard information items to CV system performance aspects was developed. In order to organize the extensive set of onboard variables, we grouped them under a set of functional categories/subcategories. At the highest level, the categories are Vehicle State, Roadway/Environment State, Driver State, Driver Intention, and External Object Detection. Table 2 shows the structured set of variables.

Table 2. On board variable categories and subcategories

Vehicle State	Roadway/ Environment State	Driver State	Driver Intention	External Object Detection
Vehicle Characteristics	Road Conditions	Distraction	Lane change/merge	Obstacle distance
Vehicle Install Factors	Traffic Conditions	Drowsiness	Right/left Turn	Obstacle direction
Vehicle Dynamics	Environmental Conditions	Alcohol Impairment	Passing/overtaking	Time detected
Vehicle Systems Status		Other/general Impairment	Slowing/stopping	Vehicles
			Intended Route	Pedestrians
				Fixed/stationary object
				Sign recognition
				Road marking

3.2 System Performance Aspects and Associated Behavioral Outcomes

Six general categories of system performance aspects were identified against which the potential impact of the variables could be assessed. These system performance aspects are:

- Resolution, Precision: Does the lack/impairment of a variable limit the ASD's ability to capture variables with maximum resolution, precision, accuracy, confidence, etc.? These descriptors can relate to time, distance, latency, and various other measures.
- System Redundancy, Complement: Does the lack/impairment of a variable limit the ASD's ability take advantage of redundancy or complementary data streams? Data redundancy can increase system robustness in case one stream is unavailable or unreliable (e.g., CAN speed can replace GPS speed when traveling in a tunnel). Complementary data streams may improve data precision or confidence level (e.g., if data from two sources agree, can be confident that it is accurate).
- Predict Conflict/Hazard: Does the lack/impairment of a variable reduce the ASD's ability to predict or detect a conflict/hazard? Example: lack of yaw (vehicle lean/roll) data could reduce the system's ability to detect excessive curve speed.
- Adapt Warning Algorithm: Does the lack/impairment of a variable limit the ASD's ability to tailor warning algorithms? A wide range of variables could be considered, including driver state, vehicle state, environmental conditions, etc.
- Adapt Warning Display: Does the lack/impairment of a variable limit the ASD's ability to adapt the warning display in a way that is suited to current conditions? This could include changing physical aspects of the warning (mode, intensity) but does not include message timing or priority (those are separate system performance aspects).
- Message Priority: Does the lack/impairment of a variable limit the ASD's ability to prioritize/suppress warnings and less urgent messages appropriately? A wide variety of variables could potentially feed into these calculations. Prioritization could include prioritization of messages with the CV environment, as well as prioritization of messages from other sources such as the vehicle itself.

The impact of any particular variable may depend to some degree on the specific CV application. The analysis shown here is specific to IMA and LTA applications. IMA/LTA applications are particularly critical CV applications with high potential for safety benefits. A given system performance limitation will have an impact on CV functional performance, which in turn will result in particular driver behavior outcomes. The matrix in Table 3-2 shows the predominant behavioral effects that may be associated with particular performance limitations.

3.3 Mapping of Onboard Variables to System Performance Aspects

A matrix was constructed mapping the onboard variables against the set of system performance factors. Seven experienced researchers independently identified cells in this matrix where there were anticipated to be meaningful effects. The seven analysts included those with degrees in human factors, industrial engineering, electrical engineering, and research psychology.

The matrix in Table 4 shows the outcome of this analysis. Cells where there was strong agreement (at least 5 of 7 analysts indicated the cell) are marked with an X and highlighted. Also, row totals for the total number of checks for a given variable are shown in the right-most column. The degree of shading of these cells also indicates the frequency of citing (deeper reds are more often cited). This matrix thus shows what performance aspects a given variable may influence (going across rows), what variables may affect a given performance aspect (going down columns), and what variables have broad impacts across performance aspects (row totals). While there is a subjective component to this analysis, it provides an initial indication of where ASDs might suffer relative to OEM systems and what sorts of onboard data, or similar data from other sources, might improve ASD benefits. Results showed that lack of ASD access to vehicle CAN bus data could potentially have detrimental effects on ASD performance and driver behavior across a wide range of variables. It is also important to note that two required components of the BSM Part 1 (transmission state and steering wheel angle) are not available to an ASD without access to vehicle status information.

Table 3. Mapping of behavioral effects to system performance limitations

PERFORMANCE LIMITATION	BASIS OF LIMITATION	POTENTIAL FUNCTIONAL IMPACT	POTENTIAL BEHAVIORAL OUTCOMES				
			Delayed or missed driver response	Confusion, poor comprehension	Inappropriate or non-optimal driver response	System non-use, defeat	Consumer will not acquire or install
Resolution, precision	Spatial and temporal aspects of algorithms, such as location, path, vehicle boundaries, less well specified	Misses, false alarms, overly conservative algorithms	X			X	X
System redundancy, complementary measures	Cannot compare vehicle-based and CV prediction, for confirmation or independent detection	Missed events, false alarms	X			X	X
Prediction of driver intent, conflict	Cannot incorporate cues to intent such as signal use, steering, braking, point of gaze, head pose	Delayed system recognition, poorer suppression of unnecessary alarms	X	X	X	X	X
Adaptation of warning algorithm to current state: Determination of current driver state	Cannot incorporate attention, distraction, drowsiness, alcohol/drug impairment	Algorithms cannot compensate for reduced operator ability	X	X			
Adaptation of warning algorithm to current state: Determination of roadway/environment state	Cannot incorporate traction, rain/snow, temperature, grade	Algorithms cannot compensate for changes in vehicle response	X				

PERFORMANCE LIMITATION	BASIS OF LIMITATION	POTENTIAL FUNCTIONAL IMPACT	POTENTIAL BEHAVIORAL OUTCOMES				
			Delayed or missed driver response	Confusion, poor comprehension	Inappropriate or non-optimal driver response	System non-use, defeat	Consumer will not acquire or install
Adaptation of warning algorithm to current state: Determination of current vehicle state	Cannot incorporate gear status, brake status, tire status, load, etc.	Algorithms cannot compensate for current vehicle response, or overly conservative algorithms	X			X	X
Display adaptation to current condition	Interface display too loud/soft, too bright/dim	Missed or misinterpreted warnings, annoying or distracting signals	X	X			
Prioritization among threats	Cannot consider both CV and vehicle-based events in determining message priority	Non-optimal warning, interference among warnings	X	X	X		
Coordination with active driver assist functions	Vehicle actions are not coordinated with ASD alerts	Driver confusion, signal credibility		X	X		

Table 4. Mapping of onboard data elements to CV system performance aspects for IMA and LTA applications

			System Performance Aspect						
	Inherent to Minimal ASD	BSM1 Required	Resolution, Precision	System redundancy, complement	Predict conflict/ hazard	Adapt warning algorithm	Adapt warning display	Message priority	Count
VEHICLE STATE									
Vehicle Characteristics									
Vehicle size									
Vehicle width	Input	Y							5
Vehicle length	Input	Y							4
Vehicle data (referred to as a "complex type" in J2735, rather than an element or frame)									
Vehicle height	Input								0
Bumper heights									
Bumper height front	Input								1
Bumper height rear	Input								1
Vehicle mass	Input								9
Trailer weight	Input								7
Vehicle type	Input								5
Vehicle class	Input								5
Vehicle Install Factors									
Antenna location	Input								6
Antenna location relative to vehicle dimensions	Input								6
Vehicle Dynamics									
-Position (local 3D) (DF)									
Latitude	GPS	Y							2
Longitude	GPS	Y							2
Elevation	GPS	Y							2
Positional accuracy	GPS	Y							0
-Motion (DF)									
--Transmission and speed (DF)									
Transmission state	No	Y							12
Speed	GPS	Y							10
Heading	GPS	Y							14
Steering wheel angle	No	Y							23
RPM	No								8

			System Performance Aspect						
	Inherent to Minimal ASD	BSM1 Required	Resolution, Precision	System redundancy, complement	Predict conflict/ hazard	Adapt warning algorithm	Adapt warning display	Message priority	Count
Clutch position	No								6
Handbrake/Emergency brake	No								10
Pitch (longitudinal angle)	No								10
--Steering, sequence of:									
Steering wheel angle rate of change	No				X	X			22
Driving wheel angle	No			X					15
--Acceleration set (DF)									
Longitudinal acceleration	GPS	Y							10
Lateral acceleration	GPS	Y							10
Vertical acceleration	GPS	Y							3
Yaw rate / yaw rotation	Potential	Y							14
--Path history (DF)									
--Full position vector (DF)									
Date and time stamp	GPS								4
Transmission and speed (DF) – same as in Part 1									
Time confidence									3
Position confidence set (DF)									
Position confidence									8
Elevation confidence									10
--Speed and heading and throttle confidence (DF)									
GPS status	GPS								10
Count – number of “crumbs” in the history	GPS								5
-Transmission and speed (DF) – same as in Part 1, NOT an offset									
--Path Prediction (DF)									
Radius of curve									16
Vehicle Systems Status									
-Brake system status (DF)									
Brake applied status	No	Y		X	X	X		X	31
Brake status not available	No	Y							11
Traction control state	No	Y							16
Antilock brake status	No	Y							15
Stability control status	No	Y							15

			System Performance Aspect						
	Inherent to Minimal ASD	BSM1 Required	Resolution, Precision	System redundancy, complement	Predict conflict/ hazard	Adapt warning algorithm	Adapt warning display	Message priority	Count
Brake boost applied	No	Y							13
Auxiliary brake status	No	Y							5
-Vehicle safety extension (DF)									
--Event flags – A data element consisting of single bit event flags:									
Hazard lights	No								6
Intersection stop line violation	Potential (V2I)				X				16
ABS activated	No				X	X			19
Traction control loss	No				X	X			19
Stability control activated	No				X	X		X	22
Emergency response	Accel, yaw								7
Hard braking	Accel, yaw								9
Lights changed	No								5
Wipers changed	No								6
Flat tire, tire pressure	No								9
Disabled vehicle	No								5
Air bag deployment	No								1
-Vehicle status (DF)									
Exterior lights	No								11
Light bar in use	No								2
Cruise control/ACC status	No					X			18
Vehicle occupancy	No								7
Driver identification	No					X			8
Seat belt status	No								8
Fuel level, low fuel warning	No								2
Infotainment system status	No						X		14
State of automated functions (if present)	No				X	X	X	X	28
Check engine light status	No								2
Active safety system status (on/off, active/not active)	No				X	X			22
Active safety system activation	No							X	16

			System Performance Aspect						
	Inherent to Minimal ASD	BSM1 Required	Resolution, Precision	System redundancy, complement	Predict conflict/ hazard	Adapt warning algorithm	Adapt warning display	Message priority	Count
ROADWAY/ENVIRONMENT STATE									
Road Conditions									
Traction Control	No								12
Road data (from GPS data; includes road class, speed limit, traffic control devices, etc.)	No								19
Lane lines (detection, confidence)	No				X				18
Traffic Conditions									
Traffic conditions ahead (from NAV/traffic data)	No				X	X			17
Environmental Conditions									
-Wipers (DF)									
Wiper status front	No					X			13
Wiper rate (front)	No					X			14
Wiper status rear	No					X			12
Wiper rate (rear)	No					X			13
Rain sensor	No					X			15
Ambient air temperature	No					X			11
Ambient pressure	No								1
-Weather report, defined as a sequence of the following:									
Is raining – defined in NTCIP standard	Potential (V2I)					X			14
Rain rate – defined in NTCIP standard	Potential (V2I)					X			15
Precipitation situation – defined in NTCIP standard	Potential (V2I)					X			14
Solar radiation – defined in NTCIP standard	Potential (V2I)								5
Mobile friction – defined in NTCIP standard	Potential (V2I)								9
Time of day	Yes								5
Ambient light (sensor)	No								14
Sun glare	No						X		15
Ambient noise	No						X		12
DRIVER STATE									
Distraction									

			System Performance Aspect						
	Inherent to Minimal ASD	BSM1 Required	Resolution, Precision	System redundancy, complement	Predict conflict/ hazard	Adapt warning algorithm	Adapt warning display	Message priority	Count
Head pose	No					X	X	X	25
Eye glance direction	No					X	X	X	25
Infotainment system interactions (music, communications, internet search, etc.)	No					X	X		18
Current manipulation of other vehicle controls	No					X	X		18
Drowsiness									
Eyelid closure (PerClose)	No					X	X		21
Head pose	No					X	X		22
Time of day	GPS								6
Alcohol impairment									
Passive alcohol detection	No					X	X		22
Other/General Impairment									
Lane position, stability	No								12
DRIVER INTENTION									
Lane Change, Merge									
Turn signal status	No								17
Lane position	No				X				12
Head pose	No				X	X	X		21
Eye glance direction	No					X	X		20
GPS/Routing data	GPS								4
Right/Left Turn									
Head pose	No						X		17
Eye glance direction	No						X		18
Steering wheel angle	No								17
Turn signal status	No								18
GPS/Routing data	No				X				14
Passing/Overtaking									
Lane position (e.g., cross centerline)	No								13
Acceleration	GPS								5
Speed	GPS								5
Tachometer/RPM	No								6
Turn signal status	No								15

			System Performance Aspect						
	Inherent to Minimal ASD	BSM1 Required	Resolution, Precision	System redundancy, complement	Predict conflict/ hazard	Adapt warning algorithm	Adapt warning display	Message priority	Count
Passed vehicle characteristics (e.g., speed, length)	V2V								4
Slowing, Stopping									
Driver foot position	No					X			16
Brake pedal position	No				X	X			20
Acceleration	GPS, accel								10
Speed over time	GPS, accel								9
Intended Route									
Driving route history	No								8
Time	GPS								2
Position (GPS)	GPS								4
Navigation system routing	No								10
EXTERNAL OBJECT DETECTION									
Object data, sequence of:									
Obstacle distance	No			X	X				27
Obstacle direction	No			X	X				27
Time obstacle detected	No								15
Vehicles	No			X	X			X	25
Pedestrians	No			X	X			X	26
Fixed/stationary objects	No				X			X	25
Signage recognition	No				X	X			22
Road markings	No			X	X	X			26

4. Driving simulator study

4.1 Hypotheses

The primary hypotheses tested in the simulator experiment are provided below as assertive predictions, rather than as the related "null hypotheses" for inferential statistical testing:

- Driver response time to and type of response to a warning are related to the ASD interface and onboard information, the CV application, and their interaction.
- The benefits of ASD warnings on the event outcome are related to the ASD interface and onboard information, the CV warning application, and their interaction.
- Driver comprehension of an ASD warning is related to the ASD interface and onboard information, the CV warning application, and their interaction.
- The perceived benefits and acceptance of an ASD system is related to the ASD interface and onboard information, the CV warning application, and their interaction.

4.2 Method

The simulator experiment focused on driver response to potential crash situations providing data on response time and event outcomes for different ASD interfaces in a safe and controlled environment. The pattern of accelerator pedal release, brake application, and steering responses as a function of ASD system and interface provides an understanding of benefits associated with different interface aspects. Additionally, user comprehension data were collected to further understand the effects of the interface on driver response and event outcome. The simulator experiment placed drivers in potential crash situations that were not possible in an on-road study. The events and driving scenarios provided realistic CV warnings to drivers in situations where the absence of a driving response would lead to a crash. The driving simulator study focused on driver response measures: accelerator pedal release time from incursion vehicle visible, brake response time from incursion vehicle visible, steering response time from incursion vehicle visible; and the outcome measure collisions.

The experiment employed a 3 x 3 x 2 between-groups factorial design. Three ASD DVIs were compared for three different CV applications, with each DVI occurring with and without access to onboard data access. Thus, there were 18 experimental groups, with six participants per group.

4.2.1 Safety Applications

4.2.1.1 Left Turn Assist (LTA)

These systems warn a driver who is attempting to turn left that there is oncoming traffic that would make the turn unsafe. The system warns when it determines that a collision will occur unless the driver responds. These V2V systems provide warnings even when the oncoming vehicle is not visible to the driver.

4.2.1.2 Intersection Movement Assist (IMA)

These systems warn the driver about intersection crashes. Two common scenarios are the situation where the driver is stopped at an intersection before proceeding and when the driver is proceeding through an intersection without stopping. In either case, the system warns the driver that a vehicle is on a collision course with them in the intersection and a driver response is required. In some cases, this can be associated with an incurring vehicle that does not stop at a controlled intersection.

4.2.1.3 Emergency Electronic Brake Lights (EEBL)

In EEBL systems, a remote vehicle sends information about an emergency braking event that a CV system receives, presenting an alert to the driver, if appropriate. The remote vehicle is more than one vehicle ahead of the driver.

4.2.2 ASD DVIs

Three prototype ASD DVIs were included in this experiment. These systems' features were developed to meet three primary goals: 1) each system should represent a distinct approach to CV instrumentation; 2) each system should include design and interface features that currently exist in warning systems, or are likely to exist in CV systems; and 3) other than the key variables of interest related to warning approach, system features should be held constant across systems so that differences in driver behavior can be attributed to specific variables that are manipulated. One challenge in developing these systems was that very few examples of prototype CV systems have been made public, so it was unclear what features would be "typical" of such systems. While there are many examples of onboard, sensor-based warning systems, it is possible that CV warning systems may be distinctly different in some ways due to their broader range of applications and capabilities. As a result, the prototype system interfaces were based on a combination of existing sensor-based systems, the few available examples of prototype CV systems, human factors research and guidance, expert judgment regarding likely interface approaches for future CV systems, and feasibility of experimental implementation.

All three systems had the same master warning sound used for all warning scenarios. The warning signal was a beep with a burst duration of 0.2 seconds. The burst was repeated 11 times with no gap between bursts for a total signal duration of 2.2 seconds. The sound had a dominant frequency of 1575 Hz. Previous research suggests that drivers unambiguously interpret this sound as a warning (Lewis, Eisert, Baldwin, Singer, & Lerner, 2017). The paragraphs below describe each DVI level.

Level 1 (audio only) was based on the ASDs used in the Ann Arbor CV Safety Pilot (Gilbert, 2012). This system had an auditory-only interface that was essentially nothing more than a single small speaker. The warning sound played once for approximately two seconds and did not provide any context to indicate the nature or location of the hazard.

Level 2 (audio-visual) used the same audio alert as Level 1 and added a visual display component that was mounted on the dashboard to the right of the steering wheel. Each warning included a visual icon. The icon showed an overhead diagram of the subject vehicle with the general direction of the hazard indicated by a flashing red bar and warning triangle, as seen in Figure 2. Possible hazard directions included left side, diagonal forward/left, straight ahead, diagonal forward/right, and right side. The auditory warning played once for approximately two seconds, but the visual display indicated the threat for five seconds. Figure 3 shows the Level 2 display as mounted in the simulator cabin.

Figure 2. Directional visual icons

Figure 3. Level 2 (audio-visual) display on simulator dash to right of steering wheel

Level 3 (integrated display) represented a system professionally installed into a vehicle, using both existing vehicle systems and newly added displays. This system was able to provide directional auditory warnings, either emanating from the driver's left, right, or center/front. The visual warning system used a series of red LED light bars located around the simulator cabin to indicate the direction of the hazard. The light bars were a part of the simulated dash and A-pillar. When a hazard was emerging, the auditory warning played from the appropriate direction (left speaker for hazards left as in the IMA event, and center for hazards ahead of the vehicle as in the EEBL and LTA events). The appropriate LED bar would flash using the same directional logic as used for the visual display in Level 2. This system was based on the Volvo FCW HUD that flashes a red light bar on the windshield to orient drivers' attention to a forward collision threat. Level 3 expanded this concept to provide visual threat indications in front of the driver, diagonally on the left and right A-pillars, and to the left and right of the vehicle near the side view mirrors. Figure 5 shows the forward and left A pillar light bars. This system also had the advantage of being feasible to retrofit in a wide variety of vehicles and did not require the vehicle to have configurable LCD panels or other advanced onboard display capabilities. It also provided a distinct contrast to Level 2, while maintaining the same basic approach to directional warning. The auditory warning played once for approximately 2 seconds, but the visual display indicated the threat for 5 seconds.

Figure 4. Level 3 (integrated display) with "left" warning displayed

Cab modifications to include LED alerts are built into the cab, which represents a vehicle the simulator driver occupies and controls during a scenario simulation. The alert geometry was built using references provided by the client for location, relative size and general appearance. The alerts were integrated into the nadscab_taurus2011 cab model, and include options for:

a) Not present (no alert visible, default cab appearance)
b) Present but OFF
c) Present but ON

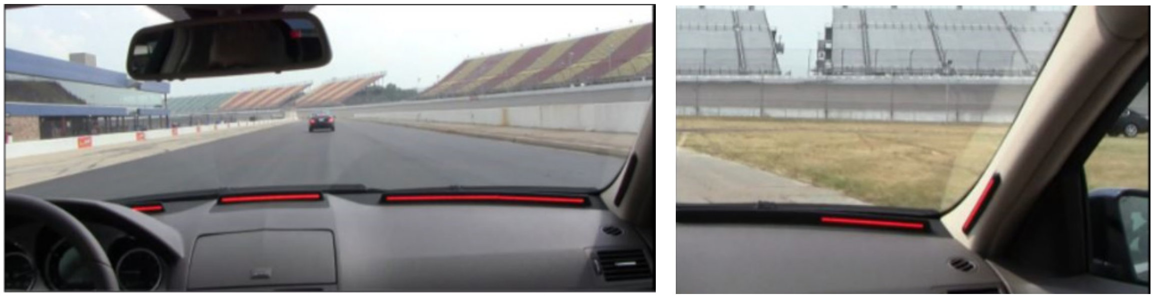


Figure 5. Reference for alert display in cab model

The cab is a 3D model, and is rendered within the same graphics context as other simulated scenery visible to the driver. Elements in the scene are rendered using a directional light source. In order for the cab and alerts to be rendered without the influence of a directional light source, the model uses a technique called flat-shading. When polygons are flat-shaded, they render at full intensity, irrespective of the light source. Thus, during daytime scenarios, the interior renders at full intensity. Because the polygons which comprise the ownship are textured, full intensity is lessened somewhat as texture provides visual detail but also acts as a brightness filter.

The cab interior and alerts are contained within time-of-day nodes in the model that control what geometry is visible during day or night simulation. The cab is constructed using standard shading for night-time, which prevents it from appearing unnaturally bright during night simulation.

4.2.3 Apparatus

The NADS ¼ cab miniSim was used for data collection. This miniSim has three 42-inch 720p plasma displays as shown in Figure 6. The miniSim includes three screens (each 3.0 feet wide by 1.7 feet tall) placed 4 feet away from the driver's eye point. This configuration produces a horizontal field of view of 132 degrees and a vertical field of view of 24 degrees. Visual icons could be displayed within the visual field, for example on the A-pillars or in the rearview mirror, in the configurable instrument panel, or as additional equipment on the dash or other appropriate location relative to the driver's eye point. The audio system default included speakers mounted below the left and right displays. Driving performance data relating to lane position, speed, steering, accelerator pedal, and brake pedal are recorded at 60 Hz.

Figure 6. miniSim driving simulator

4.2.4 CV Safety Applications

The scope of the project allowed for three CV safety applications: IMA, LTA, and EEBL. The driving scenarios were designed to present a single warning event at the end of the drive for a total of three scenarios. A practice drive with no warning or crash events preceded each scenario to allow the participant to acclimate to the simulator. The use of only one event type per scenario minimized the potential for sensitizing participants to potential crash events ensuring an unprimed response to the alert and event.

In order to collect data on participants' comprehension of the alert, no training on the warning systems was provided. The warning systems were implemented through the driving scenarios to allow full control of experimental conditions, consistent timing and orchestration of events Each of the three scenarios described above was implemented with each combination of experimental conditions, as shown in Table 5.

Table 5. Experimental conditions

	No Onboard Data	**Onboard Data Present**
Audio Only	EEBL, IMA, LTA	EEBL, IMA, LTA
Audio-Visual	EEBL, IMA, LTA	EEBL, IMA, LTA
Integrated Display	EEBL, IMA, LTA	EEBL, IMA, LTA

This experiment used three CV applications (IMA, LTA, and EEBL). The intersection-related applications (IMA, LTA) were the highest priority, since NHTSA has identified them as priority applications for safety benefit. EEBL was included because it was also of interest and represented a conflict that occurs at locations other than an intersection. All events occurred at the end of each drive.

4.2.5 Presence of Onboard Data

The availability of onboard vehicle data from the host vehicle to the CV system was implemented at two levels, present and not present. The three onboard data streams used when onboard data were present were turn signal, brake application, and steering wheel angle. In experimental conditions where onboard data were not present, the event used only CV data from the remote vehicle or incursion vehicle to orchestrate the event. The presence of onboard data allows CV systems to better predict driver intention and situation awareness. Since the three onboard data streams from the host vehicle have different implications for each of the scenario events, their importance varies across the events. Table 6 summarizes the onboard data variables.

Table 6. Implications of onboard data when present

	Turn Signal	Brake Application	Steering Wheel Angle
EEBL	Possible passing/lane change maneuver intended	Driver in process of responding	Possible lane change/maneuver intended
IMA	Not activated indicates probably continuation on forward path	Application indicates early response to potential threat	Small angle indicates no current deviation from current path
LTA	Activation indicates an intention to turn	Brake release indicates intention to proceed through intersection	Angle indicates current path through intersection

When onboard data were present, the alert was suppressed if the driver was already in the process of responding at the time an alert would have been issued. When onboard data were not present, the timing of the warning was based solely on the presence and location of the remote or incursion vehicle compared to the location of the host vehicle (see Table 7).

Table 7. CV warning presentation conditions

	No Onboard Data	Onboard Data Present
EEBL	Remote vehicle brake lights activate	Remote vehicle brake lights activate and host vehicle deceleration and intended path indicate conflict
IMA	Remote vehicle is present as cross traffic	Remote vehicle is present and host vehicle onboard data indicates insufficient response by host vehicle
LTA	Remote vehicle is present as oncoming traffic	Remote vehicle is present and onboard data indicates intention of host vehicle to proceed through intersection and cross remote vehicle path

4.2.6 Driving Scenarios

Participants experienced one practice drive followed by one study drive that concluded with one crash scenario with a CV crash warning applications (EEBL, IMA or LTA). Each participant experienced only one crash scenario. All crash scenarios included an alert from one of the three CV applications. The focus of this effort was to determine whether the types of displays expected in aftermarket systems elicit different responses from driver than OEM-installed systems. The audio only and audio-visual represent the potential aftermarket display types, while the integrated display represents a highly integrated or OEM-installed system.

4.2.7 Practice Drive

All participants' first simulator drive was a practice drive, which allowed them to get used to driving the simulator, following the lead vehicle, and maintaining lane position. The drive began with the participant's vehicle stopped in the lane on a two-lane rural highway with light ambient traffic in the oncoming lane and a speed limit of 35-45 mph. Audio instructions were embedded in the scenario instructing participants to shift the transmission into drive and begin driving. Once the participant had started driving, the participant followed a lead vehicle, which maintained a headway of 10 seconds. A follow (trailing) vehicle maintained a five-second headway behind the participant. The lead vehicle obeyed the speed limit and the maintain gap had reasonable values for max acceleration/deceleration to minimize any visual artifacts. The maintain gap for the lead vehicle had a minimum speed of 45 mph. The maintain gap for the follow vehicle had a minimum speed of 20 mph. The participant encountered a stop sign that provided an opportunity to apply the brakes to become familiar with the deceleration of the vehicle. The initial speed limit of 45 mph reduced to 35 mph partway through the drive to give the participant variability in driving conditions. The practice scenario ended when the driver encountered a stop sign at a T-intersection, with the lead vehicle turning off. The practice drive lasted approximately six minutes.

4.2.8 Study Drives

The study drives are described in Sections 4.3.1, 4.4.1, and 4.5.1, specific to each drive, for ease in reference when considering the study results.

4.2.9 Sampling and Participant Recruitment

One hundred eight (108) participants were necessary to complete the experimental protocol, as shown in Table 8. The participant sample was balanced for gender and included individuals age 25-55. Participants had no prior simulator study experience with any of the systems presented during the simulator drives. Further inclusion requirements were that participants were in good general health, reported normal or corrected to normal vision and hearing, drove at least 3,000 miles per year, and drove at least once per week. Mean and standard deviation of driver age are provided for each scenario in Sections 4.3.1.2, 4.4.1.2, and 4.5.1.2.

Table 8. Participant distribution across experimental conditions

	No Onboard Data	Onboard Data Present	# of Participants
Audio Only	EEBL = 6 IMA = 6 LTA = 6	EEBL = 6 IMA = 6 LTA = 6	36
Audio-Visual	EEBL = 6 IMA = 6 LTA = 6	EEBL = 6 IMA = 6 LTA = 6	36
Integrated Display	EEBL = 6 IMA = 6 LTA = 6	EEBL = 6 IMA = 6 LTA = 6	36
# of Participants	54	54	108

Participants were recruited through emails to the NADS volunteer registry and to the University of Iowa community. Researchers first screened interested individuals who contacted the research team via a telephone questionnaire. Individuals who were willing to participate and met all inclusion criteria were scheduled for a study visit. Participants were considered enrolled once they had provided informed consent at the beginning of their study visit.

4.2.10 Independent Variables

The study had a between-subjects design in order to provide each driver with only experiencing one crash scenario during any one study. This prevents priming drivers to have faster responses in crash situations. The independent variables were driving scenario (IMA, LTA, EEBL), ASD interface (audio only, audio-visual, integrated display), and the presence of onboard data (present, not present) to allow for alert suppression. Gender was balanced in each experimental block.

4.2.11 Dependent Measures

The dependent measures included the outcome measure of collision, driving performance measures, and subjective measures of experience with the alert administered through a post-drive survey. Measure definitions and question stems are provided in Table 9. All driving performance measures were calculated from the point where the incursion vehicle became visible to the driver. Negative values are responses after the alert and before the vehicle was visible. Positive values are responses after the incursion vehicle was visible. Accelerator pedal position is measured from 0 = not depressed to 1 = full depression. Brake application is measured in pounds of pressure where 0 = no braking. The first response variable was included to capture all driver performance responses due to low numbers of specific responses in some events.

Table 9. Dependent measures

Dependent Measure	Description
Outcome	
Collisions	Binary measure indicating whether the driver collided with incursion vehicle during scenario event
Driver Response	
Accelerator Pedal Release Time from Visible	Time to full accelerator pedal release, accelerator pedal position 0
Brake Response Time from Visible	Time to brake application as indicated by 3 pounds force (lbf) on the brake pedal
Steering Response Time from Visible	Time to participant turning steering wheel 6 degrees or greater with a steering wheel velocity of 120 degrees per second during the response.
Accelerator Application Time from Visible	Time to accelerator pedal position of .4 or greater; additionally, in the LTA scenario if the accelerator position was .4 or greater at visible point an absolute change of .1 was considered an accelerator application (for example, a change from .42 to .52)
First Response from Visible	Time to driver's first response whether it was accelerator pedal release, braking, steering, or accelerator pedal application
Post-drive Question Stems	
Did you know what sort of event the warning was trying to alert you to before you saw the other vehicle? - Selected Choice (yes/no)	
How easily and quickly could you interpret this warning? - Please rate using this 1-5 scale 1= very easily/quickly, 5 = very difficult/slowly	
How useful was the warning to you in this situation? - Please rate using this 1-5 scale 1 = very useful, 5 = not useful at all	
How distracting was this warning? - Please rate using this 1-5 scale 1 = not distracting at all, 5 = very distracting	
Would you pay to have this type of system installed in your vehicle? - Selected Choice (yes/no)	
If yes, how much (in dollars)? – open text field	

4.2.12 Experimental Procedure

Study participants attended a single study visit that included three phases: briefing, simulator drives, and debriefing. After participants provided informed consent, they completed a demographic questionnaire. This questionnaire asked questions about driving experience and experience with in-vehicle safety systems. A researcher confirmed that the participant had a valid driver's license with nothing more than vision restrictions. Participants next viewed a presentation that reviewed the driving simulator and instructed them to drive as they normally would during the study drives. In order to collect uninfluenced alert comprehension data following their drives, the experimenter did not explain the CV systems they experienced during their drives. After the simulator overview, participants moved to the driving simulator.

A researcher pointed out features of the simulator to participants, such as the seat and steering wheel adjustment controls and ensured the participant was comfortably seated in the simulator before the simulator drives. Each participant completed one practice drive consisting of roughly 6 minutes of rural driving. After the practice drive, participants immediately completed a short wellness survey that asked the participant to report symptoms of simulator sickness to ensure they were able to progress to the study drive. Each participant next completed one of the three study drive scenarios. Following the study drive, participants immediately completed another short wellness survey. This was done immediately following the drive to ensure capture of any symptoms that may have affected their driving response to events during the drive.

4.2.13 Debrief

After the scenario ended, participants completed a post-drive survey about the events they experienced and the CV warnings presented. Once the survey was completed, participants completed a short survey that asked about the realism of the simulator. Following the realism survey, any questions participants had about the study were answered and the study visit ended.

4.2.14 Data Handling

For driving performance data, summary statistics were used to describe the data and inferential statistics will be used to compare different ASDs and components of the individual systems. Analyses focused on the effect of ASDs on drivers' responses in collision-imminent scenarios. This included qualifying the nature of driver responses (steering, braking) and quantifying the speed of the response (e.g. brake response time). These measures were compared using inferential statistical approaches to compare different ASD systems or individual components of the interfaces.

For demographic and driving experience data collected through surveys, summary statistics were used to describe the participants' age and responses regarding the alert interface. Driving performance measures were used to compare the three ASD interfaces and three driving scenarios. Analyses focused on the:

- Nature of driver initial response (steering, braking, accelerator pedal application, no response)
- Speed of response (e.g., brake response time)

Data reduction was performed using MATLAB. During data reduction, each data file was individually opened and the required variables were read into the MATLAB workspace. Some raw values, e.g., lane deviation, required cleaning in order to calculate the specified dependent measures. Once the raw data were clean for the entire file, dependent measures were calculated for each of the scenario events.

4.2.15 Data Analysis and Statistical Modeling

Driver response variables were analyzed from the point the incursion vehicle became visible. Responses due to the alert prior to the point where the incursion vehicle is visible have a negative value. This approach supports discussion of whether the CV alert prompted drivers to respond before they would have without the alert.

Dependent measures were calculated and analyzed for each event (Table 10). No steering or accelerator pedal application responses occurred for the EEBL event, as would be expected. For each dependent measure, the number of responses may not equal the total sample size; that is, not all participants exhibited all possible responses. Additionally, drivers' first response from the incursion vehicle becoming visible was also analyzed, regardless of which type response they had.

Table 10. Dependent variables for each event

Dependent Measure	EEBL	IMA	LTA
Collisions	●	●	●
Accelerator Pedal Release Time from Visible	●	●	●
Brake Response Time from Visible	●	●	●
Steering Response Time from Visible		●	●
Accelerator Pedal Application Time from Visible		●	●
First Response from Visible	●	●	●

An ANOVA was conducted for all response time variables using the SAS Mixed procedure. The independent variables included in the model were level of display, age, gender and suppression along with interactive effects. Due to small sample size, it was decided a priori for level of display, that post hoc comparisons would be considered at the $p<0.05$ level when a main effect of $p<0.1$ was obtained. For all other main effects a significance of $p<0.05$ was maintained. Post hoc tests were based on the SAS Least Squares Post Hoc test.

4.2.16 Alert Suppression Using Vehicle Onboard Data

Driving scenarios allowed suppression of alerts if vehicle onboard data indicated the driver was responding to the potential collision situation prior to the alert, yet no alert suppression occurred. There were no instances where the driver was responding to the potential collision at the point the alert would have been issued. Since no alert suppression occurred, all drives within a scenario–interface combination were analyzed as one condition, regardless of whether onboard data were present. This effectively doubled the number of participants in each ASD display condition to 12.

4.3 Intersection Movement Assist Scenario

4.3.1 Specific Method

4.3.1.1 Driving Scenario

The IMA scenario was an urban drive during which participants approached several traffic signal controlled intersections. There was no set lead vehicle in this scenario. There was light ambient traffic in the oncoming lane and the speed limit was set to 35 mph on an urban street, indicated by a speed limit sign. At several intersections prior to the event intersection, traffic crossed the intersection in front of the driver with a green or yellow light in the direction of the cross-traffic. All traffic signals cycled to green as the driver approached the intersection. As the driver approached the event intersection, the incursion vehicle was created as cross traffic from the left at the driver's speed, 360 feet from the collision point. The incursion vehicle approach was hidden by semi-trucks in a parking lot next to the road. Timing of the IMA event is shown in Figure 7. The scenario ended with a prompt after the driver reacted to the incursion vehicle and continued through the intersection and down the road. This scenario lasted 3-4 minutes. Figure 8 provides a visualization of the driving scene at the point of the IMA warning.

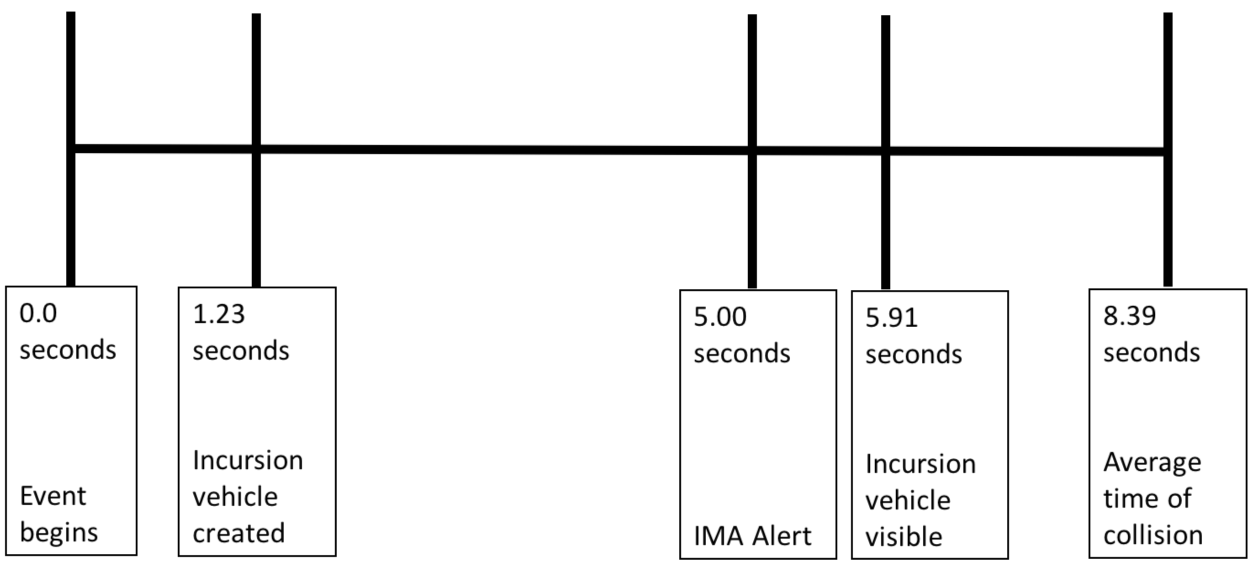


Figure 7. Timing of IMA scenario

Figure 8. IMA scenario at point when incursion vehicle becomes visible

4.3.1.2 Participants

Table 11 provides the distribution of age for the IMA scenario. For the three ASD DVI warning levels (audio only, audio-visual, and integrated display).

Table 11. Participant gender for each ASD DVI level for the IMA scenario

	# of Participants	Mean Age (std. dev.)
Audio Only	12	37.22 (8.87)
Audio-Visual	12	37.00 (10.07)
Integrated Display	12	42.00 (11.02)
Total	36	38.68 (10.28)

4.3.2 Results

4.3.2.1 Outcome

Most participants experienced crashes in the IMA event (Table 12). There were slightly fewer crashes for the integrated display.

Table 12. Crashes for each display type in the IMA event

	Audio Only Display	Audio-Visual Display	Integrated Display	Total
No Collision	0	1	3	4
Collision	12	11	9	32
Total	12	12	12	36

4.3.2.2 Driver Performance

Most participants had an accelerator pedal release response (Table 13). For accelerator pedal release time, a significant effect was found for display type (p=0.0007). In follow-up tests, the audio only display (p=0.0002) and the audio-visual display (p=0.074) were both different from the integrated display. The integrated display had a lower accelerator pedal release time than the other two displays. The audio only and audio-visual displays were not different (Figure 9). Note that the means are indicated by the horizontal bar within the boxplot and the diamonds connected by lines across the boxplots indicate the medians. Outliers are indicated by small circles above or below the boxplot.

Table 13. Number of accelerator pedal release responses by display type for IMA event

	Number of Responses
Audio Only	11
Audio-Visual	12
Integrated Display	12

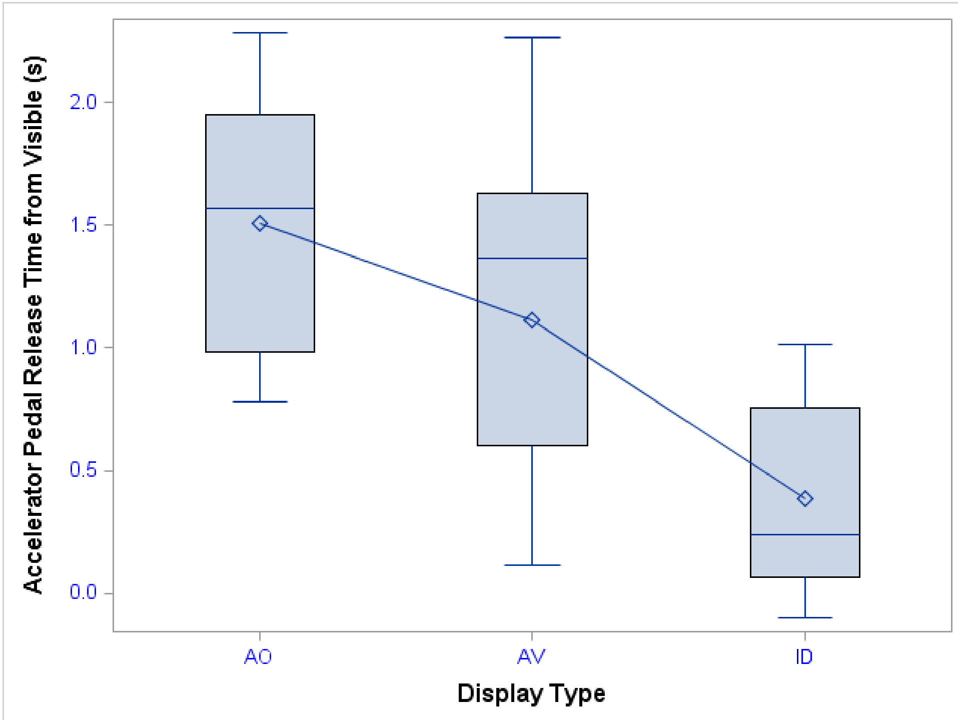


Figure 9. Accelerator pedal release time from visible for IMA event

Most participants had a brake application response (Table 14). A significant effect for display type was found (p=0.0140) for brake response time. Follow-up tests showed the audio only and audio-visual displays were not different, while both the audio only (p=0.0306) and the audio-visual (p=0.0064) displays were different from the integrated display. The integrated display had a lower brake application time than the other two displays. The audio only and audio-visual displays were not different from one another (Figure 10).

Table 14. Number of brake responses by display type for IMA event

	Number of Responses
Audio Only	10
Audio-Visual	10
Integrated Display	12

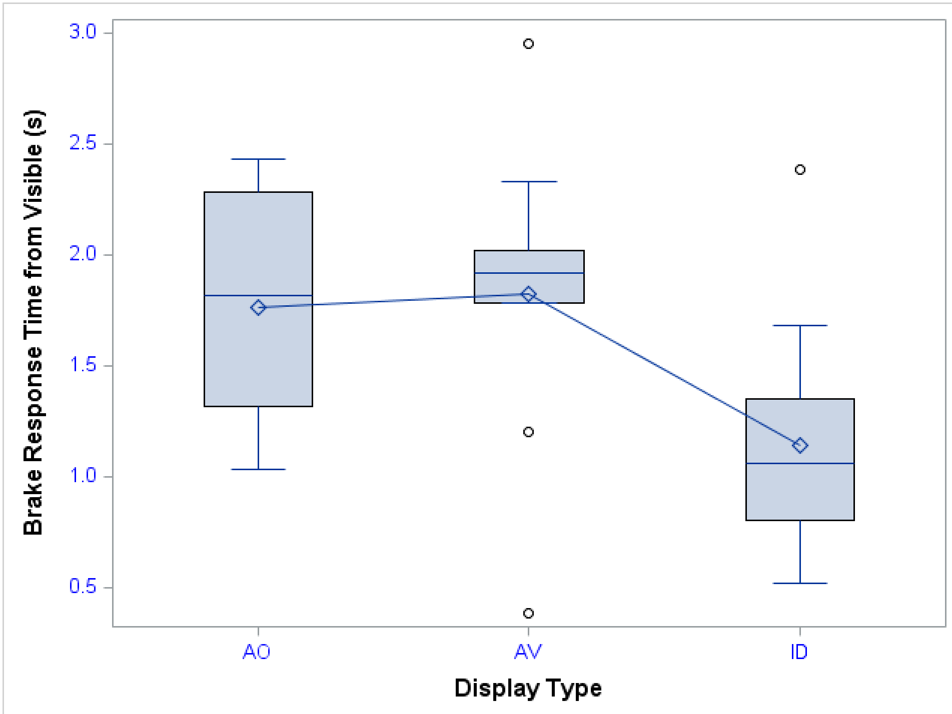


Figure 10. Brake response time from visible for IMA event

For steering response time, there were seven steering responses for IMA event (Table 15), a sample size too small for ANOVA. Steering responses across the display types do not show a trend (Figure 11).

Table 15. Number of steering responses by display type for IMA event

	Number of Responses
Audio Only	3
Audio-Visual	2
Integrated Display	2

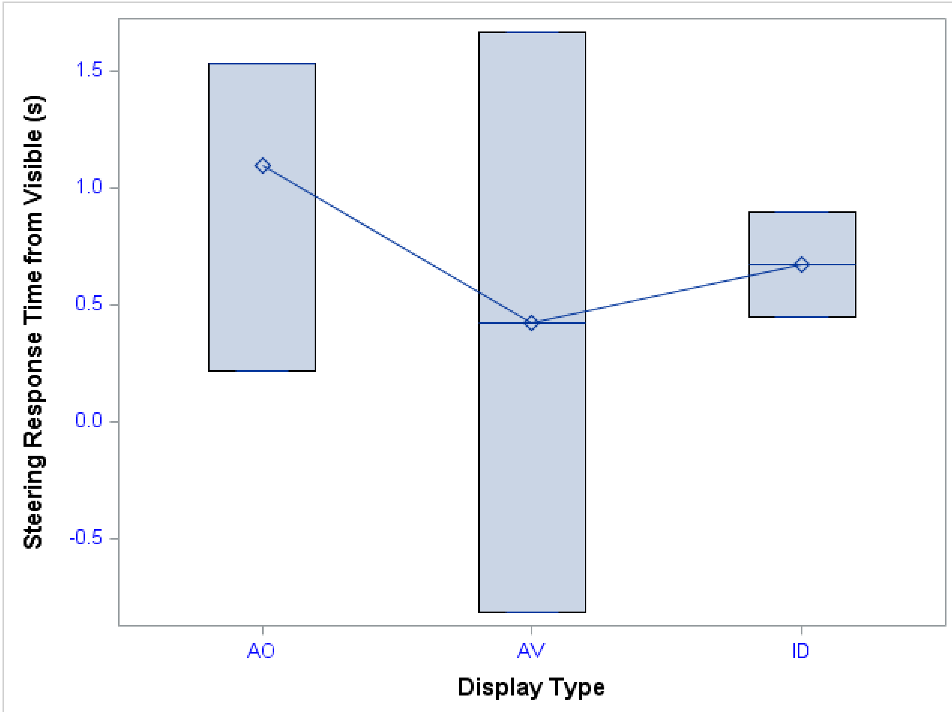


Figure 11. Steering response time from visible for IMA event

Very few accelerator pedal application responses in the IMA event occurred (Table 16). There was no statistically significant result for accelerator pedal application response time, as there were too few responses for analysis. No follow-up tests were conducted. No figure is provided for these data due to the low response count.

Table 16. Number of accelerator pedal application responses by display type for IMA event

	Number of Responses
Audio Only	2
Audio-Visual	1
Integrated Display	0

Since first response is the shortest of a participant's accelerator pedal release, braking, steering, or accelerator pedal application responses, the number of responses available for analysis are greater (Table 17). A significant effect was found for first response (p=0.0086). In follow up tests, the audio only display was found to be different than the integrated display (p=0.0024) and a difference between the audio-visual display from the integrated display was near significance (p=0.0575). The integrated display prompted faster first responses than the audio only and the audio-visual display (Figure 12). Recall that first response is defined as the shortest response time for accelerator pedal release, braking, steering, or accelerator pedal application response for each participant.

Table 17. Number of first responses by display type for IMA event

	Number of Responses
Audio Only	11
Audio-Visual	11
Integrated Display	12

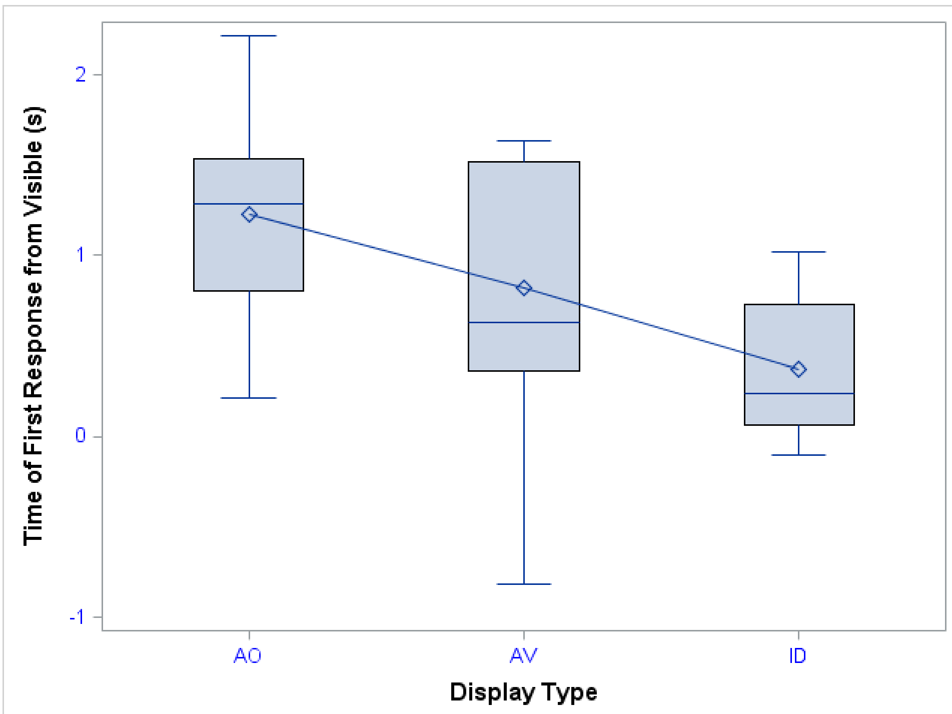


Figure 12. First response time from visible for IMA event

4.3.2.3 Subjective Data

Recall the rating scales used for question responses (Table 9) where the lower the rating, the more positive the view. Most participants reported they did not know the sort of event the warning was alerting them to across all three display types (Figure 13) and most responses tended toward very difficult or slow to interpret end of the scale (Figure 14) None of the three displays was rated as useful, with the audio-visual rates as the least useful (Figure 15) and the most distracting (Figure 16). More participants reported they would pay for the integrated display than the other two (Figure 17), yet the highest mean dollar amount was reported for the audio-visual display (Figure 18).

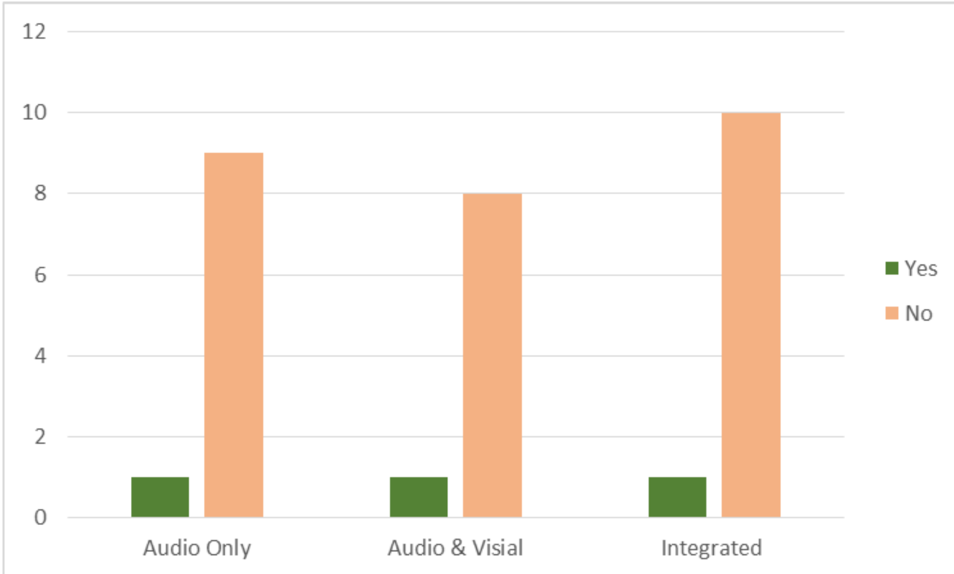


Figure 13. "Did you know what sort of event the warning was trying to alert you to before you saw the other vehicle?" for IMA event

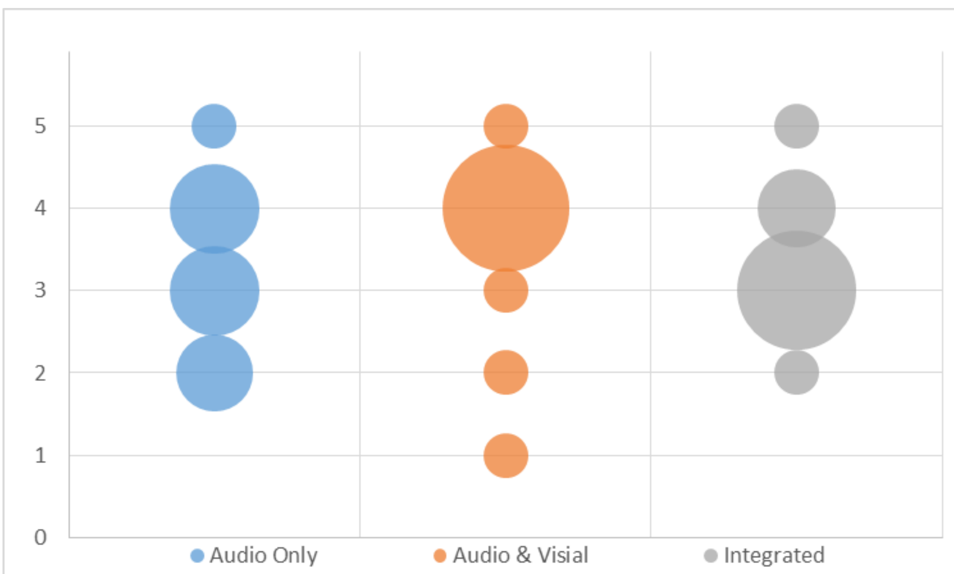


Figure 14. "How easily and quickly could you interpret this warning?" for IMA event

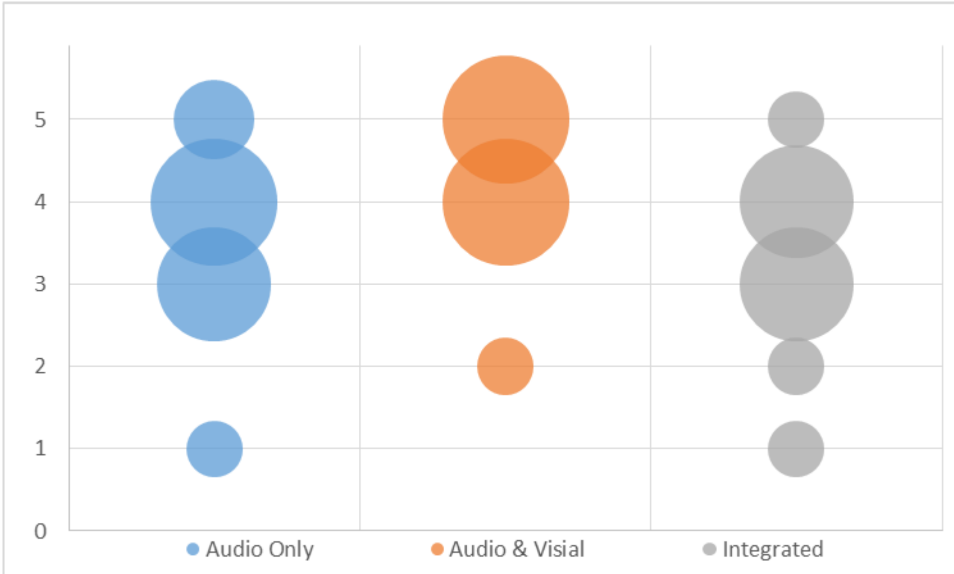


Figure 15. "How useful was the warning to you in this situation?" for IMA event

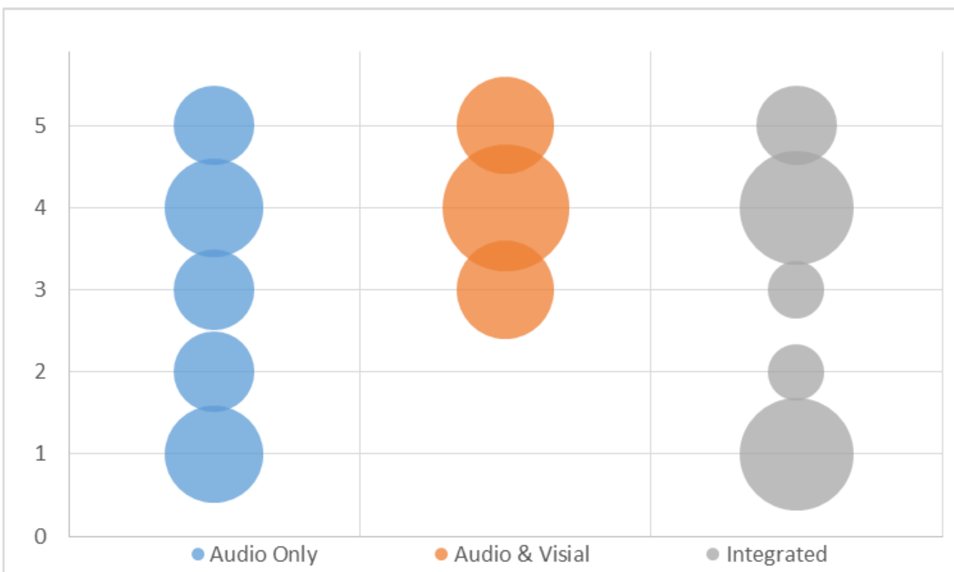


Figure 16. "How distracting was this warning?" for IMA event

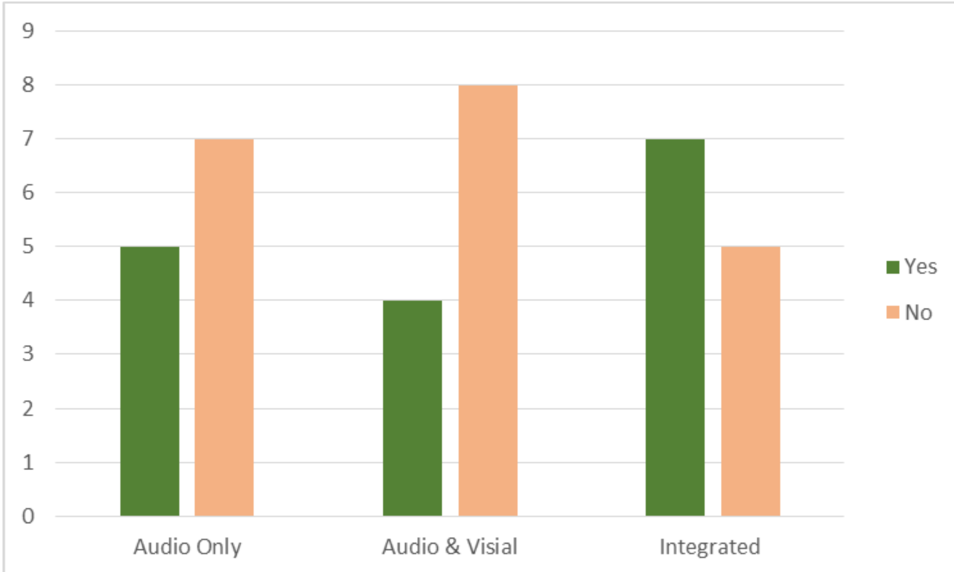


Figure 17. "Would you pay to have this type of system installed in your vehicle?" for IMA event

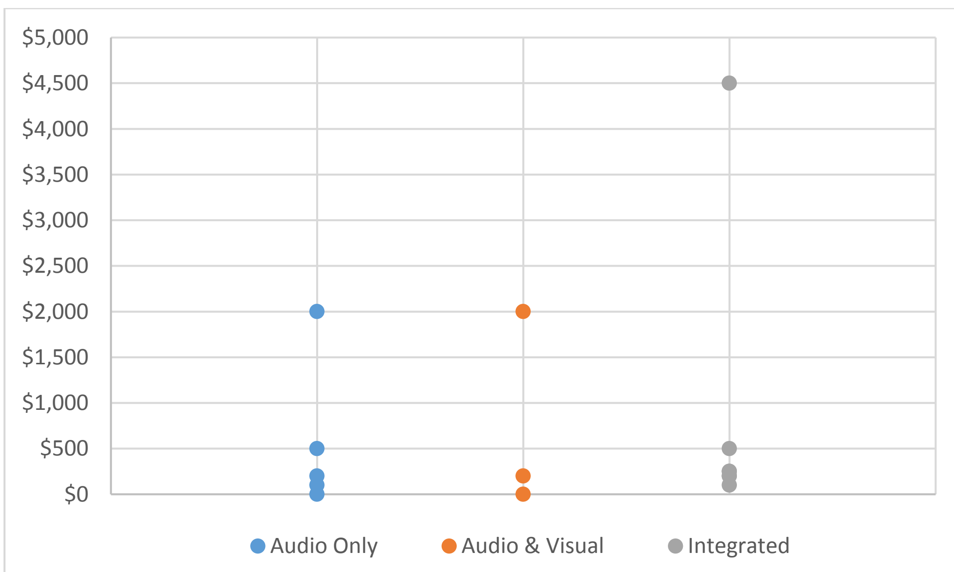


Figure 18. "If yes, how much (in dollars)?" for IMA event

4.4 Left Turn Assist Scenario

4.4.1 Specific Method

4.4.1.1 Driving Scenario

The LTA was an urban drive during which participants passed through several traffic light-controlled intersections with the left turn event at the final intersection with oncoming traffic. At intersections prior to the event intersection, cross traffic moved through the intersections as the driver approached. All traffic signals cycled to green as the driver approached. There was no lead vehicle in this scenario. The speed limit was set to 35 mph on an urban street, indicated by a speed limit sign. The driver was prompted to take the next left turn just before the event intersection. As the driver approached the turn lane, a vehicle turned right on red, coming from the oncoming lane. The traffic lights cycled at this time, turning to a green left turn signal for the driver. As the driver crossed the stop bar of the turn lane, the incursion vehicle, hidden by semi-trucks in the oncoming left turn lane, was created going 50 mph in the oncoming lane. Figure 19. shows the timing of the LTA event. At the same time, the warning was triggered. The scenario ended with a prompt after the driver reacted to the incursion vehicle and continued turning through the intersection and down the road. This scenario lasted 3-4 minutes. Figure 20 provides a visualization of the driving scene at the point of the LTA warning and Figure 21 provides a visualization of the driving scene at the point the where the incursion vehicle becomes visible.

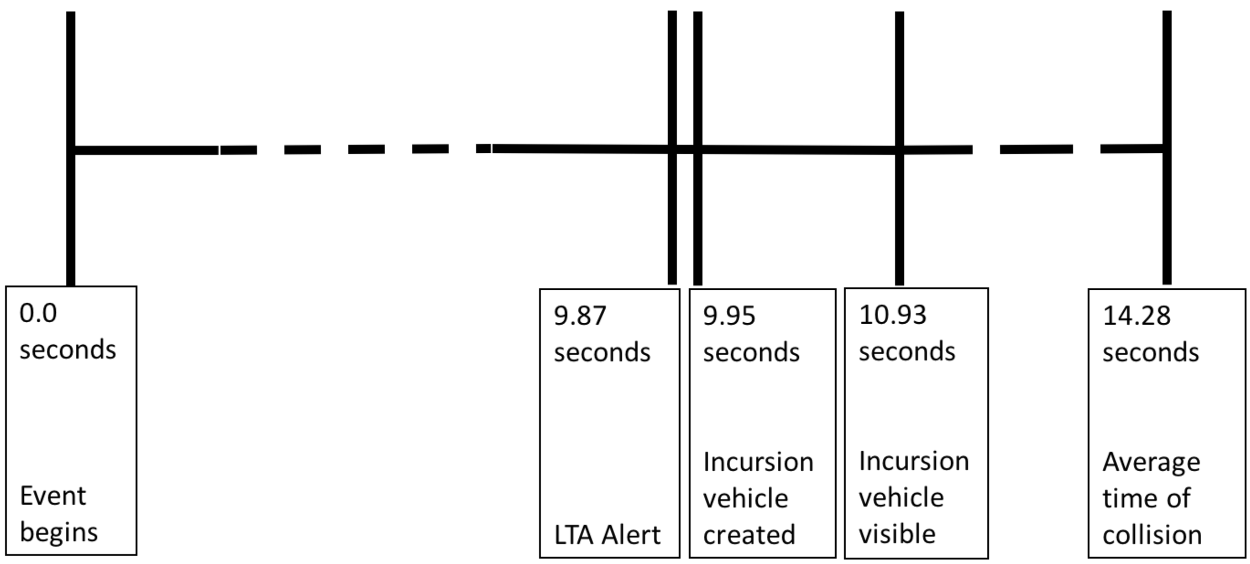


Figure 19. Timing of LTA scenario

Figure 20. LTA scenario at point when alert is issued

Figure 21. LTA scenario at point where incursion vehicle becomes visible

4.4.1.2 Participants

Table 18 provides the distribution of gender and age for the LTA scenario. For the three ASD DVI warning levels (audio only, audio-visual, and integrated display).

Table 18. Participant gender for each ASD DVI level for the LTA scenario

	# of Participants	Mean Age (std. dev.)
Audio Only	12	38.57 (8.88)
Audio-Visual	12	39.30 (8.47)
Integrated Display	12	36.27 (10.14)
Total	36	37.93 (9.36)

4.4.2 Results

4.4.2.1 Outcome

Most participants did not experience crashes in the LTA event (Table 19). There were slightly more crashes for the integrated display.

Table 19. Crashes for each display type in the LTA event

	Audio Only Display	Audio-Visual Display	Integrated Display	Total
No Collision	11	9	8	28
Collision	1	3	4	8
Total	12	12	12	36

4.4.2.2 Driver Performance

For accelerator pedal release, no significant effect for display type was found (p=0.1946). Since the p-value is greater than 0.1, no follow up tests were conducted. The lack of significant results could be due to the low occurrence rate of the accelerator pedal release results (Table 20). The audio-visual display tended to have a longer accelerator pedal release time than the audio only or integrated displays (Figure 22).

Table 20. Number of accelerator pedal release responses by display type for LTA event

	Number of Responses
Audio Only	6
Audio-Visual	5
Integrated Display	5

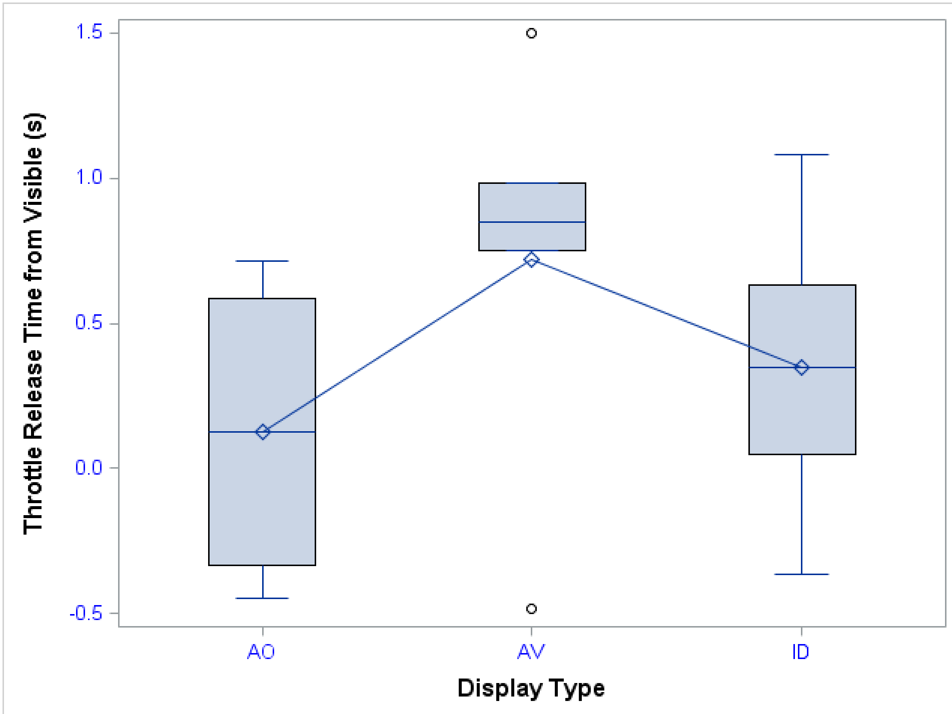


Figure 22. Accelerator pedal release time from visible for LTA event

No significant effect of display type was found (p=0.6365) for brake application response. Since the p-value is greater than 0.1, no follow up tests were conducted. The lack of significant results could be due to the low occurrence rate of the accelerator pedal release results (Table 21). It should be noted, that participants may have released the accelerator pedal and not followed with a brake response. The audio-visual display tended to have longer brake response times than the audio only and integrated displays (Figure 23).

Table 21. Number of brake responses by display type for LTA event

	Number of Responses
Audio Only	2
Audio-Visual	4
Integrated Display	2

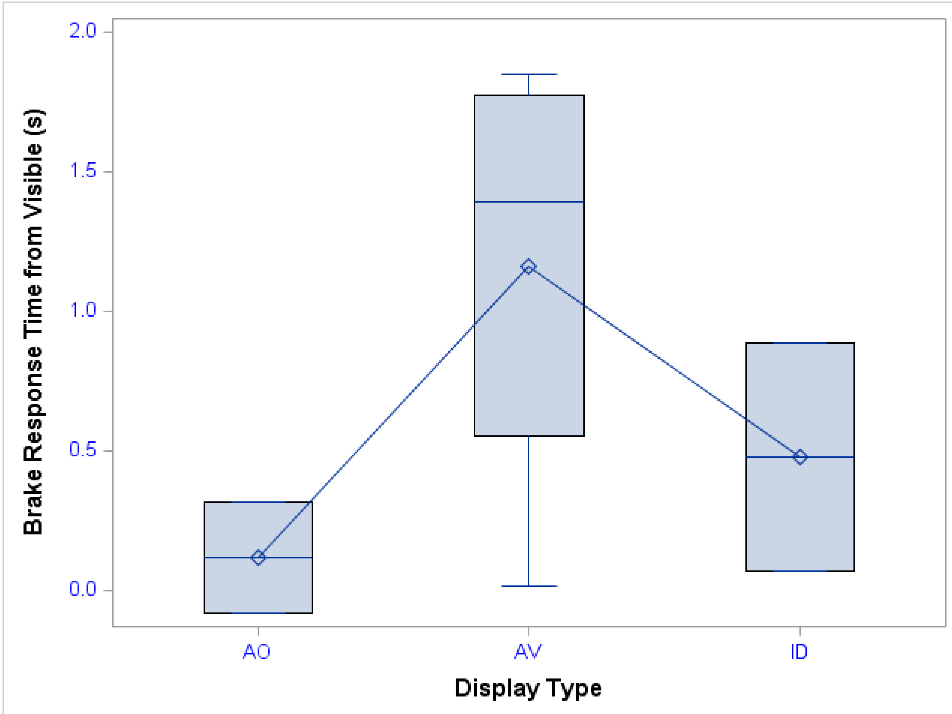


Figure 23. Brake application response time from visible for LTA event

For steering response, no significant effect was found for display type (p=0.5375). No follow-up tests are reported. The lack of significant results could be due to the low occurrence rate of the steering response results (Table 22). The audio-visual display tended to have longer steering response times than the audio only and integrated displays (Figure 24), yet this trend is not as distinct as was seen for accelerator pedal release and brake response.

Table 22. Number of steering responses by display type for LTA event

	Number of Responses
Audio Only	5
Audio-Visual	5
Integrated Display	8

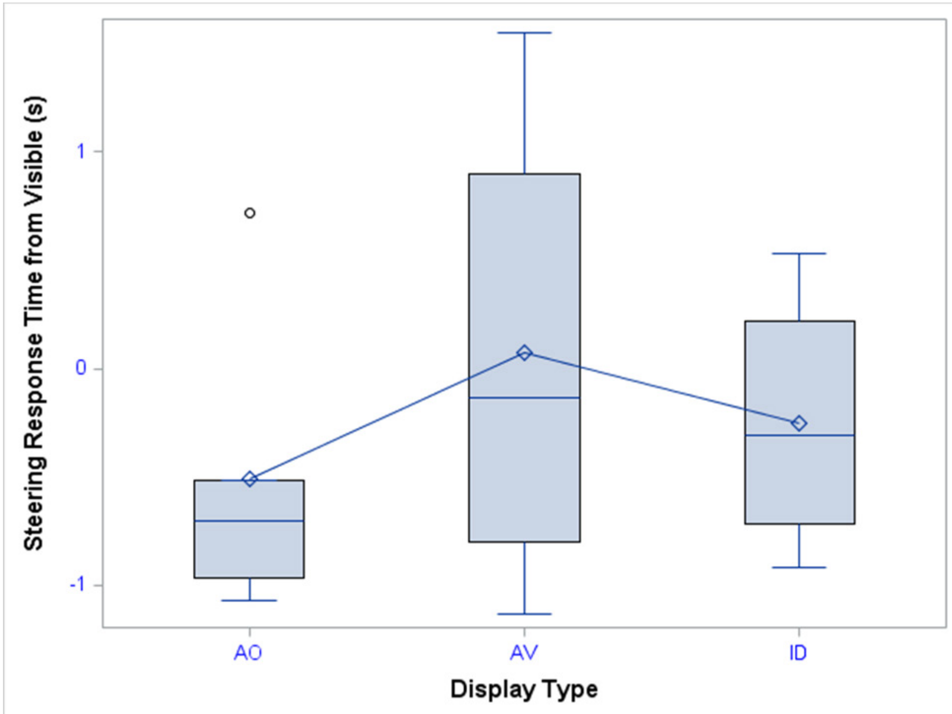


Figure 24. Steering response time from visible for LTA event

There were only two accelerator pedal application responses for the LTA event (Table 23); one in the audio only and one in the integrated display condition, too few for any analysis. The negative value for accelerator pedal application in the audio only condition indicates that the accelerator pedal was pressed one second before the incursion vehicle was visible at the time the alert was issued. In the integrated display condition, the accelerator pedal application was two seconds after the incursion vehicle became visible. No figure is provided due to the low counts.

Table 23. Number of accelerator pedal application responses by display type for LTA event

	Number of Responses
Audio Only	1
Audio-Visual	0
Integrated Display	1

A significant effect for first response was not found (p=0.7090) and follow-up tests were not conducted. The data do not show a trend. The lack of significant results was due to the substantial variance in response times, particularly for the audio-visual display rather than the number of responses (Table 24)

Table 24. Number of first responses by display type for LTA event

	Number of Responses
Audio Only	8
Audio-Visual	8
Integrated Display	9

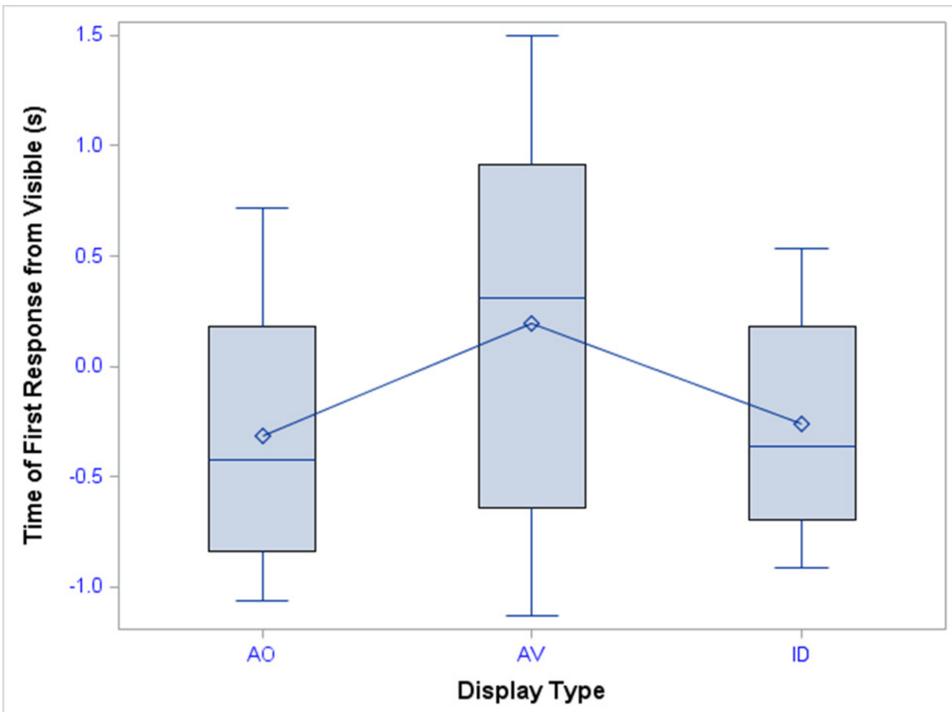


Figure 25. First response time from visible for LTA event

4.4.2.3 Subjective Data

Across all three display types, participants reported that they did not know what sort of event the warning was alerting them to (Figure 26). In fact, only one participant who experienced the audio-visual display reported "yes." Also participants reported they could not easily and quickly interpret the warning (Figure 27) and overall that the warning was not useful (Figure 28). Fewer participants reported the audio only display to be very distracting (Figure 29) yet the responses were again fairly evenly distributed. Most participants reported they would not pay for this type of system to be installed in their vehicle (Figure 30) and, of those who said "yes," most provided low dollar amounts.

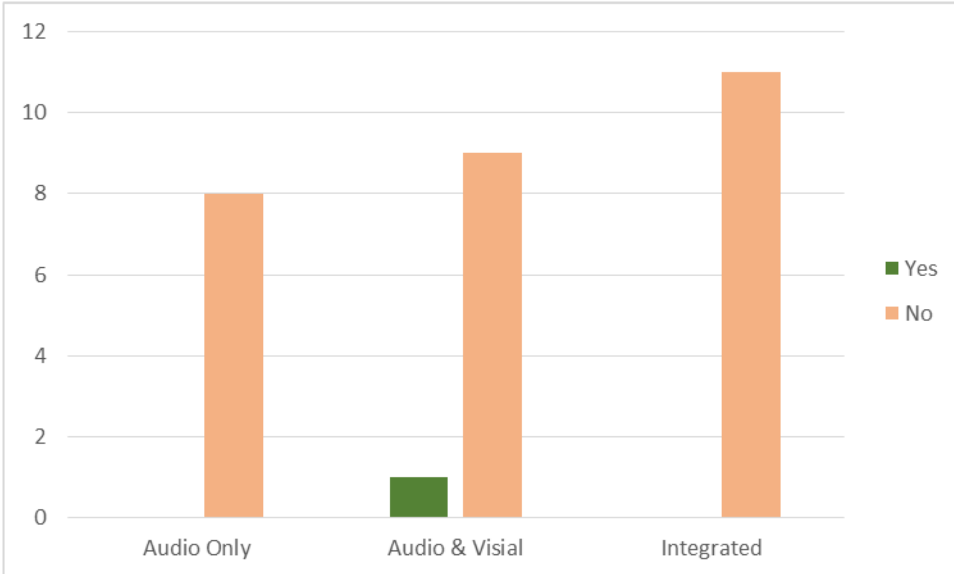


Figure 26. "Did you know what sort of event the warning was trying to alert you to before you saw the other vehicle?" for LTA event

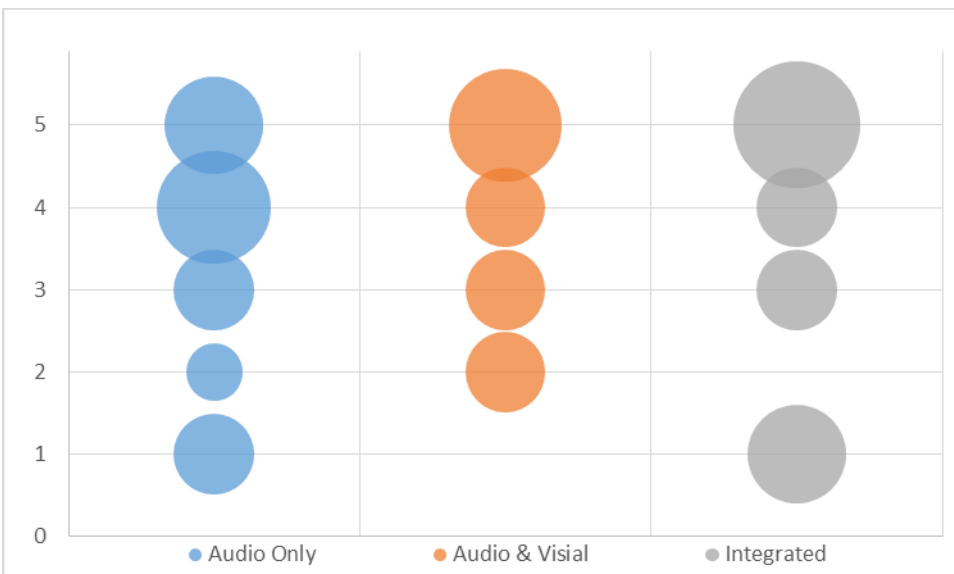


Figure 27. "How easily and quickly could you interpret this warning?" for LTA event

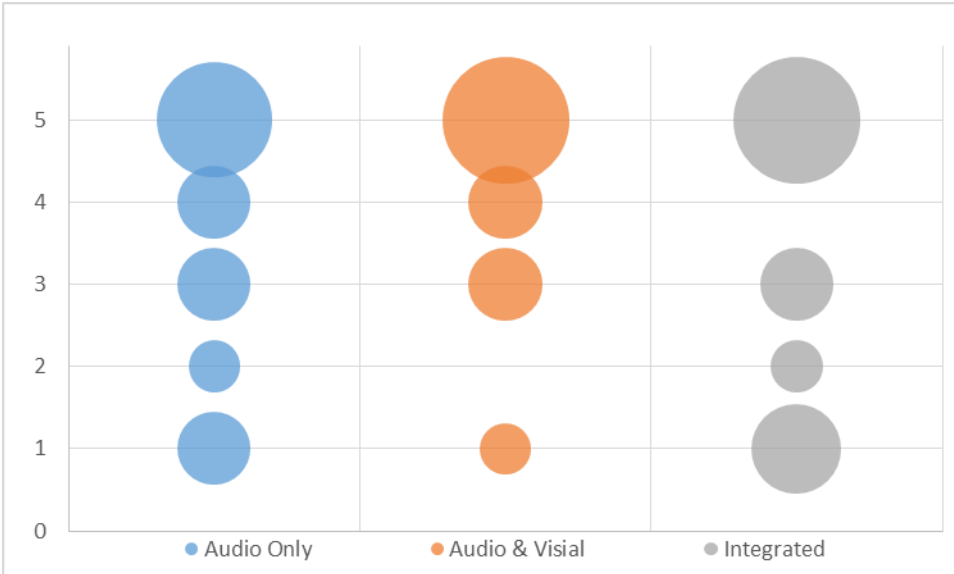


Figure 28. “How useful was the warning to you in this situation?” for LTA event

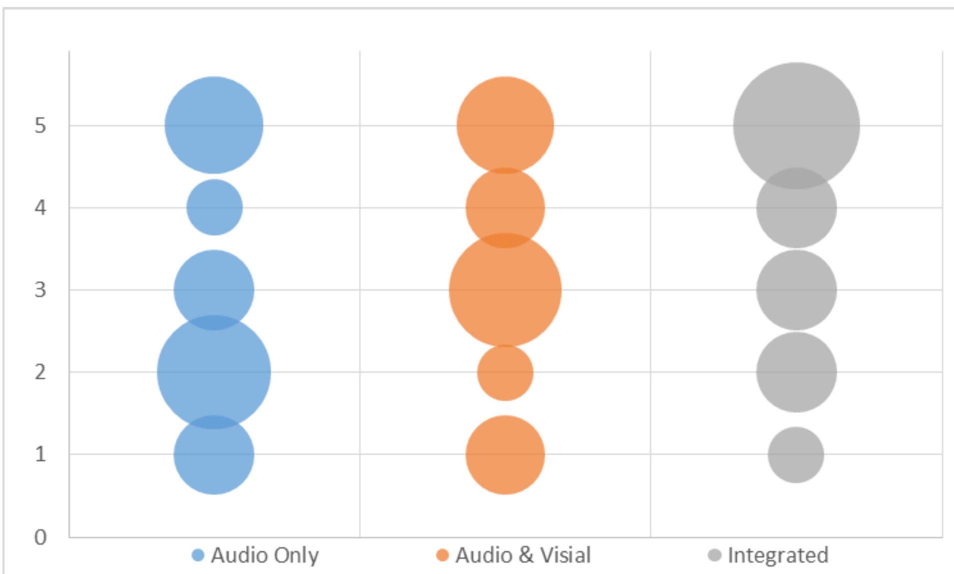


Figure 29. “How distracting was this warning?” for LTA event

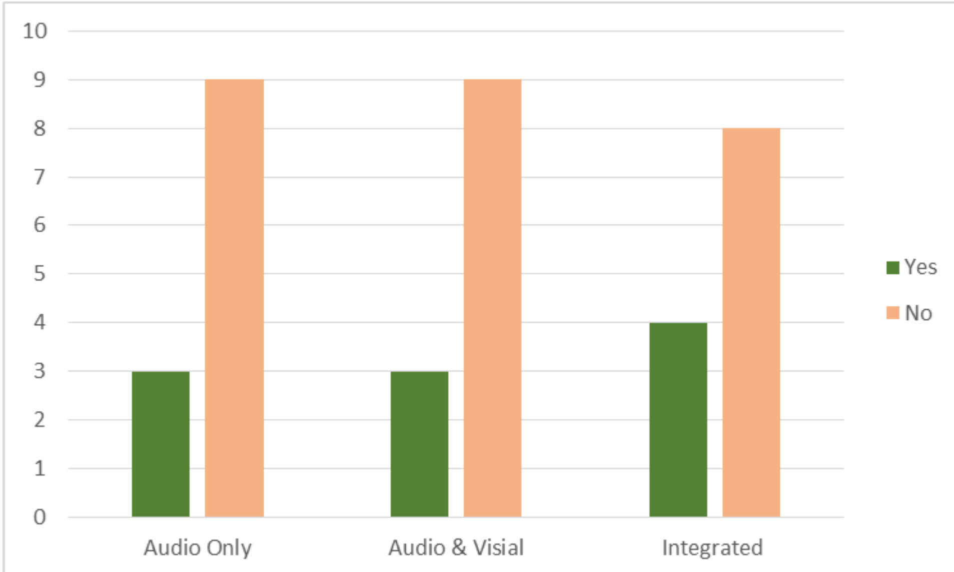


Figure 30. "Would you pay to have this type of system installed in your vehicle?" for LTA event

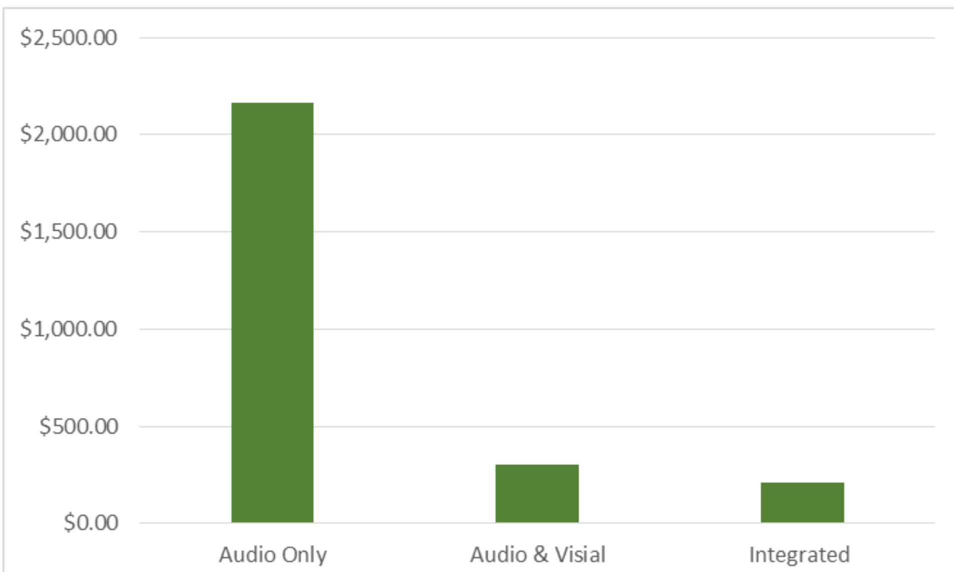


Figure 31. "If yes, how much (in dollars)?" for LTA event

4.5 EEBL Scenario

4.5.1 Specific Method

4.5.1.1 Driving Scenario

The EEBL scenario began with the participant vehicle parked in the lane of a rural roadway and an automated audio instructing the participant to shift into drive and begin driving. The speed limit was 55 mph on a rural highway, indicated by a speed limit sign. There was light ambient traffic in the oncoming lane. There was a lead vehicle and a remote vehicle in this scenario, both of which turned onto the roadway several seconds into the drive ahead of the driver. The remote vehicle was ahead of the lead vehicle. The lead vehicle maintained a 2-second gap ahead of the driver. The remote vehicle maintained a 4-second gap ahead of the driver. The lead and remote vehicle speeds were bounded between 45-70 mph to allow them to maintain their gaps with the driver.

As the vehicles approached a controlled access freeway on-ramp, the remote vehicle suddenly braked to 25 mph at 0.4G, its brake lights concealed by the lead vehicle, then turned onto the on-ramp (Figure 32). The EEBL warning was triggered 250 ms after the onset of remote vehicle braking. One second following onset of remote vehicle braking, the lead vehicle braked to 15 mph at 0.7G. Figure 33 shows timing of the EEBL event. The remote vehicle was not visible to the driver when braking began and the alert was issued. Figure 34 provides a visualization of the driving scene at the point the EEBL alert. The remote vehicle then made the turn and the lead vehicle resumed the speed limit. The scenario ended with a prompt after the driver reacted to the remote vehicle and continued turning through the intersection and down the road. This scenario lasted 3-4 minutes.

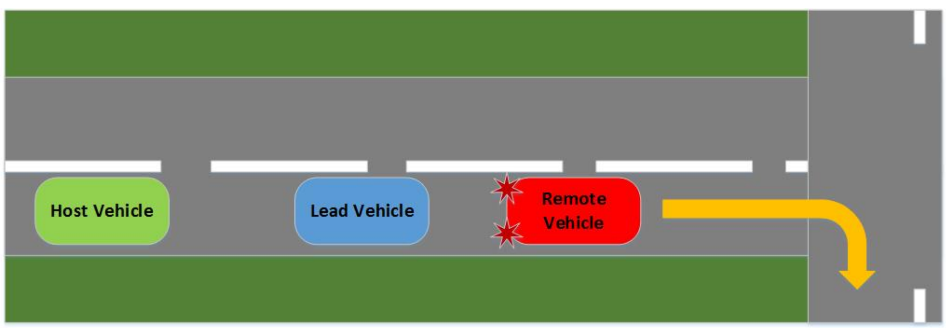


Figure 32. Diagram of EEBL scenario

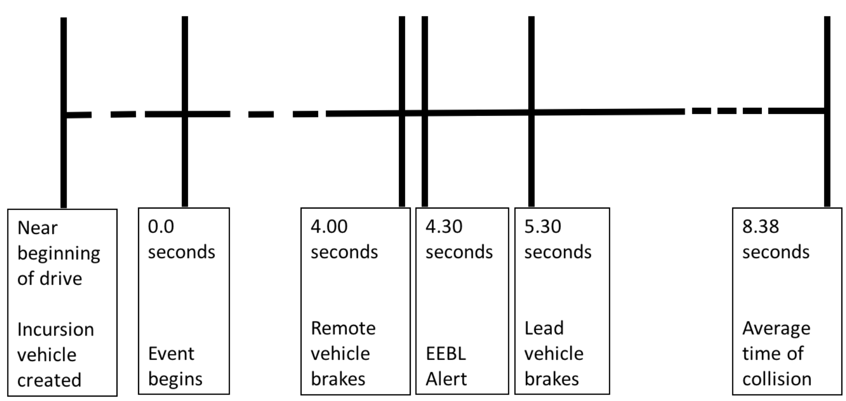


Figure 33. Timing of EEBL scenario

Figure 34. EEBL scenario when alert is issued

4.5.1.2 Participants

Table 25 provides the distribution of gender and age for the EEBL scenario. For the three ASD DVI warning modes (audio only, audio-visual, and integrated display), the characteristic being tested is the only condition being tested.

Table 25. Participant gender for each ASD DVI level for the EEBL scenario

	# of Participants	Mean Age (std. dev.)
Audio Only	12	38.70 (8.99)
Audio-Visual	12	37.90 (9.57)
Integrated Display	12	37.80 (8.60)
Total	36	38.13 (9.07)

4.5.2 Results

4.5.2.1 Outcomes

Most participants were able to avoid a collision in the EEBL event and there was no difference in collisions across the three display conditions (Table 26).

Table 26. Crashes for each display type in the EEBL event

	Audio Only Display	Audio-Visual Display	Integrated Display	Total
No Collision	11	11	11	33
Collision	1	1	1	3
Total	12	12	12	36

4.5.2.2 Driver Performance

For accelerator pedal release, no significant effect for display type was found (p=0.0759). Yet follow-up tests indicated that the audio only display was different than the audio-visual display (p=0.0288), though not from the integrated display. All 12 participants had a accelerator pedal release response. There was a trend toward faster responses for the audio-visual and integrated displays (Figure 35). Since all 12 participants had an accelerator pedal release response, this was always their first response and further analysis was unnecessary.

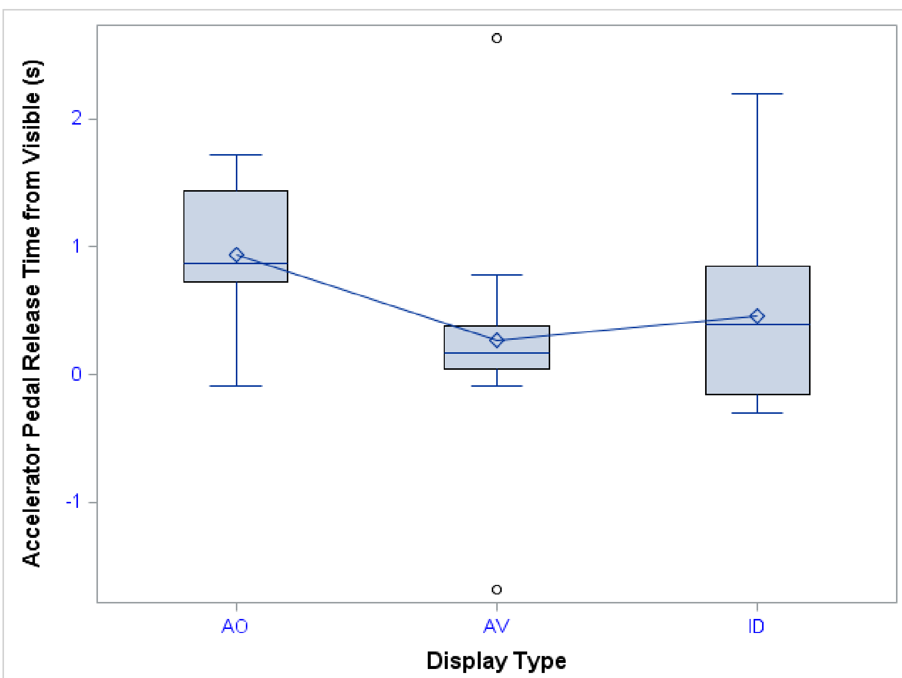


Figure 35. Accelerator pedal release time for EEBL event

A significant effect was not found for display type (p=0.6730) for brake response. No follow-up tests were conducted. All 12 participants had a brake response. There was a trend toward faster responses for the audio-visual display (Figure 36).

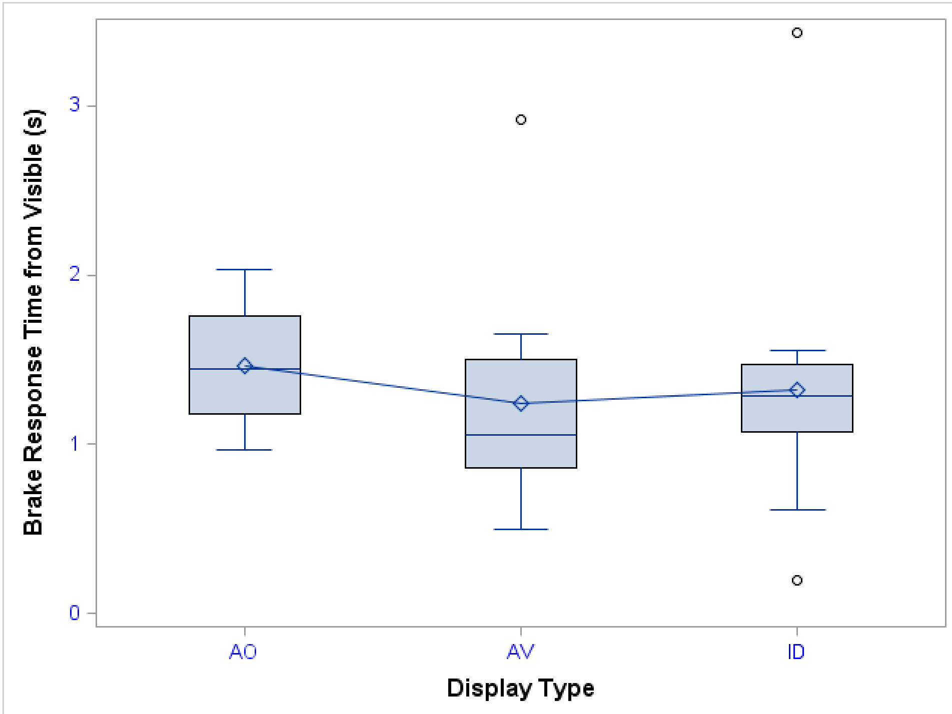


Figure 36. Brake response time from visible for EEBL

There were no steering or accelerator pedal application responses for the EEBL event. Also, since all participants had a accelerator pedal release response that was their first response. No analysis of steering, accelerator pedal application, or first response was conducted.

4.5.2.3 Subjective Data

Participants who experienced the audio-visual and integrated displays reported that they better understood the sort of event the warning was alerting them to (Figure 37), yet they reported similarly positive responses for all display types for how easy and quick the alert was to interpret (Figure 38) and for the usefulness of the warning (Figure 39). The integrated display was reported to be more distracting (Figure 40) though the responses for this display were fairly evenly distributed. Similarly, fewer reported they would pay for the system with the integrated display to be installed in their vehicle (Figure 41) and, of those who responded “yes,” the highest amount was for the audio-visual display (Figure 42).

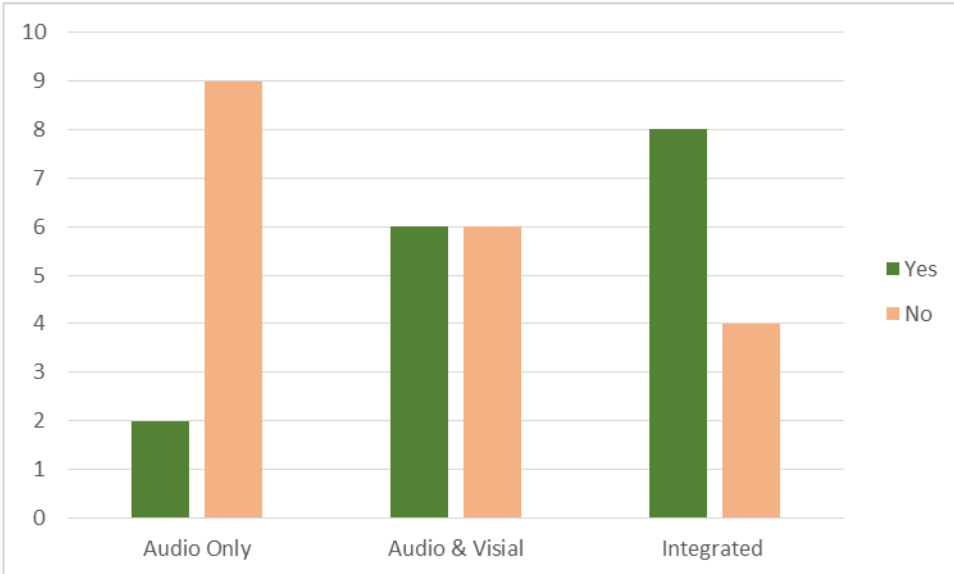


Figure 37. "Did you know what sort of event the warning was trying to alert you to before you saw the other vehicle?" for EEBL event

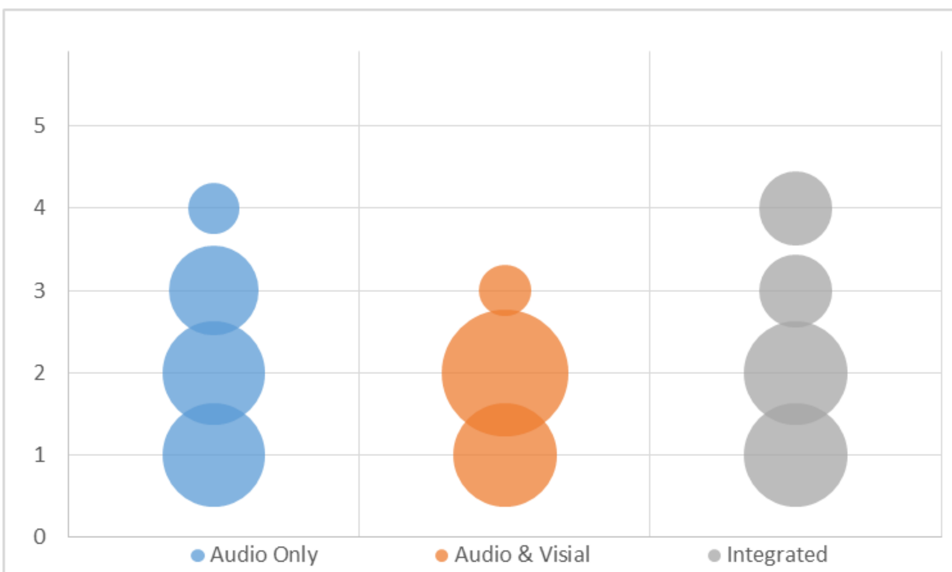


Figure 38. "How easily and quickly could you interpret this warning?" for EEBL event

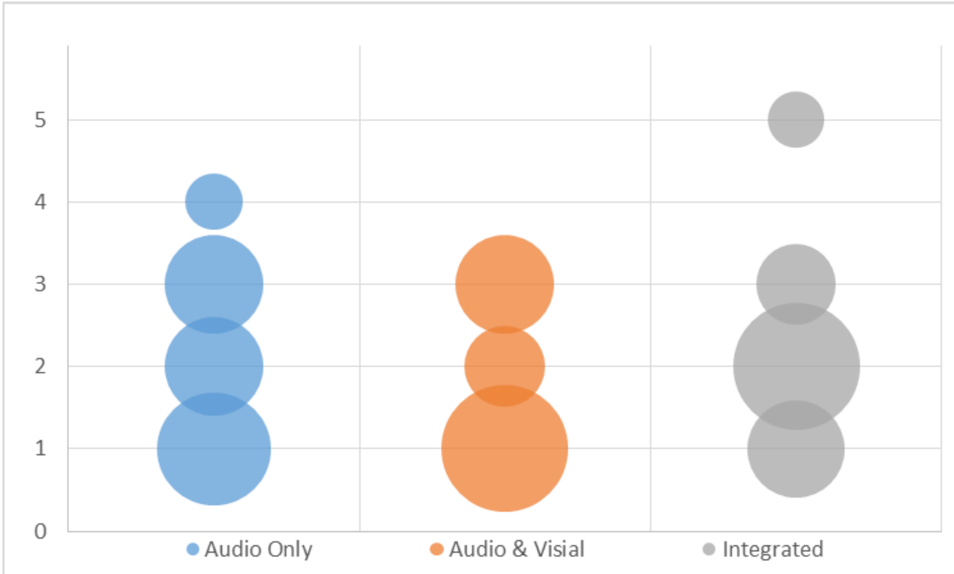


Figure 39. "How useful was the warning to you in this situation?" for EEBL event

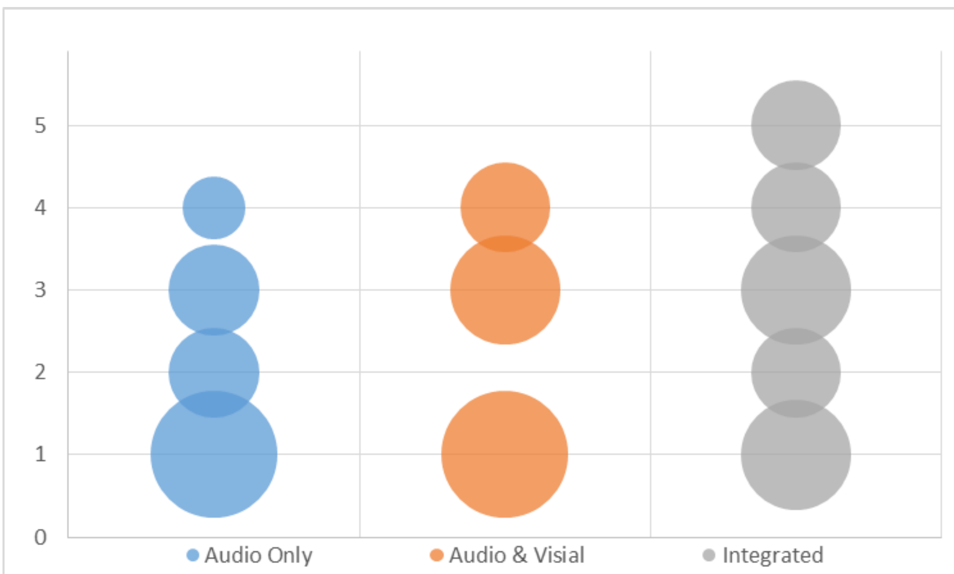


Figure 40. "How distracting was this warning?" for EEBL event

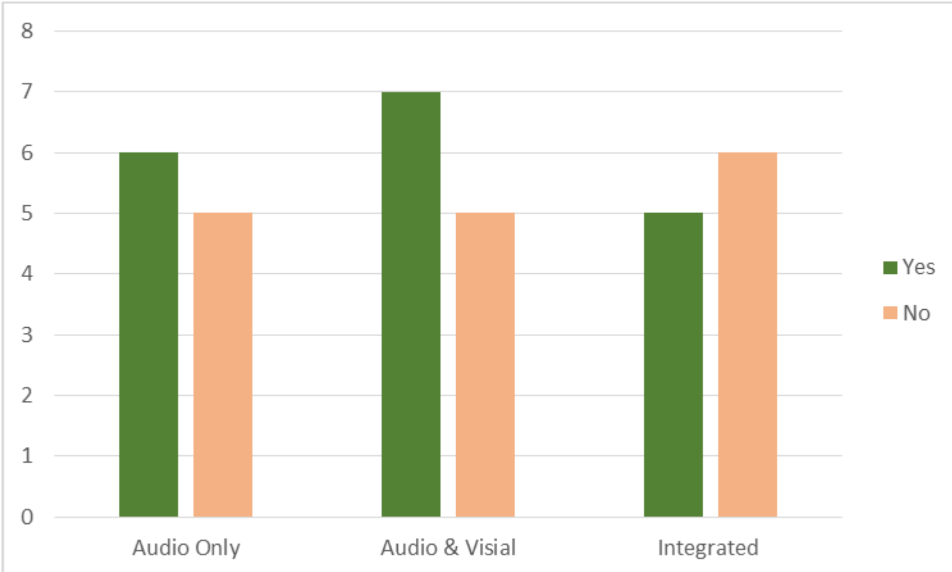


Figure 41. "Would you pay to have this type of system installed in your vehicle?" for EEBL event

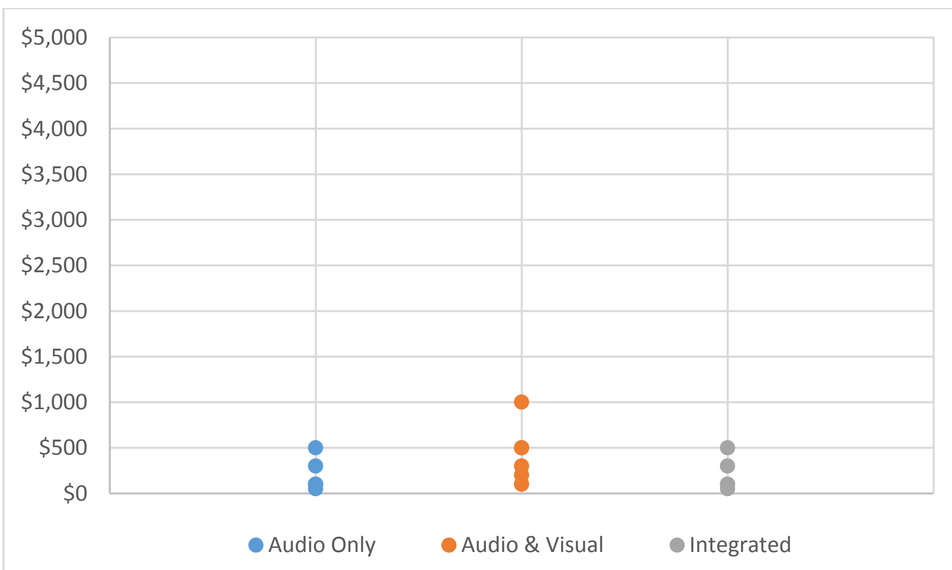


Figure 42. "If yes, how much (in dollars)?" for EEBL event

4.6 Driving Simulator Study Summary

The primary hypotheses tested in the simulator experiment are provided below as assertive predictions, rather than as the related "null hypotheses" for inferential statistical testing:

- Driver response time to and type of response to a warning are related to the ASD interface and onboard information, the CV application, and their interaction.

- The benefits of ASD warnings on the event outcome are related to the ASD interface and onboard information, the CV warning application, and their interaction.
- Driver comprehension of an ASD warning is related to the ASD interface and onboard information, the CV warning application, and their interaction.
- The perceived benefits and acceptance of an ASD system is related to the ASD interface and onboard information, the CV warning application, and their interaction.

4.6.1.1 Driver response time to and type of response

Response time varied depending on the ASD interface and CV application. The integrated display resulted in faster responses in the IMA event than audio only and audio-visual displays. In the EEBL event there was a trend towards faster responses with the audio-visual and integrated displays. However, the integrated and audio only displays had faster mean first response times than the audio-visual display in the LTA event, even though the difference did not reach statistical significance. These patterns of response time and display type were consistent within each CV application event type for accelerator pedal release, brake response, and the first response variables.

Response type also varied with the CV application, yet did not vary across the ASD interface levels within CV applications. There were essentially the same number of each type of response, regardless of whether or not the display contained information about the direction of the threat. In the IMA and EEBL events, most participants had both accelerator pedal release and brake application responses. Significantly fewer had steering or accelerator pedal application responses in the IMA event and none had either of these responses in the EEBL event. A different pattern was seen in the LTA event where approximately half the participants had accelerator pedal release and/or steering responses, yet very few had either brake or accelerator pedal application responses. Response type was dependent on the collision situation rather than the ASD display.

One possible explanation for differences in response type is whether the driver is actively engaged in a maneuver (steering, acceleration or deceleration) at the time of alert. Steering responses were certainly valid response types for both the IMA and EEBL events, yet very few or none occurred in these events. In the LTA event where drivers were already engaged in a maneuver, the response type varied and no one response type dominated.

There were no instances of alert suppression in this study as a result of availability of CAN bus data. This result does not necessarily mean that ASD access to the vehicle's CAN bus data has no benefit. Other real-world driving scenarios may be more likely to allow alert suppression when the driver is already responding to the potential collision situation. Yet, what was not considered in this study was prioritization of alerts. If there are OEM warning systems and aftermarket warning systems in the same vehicle, without integration of onboard data there is no opportunity to prioritize alerts from various systems that could result in multiple alerts issued simultaneously or in close temporal proximity. Additionally, the potential utility of alert suppression in untested CV applications, such as Lane Departure or Blind Spot Warning, is unclear. Importantly, this experiment was not able to investigate the effects of response suppression strategies over repeated experience with the system. More precisely adapted alerting algorithms may improve warning validity and timing, which ultimately may improve the speed and appropriateness of driver response as well as user acceptance and system use. Such benefits can only be assessed through longer term exposure to alternative systems.

Overall, based on driver response across all three CV applications, the integrated display performed better than the audio only and audio-visual displays suggesting that ASD DVIs may be less effective than OEM installed systems. Further, these results support the application to EEBL systems of the SAE and HFCV guidance (SAE, 2003; Campbell et al., 2007) for FCW systems recommending audio and visual components.

The driving simulator study provided a comparison among three prototype ASD concepts, with a focus on how systems without vehicle integration compare with highly integrated or OEM systems. The experiment did not provide any direct comparison of these systems with a "no warning" system. However, some inference can be made based on the absolute values of the response times. In some instances, response times are shorter than reasonably would be expected in reaction to a visible, unanticipated event. Figure 12 showed "first response" latency for the IMA event from the onset of the conflicting vehicle becoming visible. Although the Level 3 (integrated) system had the briefest response time, the response time for the Level 2 (audio-visual) system were typically in the 0.50 to 0.75 second range. For the LTA event, mean accelerator pedal release time for the Level 1 (audio only) system was at nearly the same moment as the conflicting vehicle became visible (Figure 22). For the EEBL event, mean accelerator pedal release time was less than 1 second for Level 1 and only about a quarter second for Level 2. While not definitive, the occurrence of driving responses so shortly after the appearance of a conflicting vehicle suggests that many participants initiated an action in response to the preceding alert or were primed to respond quickly because of the alert. Thus even lower capability systems may offer safety benefits relative to no warning under some conditions.

4.6.1.2 Event outcome

Outcomes were more heavily influenced by CV warning application event than by the ASD display level, yet there were some important differences. In the IMA event, most participants experienced crashes. In the LTA and EEBL events, most participants were able to avoid crashes. All three events were designed to have similar and consistent timing (1 second from alert to incursion vehicle visible, then 3 seconds from visible to collision), though actual timing was influenced by driver speed and response. Due to variations in driver speed, the IMA event had a slightly lower visible-to-collision time (2.48 seconds) and it would be tempting to suggest that this shorter visible-to-collision time is the reason for the higher rate of collisions in the IMA event, yet this is not supported by the timing of the LTA and EEBL events. The EEBL event had a visible-to-collision time of 3.08 seconds and the fewest crashes, while the LTA had a longer visible-to-collision time of 3.35 seconds and more crashes than EEBL, though fewer than IMA.

Table 27. Total number of collisions for each event and interface

Event	Audio Only Display	Audio-Visual Display	Integrated Display
IMA	12	11	9
LTA	1	3	4
EEBL	1	1	1
Total	14	15	14

Two significant differences between the three types of events were the uncertainty of the direction of the collision threat and whether or not the driver was in the process of completing a maneuver. In the EEBL event, the direction of threat was clearly a rear-end collision with the vehicle ahead and no maneuver in progress. In the IMA and LTA events, the drivers were passing through an intersection and the direction of threat could be from either side in the IMA event and any of three directions (left, right, or oncoming) in the LTA event. Only in the LTA event was a maneuver in progress. This may suggest that direction of the threat and whether or not a maneuver is in progress should be considered in the design of warning displays.

Recall that the audio only display included no directional information, the audio-visual included the same audio alert and a visual icon with threat direction displayed in a box on the dash of the vehicle, and the integrated display included the same audio alert and indicated the direction of threat by illuminating light strips to indicate direction of threat (left = left A-pillar and left front strips, forward = the two front strips, right = right front and right A-pillar strips). The effect on outcome for the three levels of ASD display was mixed across the three types of events studied. With the integrated display, there were fewer crashes in the IMA event and more crashes in the LTA event than the audio only or audio-visual displays, and no difference in the EEBL event.

No difference between the ASD display levels for the EEBL event suggests that there is neither a benefit nor dis-benefit to threat direction information when the direction of threat is clear and no maneuver is in progress. Fewer crashes with the integrated display in the IMA suggest that ASD systems with add-on displays may be less effective at preventing crashes than fully-integrated systems or OEM installed systems when the driver is not in the process of completing a maneuver. Yet, when drivers were in the process of completing a maneuver and direction of threat was relative to the driver's progress through that maneuver (LTA), there was a dis-benefit associated with the inclusion of directional information.

4.6.1.3 Driver comprehension

Drivers rated their comprehension of the alert differently across the three ASD application events. For the IMA and LTA events, most drivers indicated they did not know to what the warning was alerting them. The comprehension was higher for the EEBL event, particularly for the audio-visual and integrated displays where 50% and 75%, respectively, reported they did understand the sort of event to which the warning was alerting them. These patterns mirror drivers' responses to how easily and quickly they could interpret the warning. These findings are consistent with driver response and event outcome results.

4.6.1.4 Perceived benefits and acceptance

For the IMA event, none of the ASD interfaces were rated as useful and all participants rated the audio-visual display as distracting, while the responses were fairly evenly distributed for the audio only and integrated displays. More participants said they would pay for the audio-visual and integrated display and reported higher amounts they would pay for such a system, which is consistent with the driver response and outcome results.

For the LTA event, participants did not rate any of the displays as useful and the distraction ratings were evenly distributed. Fewer than 25 percent of participants indicated they would pay for the CV system and values tended to be less than $500.

For the EEBL event, participants rated all three ASD interfaces as useful, and they rated the audio only and audio-visual interfaces as less distracting than the integrated display. Similarly, more than half the participants responded that they would pay for an audio only or audio-visual system and slightly fewer than half said the same about a system in an integrated display.

5. General Discussion and Limitations

5.1 General Discussion

This project investigated human factors issues related to the DVI for ASDs providing CV safety alerts to drivers. The project activities included literature reviews, product search, interviews with industry experts, analytic assessments, and a simulator experiment of warning responses.

There is not strong consensus among industry experts and other sources regarding the likely form of ASDs and particularly regarding the needs for interfacing with the host vehicle's safety and communications systems. Some believe that ASDs will not be acceptable without a strong degree of integration with vehicle systems, for reasons related to system performance, suppression of inappropriate warnings, redundant or conflicting messages, message prioritization, and installation requirements (including appropriate antenna type and location). Others feel that stand-alone ASDs may nonetheless provide valuable safety benefits, even if they are not as capable as a fully integrated or OEM product. Less complex ASDs systems may be lower cost and easier to install, which may allow the benefits to be shared by a broader and more equitable range of drivers, including those with older or less expensive vehicles. Ultimately, the potential public safety benefits of ASDs are twofold. First, they provide potential safety benefits to the individual driver in the form of CV alerts. Second, they foster greater fleet penetration of here-I-am basic CV information, which enhances the effectiveness of the CV technology for all vehicles. Both of these aspects are important considerations for ASDs but industry expert consensus on the prospects and requirements is lacking. There are trade-off considerations between more sophisticated and precise warning and display capabilities and prospects for aftermarket consumer motivation.

There is very little direct research on CV ASDs and little in the way of existing products as exemplars. Thus, there are not clear prototype systems as a basis for research. Suppliers of CV systems generally provide their products to OEMs without a DVI or with DVI specifications provided by the OEM. OEM interfaces are proprietary. There has not been much attention given to aftermarket DVIs. The Safety Pilot Model Deployment (e.g., Bezzina & Sayer, 2015) provided drivers with actual CV warning systems. However, none of the ASDs included DVI elements other than an auditory tone. This represents a minimal DVI for an ASD and serves as a lower-end system for comparison with other interface concepts for research conducted under this project.

OEM CV systems will be able to make use of various onboard vehicle information to use in conjunction with CV information. This should allow more refined warning algorithms that may take into account vehicle state, roadway and environment factors, driver state, driver intent, and information on external objects and events (e.g., obstacles, pedestrians, vehicles) from onboard sensors. Onboard information has the potential both to optimize the timing and nature of particular warnings and also to suppress unnecessary warnings. Over driver experience with the system, this may influence user perceptions of warning validity and system acceptability. To the extent that OEMs effectively use such information, ASDs that are not highly integrated with the host vehicle may suffer in terms of relative performance. Relative to such potential OEM systems, ASDs may have more slow or missed driver responses, less system use or more system defeat, and less consumer willingness to inquire or install a CV product. Because many of the potential effects of system access to onboard data will only emerge over time and experience, research studies on this aspect are difficult and extended. Potential influences of key onboard data sources were addressed analytically in this project. It is noted that it may be possible for ASDs to collect and utilize similar information from other sources and sensors that may be part of the ASD product, but this would of course influence cost.

Fleet penetration of ASD systems will depend on consumer interest in the product. The literature indicates that consumers do not appear to be willing to pay much for CV technologies (e.g., Shin, Callow, Dadvar, & Farkas, 2015), a finding supported by observations in the driving simulator study conducted in this project. However, consumer experience and familiarity with the technology is very limited and opinion could change as public knowledge expands and as new vehicles come equipped with CV technology. Observations from the Safety Pilot Model Deployment (Bezzina & Sayer, 2015) suggest that nuisance alarm rates may be an important factor in public acceptance. Other factors raised that may improve consumer interest in ASDs include packaging the CV component with other non-safety applications (e.g., parking assistance, insurance discounts), portability, and customizability.

This research project included a driving simulator study that had a primary focus on the speed and appropriateness of vehicle control actions in avoiding a crash. This study compared three prototype ASD DVIs. One system (Level 1) simulated a stand-alone product that only provides a tonal alert. Another system (Level 2) was also stand-alone, but added a visual display on the product that depicts a crash threat and its direction. The final system (Level 3) simulated a highly integrated or OEM system. The acoustic component was directional and the visual alert was by light bars in the vehicle cabin that illuminate from the direction consistent with the threat. Three different CV applications were included: Intersection Movement Assist (IMA), Left Turn Assist (LTA), and Emergency Electronic Brake Lights (EEBL).

The driving simulator experiment found that the relative performance of the three systems depended on the particular driving scenario. Broadly speaking, the Level 3 system tended to result in somewhat faster responding (e.g., pedal release, brake activation, steering input) and fewer crashes to the threat event, although this was not a uniform finding and was not always statistically significant (sample size and response variability limit the ability to provide statistically significant findings). The driving simulator experiment did not include a direct comparison of responding with a "no warning" condition due to scope considerations to be able to include alert suppression conditions. However, a consideration of the absolute response times, based on the moment the threat vehicle became visible, suggests that even the Level 1 and 2 systems may provide some benefit in terms of faster driver response.

Based on the findings of this experiment, there appear to be benefits to an integrated DVI for ASDs, in terms of response speed and appropriateness, comprehension, and acceptance. Less clear are the benefits of lower level DVIs relative to no warning, although there is a suggestion that performance is better than in the absence of any warning.

5.2 Study Limitations

The findings of this study must be considered within the context of its limitations. ASDs are still in the early stages of development and there is no clear consensus or trend to indicate the types of ASDs that are likely to come to market. Experts and developers do not even agree on fundamental points, such as whether access to onboard vehicle CAN bus data and professional installation is necessary to make a viable CV ASD. The three ASD prototypes used in this study were designed to represent the range of device types and interfaces currently in development, or likely to be used, while also providing distinct differences between systems. They are, however, not the only possible approaches to ASD warnings.

This experiment also used a limited number of carefully scripted event scenarios and drivers who were attentive during their drives. Additionally, because this study used a between-subject design no comparison of different ASD DVIs for the same driver was possible. Effects of driver distraction and a broader range of collision scenarios were not investigated. Similarly, these experiments did not include naturalistic, longitudinal exposure to ASDs. Longer-term use of ASDs under normal driving conditions is important to understand driver attitudes toward these systems, and especially to investigate the effects of CAN bus data access on warning adaptation and suppression, and in turn, driver trust and acceptance of the system. Finally, the simulator experiment investigated differences between the three ASD levels, but did not include a no-ASD comparison condition.

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Appendix A: Simulator Experiment Phone Screening

Aftermarket Safety Devices

Generic Telephone Screening Procedures

For a participant to be eligible for a study they must meet ALL of the following criteria:

- Be able to participate when the study is scheduled
- Meet all inclusion criteria
- Pass the phone health screening questions

Instructions to the experimenter are in normal text.
Portions to be read aloud to potential participant are in **bold**.

Overview

The purpose of this research study is to investigate differences among drivers across the US.

Study Information, Time Commitment and Compensation:

Participating in this study involves 1 study visit that will last approximately 1 hour. You will be required to come to University Research Park on Oakdale Blvd in Coralville to participate.

Participation involves signing a consent form, driving a simulator, and completing some questionnaires. You will receive instructions regarding driving the simulator cab and the study drives at your visit.

You will receive $40 for completing all study procedures.

Are you still interested in participating?

- If YES, continue with Inclusion Criteria
- IF NO, **Would you like to be contacted for future studies?**
    - IF NOT interested in future studies and wishes to be deactivated in the registry
        - Make note indicating inactive status is at individual's request
        - Reason if given

1

Inclusion Criteria ~ General Driving Questions

Overview
Before this list of questions is administered, please communicate the following:

There are several criteria that must be met for participation in this study. I will need to ask you several questions to determine your eligibility.

If an individual fails to meet one of the following criteria, proceed to Closing.

1) **Do you possess a valid U.S. Drivers' License?**
   (must answer yes)

2) **How long have you been a licensed driver?**
   (must be 2 years or longer)

3) **What restrictions do you have on your license?**
   (must have no restrictions other than for corrective lenses)

4) **How many miles do you drive per year?**
   (must be at least 3,000 miles per year)

5) **How often do you drive?**
   (must be at least once per week)

6) **How old are you?**
   (must be age 25 -55 years)

7) **Do you have normal or corrected to normal vision?**
   (must answer yes)

8) **Do you have normal or corrected to normal hearing?**
   (must answer yes)

9) **Do you require any special equipment to help you drive such as pedal extensions, hand brake or throttle, spinner wheel knobs or other non-standard equipment?**
   (must answer no)

If General Inclusion Criteria are met
Proceed to General Health questions below

General Health Exclusion Criteria

Overview Before administering this list of questions, please communicate the following: ➢ **Because of pre-existing health conditions, some people are not eligible for participation in this study. I need to ask you some general health-related questions before you can be scheduled for a study appointment.** ➢ **Your responses are voluntary and all answers are confidential.** ➢ **You can refuse to answer any questions.** ➢ **No other responses will be kept.**
1) If the subject is female: ➢ **Are you, or is there any possibility that you are pregnant?**
Exclusion criteria: ☐ **If pregnant or there is any possibility of being pregnancy**
2) Have you been diagnosed with a serious illness? ➢ If YES, **Is the condition still active?** ➢ If YES, **Are there any lingering effects?** ➢ If YES, **Do you care to describe?**
Exclusion criteria: ☐ **Cancer (receiving any radiation and/or chemotherapy treatment within last 6 months)** ☐ **Crohn's disease** ☐ **Hodgkin's disease** ☐ **Parkinson's disease** ☐ **Currently receiving any radiation and/or chemotherapy treatment**
3) Do you have Diabetes? NOTE: Type II Diabetes accepted if controlled (medicated and under the supervision of physician)
Exclusion criteria: ☐ **Type I Diabetes - insulin dependent** ☐ **Type II – Uncontrolled (see above)**
4) Do you suffer from a heart condition such as disturbance of the heart rhythm or have you had a heart attack or a pacemaker implanted within the last 6 months? If YES ➢ **Please describe?**
Exclusion criteria: ☐ **History of ventricular flutter or fibrillation** ☐ **Systole requiring cardio version (atrial fibrillation may be acceptable if heart rhythm is stable following medical treatment or pacemaker implants)**

5) Have you ever suffered brain damage from a stroke, tumor, head injury, or infection?

If YES

- **What are the resulting effects?**
- **Do you have an active tumor?**
- **Any visual loss, blurring or double vision?**
- **Any weakness, numbness, or funny feelings in the arms, legs or face?**
- **Any trouble swallowing or slurred speech?**
- **Any uncoordination or loss of control?**
- **Any trouble walking, thinking, remembering, talking, or understanding?**

Exclusion criteria:

- ☐ **A stroke within the past 6 months**
- ☐ **An active tumor**
- ☐ **Any symptoms still exist**

6) Have you ever been diagnosed with seizures or epilepsy?

If YES

- **When did your last seizure occur?**

Exclusion criteria:

- ☐ **A seizure within the past 12 months**

7) Do you have Ménière's Disease or any inner ear, dizziness, vertigo, hearing, or balance problems?

NOTE: Wear hearing aids - full correction with hearing aides acceptable

If YES

- **Please describe.**

Ménière's Disease is a problem in the inner ear that affects hearing and balance. Symptoms can be low- pitched roaring in the ear (tinnitus), hearing loss, which may be permanent or temporary, and vertigo.

Vertigo is a feeling that you or your surroundings are moving when there is no actual movement, described as a feeling of spinning or whirling and can be sensations of falling or tilting. It may be difficult to walk or stand and you may lose your balance and fall.

Exclusion criteria:

- ☐ **Meniere's Disease**
- ☐ **Any recent history of inner ear, dizziness, vertigo, or balance problems**

8) Do you currently have a sleep disorder such as sleep apnea, narcolepsy or Chronic Fatigue Syndrome?

If YES

- **Please describe.**

Exclusion criteria:

- ☐ **Untreated sleep apnea**
- ☐ **Narcolepsy**
- ☐ **Chronic Fatigue Syndrome**

9) Do you have migraine or tension headaches that require you to take medication daily?

If YES,

- ➢ **Please describe.**

Exclusion criteria:

- ☐ Any narcotic medications

10) Do you currently have untreated depression, anxiety disorder, drug dependency, claustrophobia, or ADHD?

If YES,

- ➢ **Please describe.**

Exclusion criteria:

- ☐ Untreated depression and ADHD
- ☐ Dependency or abuse of psychoactive drugs, illicit drugs, or alcohol
- ☐ Agoraphobia, hyperventilation, or anxiety attacks

11) Have you experienced any pain from neck or back injuries within the last year?

If YES,

- ➢ **Is it current or chronic neck or back injury?**

Exclusion criteria:

- ☐ Any current skeletal, muscular or neurological problems in neck or back regions
- ☐ Chronic neck and back pain
- ☐ Pinched nerves in neck or back
- ☐ Back surgery within last year

12) Are you currently taking any prescription or over the counter medications?

If YES,

- ➢ **What is the medication?**
- ➢ **Are there any warning labels on your medications, such as potential for drowsiness?**

Exclusion criteria:

- ☐ Sedating medications or drowsiness label on medication UNLESS potential participant indicates they have been on the medication consistency for the last 6 months AND states they have NO drowsiness effects from this medication

13) Do you experience any kind of motion sickness? If YES ➢ **What were the conditions you experienced: when occurred (age), what mode of transportation, (boat, plane, train, car), and what was the intensity of your motion sickness?** ➢ **On a scale of 0 to 10, how often do you experience motion sickness with 0 = Never and 10 = Always** ➢ **On a scale of 0 to 10, how severe are the symptoms when you experience motion sickness with 0 = Minimal and 10 = Incapacitated**
Exclusion criteria: ☐ **One single mode of transportation where intensity is high and present** ☐ **More than 2 to 3 episodes for mode of transportation where intensity is moderate or above** ☐ **Severity and susceptibility scores rank high**
14) How did you hear about this study? If drivingstudies.com, recruitment email, or recruitment line, no further questions. If from a friend, coworker, or similar: ➢ **Find out what the individual knows about the study. Ensure they have no knowledge of specifics of the drive but do not specifically ask about the drive. We need to be sure individuals coming in are naïve to the study events.**
Exclusion criteria: ☐ Knows anything about the study drives other than length or that there are two drives
Proceed to Closing

Closing

<u>MEETS ALL CRITERIA</u>

Instructions:

- **Refrain from drinking alcohol for 24 hours prior to your driving session.**
- **Please avoid taking any NEW prescription or over the counter drugs for the 24 hours preceding your driving session. If you do need to take a new medication 24 hours preceding your driving session, please call us. Ibuprofen, Tylenol, aspirin, and vitamins are acceptable to take prior to driving session.**
- **Bring your Driver's License with you to appointment.**
- **We ask that cell phones and pagers be turned off or left home or in your car outside as they are not allowed while participating in the driving study.**
- **We request the following of all participants:**
  - **Wear flat shoes to drive in**
  - **No hats worn or gum chewing allowed while driving**
  - **Refrain from wearing artificial scents (perfume or cologne) as some staff allergic to scents**
- **If your appointment is before 8am or after 5pm, the front door may be locked, so please come to the door at your appointment time. Someone should be in the lobby waiting to let you in. If they have had to step away for a moment, they will return as soon as possible.**
- **Please call (319) 335-4666 if you are unable to make this appointment as soon as possible. We prefer 24-hour notice. Please leave a message if you receive voicemail and a staff member will return your call.**

<u>DOES NOT MEET CRITERIA</u>:

- Inform participant that they may qualify for a future study and ask if they wish to remain in our database to be called for future studies.
- If participant is not in our database, ask if they would like to be considered for future driving research studies, if yes, fill out NADS database form.

Appendix B: Simulator Experiment Informed Consent

INFORMED CONSENT DOCUMENT

Project Title: After Market Safety Device Driver Vehicle Interface Guidance Development

Principal Investigator: Dawn Marshall

Research Team Contact: Dawn Marshall, 319-335-4774

This consent form describes the research study to help you decide if you want to participate. This form provides important information about what you will be asked to do during the study, about the risks and benefits of the study, and about your rights as a research subject.

- If you have any questions about or do not understand something in this form, you should ask the research team for more information.
- You should discuss your participation with anyone you choose such as family or friends.
- Do not agree to participate in this study unless the research team has answered your questions and you decide that you want to be part of this study.

WHAT IS THE PURPOSE OF THIS STUDY?

This is a research study. We are inviting you to participate in this research study because you are between the ages of 25 and 55, are a regular driver, and are in good general health.

The purpose of this research study is to examine differences in drivers across the US.

HOW MANY PEOPLE WILL PARTICIPATE?

Approximately 180 people will take part in this study at the University of Iowa.

HOW LONG WILL I BE IN THIS STUDY?

If you agree to take part in this study, your involvement will last for approximately 1 hour during one study visit.

WHAT WILL HAPPEN DURING THIS STUDY?

An experimenter will verbally review this document and answer any questions you have. If you agree to be in the study, you will receive a copy of your signed document at the end of your visit. You will then be asked to show your driver's license so we can confirm it is valid, fill out a payment form, and complete a questionnaire that covers some general questions about your demographics (date of birth, gender, marital status, income, occupation, ethnicity and education level), driving experience, the vehicle you drive, and motion sickness. You will then watch a presentation that describes the driving simulator and driving environment.

You will next complete one practice drive of approximately 5-6 minutes. Immediately following the end of the drive, you will be asked to complete a wellness survey that asks about how you feel at that moment. After this survey, you will complete a study drive that will last approximately 3-5 minutes. Immediately following the end of the drive, you will be asked to complete a wellness survey that asks about how you feel at that moment. Following the simulator drive and wellness survey, you will be asked to fill out a post-drive survey that asks about specific experiences from your drive and a short questionnaire about the realism of the simulator. A member of the research team will complete your payment form and the study will be completed.

You may skip any questions you do not wish to answer on any of the questionnaires.

WHAT ARE THE RISKS OF THIS STUDY?

You may experience one or more of the risks indicated below from being in this study. In addition to these, there may be other unknown risks, or risks that we did not anticipate, associated with being in this study.

The risk involved with driving the simulator is possible discomfort associated with simulator disorientation. Some participants in driving simulator studies reported feeling uncomfortable during or after the simulator drive. These feelings were usually mild to moderate and consisted of slight uneasiness, warmth, or eyestrain. These effects typically last for only a short time, usually 10-15 minutes, after leaving the simulator. You should notify the researcher any time you experience these feelings and you may quit driving at any time if you experience any discomfort.

If you ask to quit driving as a result of discomfort, you will be allowed to stop immediately. If you ask to quit driving due to discomfort, you will be escorted to a room, asked to sit and rest, and offered a beverage and snack. A trained staff member will determine if and when you will be allowed to leave. If you show few or no signs of discomfort, you will be able to go home or transportation will be arranged if you feel you are unable to drive home. If you experience anything other than slight effects, a follow-up call will be made to you 24 hours later to ensure you're not feeling ill effects.

WHAT ARE THE BENEFITS OF THIS STUDY?

You will not benefit from being in this study. However, we hope that, in the future, other people might benefit from this study because we will have a better understanding of how drivers across the U.S. may drive differently.

WILL IT COST ME ANYTHING TO BE IN THIS STUDY?

You will not have any costs for being in this research study.

WILL I BE PAID FOR PARTICIPATING?

You will be paid for being in this research study. You will need to provide your address so that a check can be mailed to you.

The compensation available for completing all the study procedures is $40. If you are unable to complete the study procedures, your pay will be pro-rated based on the amount of time that you participated. You will earn $10.00 for every 15 minutes of participation.

WHO IS FUNDING THIS STUDY?

The National Highway Traffic Safety Administration is funding this research study. This means that the University of Iowa is receiving payments from the National Highway Traffic Safety Administration to support the activities that are required to conduct the study. No one on the research team will receive a direct payment or increase in salary from the National Highway Traffic Safety Administration for conducting this study.

WHAT ABOUT CONFIDENTIALITY?

We will keep your participation in this research study confidential to the extent permitted by law. However, it is possible that other people such as those indicated below may become aware of your participation in this study and may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you.

- federal government regulatory agencies,
- auditing departments of the University of Iowa, and
- the University of Iowa Institutional Review Board (a committee that reviews and approves research studies).

To help protect your confidentiality, we will assign you a study participant number that will be used instead of your name to identify all data collected for the study. The list linking your participant number and name will be stored in a secure location and will be accessible only to the researchers at the University of Iowa. All records and data containing confidential information will be maintained in locked offices or on secure password protected computer systems that are accessible to the researchers, the study sponsor, and its agents. Study documents will be kept in a locked cabinet within a secure building that can only be entered by research personnel. After completion of analysis, all hard copies except the Informed Consent Documents will be scanned, placed on a CD and placed into the NADS archival room that has limited access by designated archival personnel. The original Informed Consent Documents will be stored in the NADS archival room that has limited access by designated archival personnel.

The **engineering data** collected and recorded in this study will be analyzed along with data gathered from other participants. These data may be publicly released in final reports or other publications or media for scientific (e.g., professional society meetings), regulatory (e.g., to assist in regulating devices), educational (e.g., educational campaigns for members of the general public), outreach (e.g., nationally televised programs highlighting traffic safety issues), legislative (e.g., data provided to the U.S. Congress to assist with law-making activities), or research purposes (e.g., comparison analyses with data from other studies). Engineering data may also be released individually or in summary with that of other participants, but will not be presented publicly in a way that permits personal identification

The **simulator data** is captured and stored on hard drives located within a limited access area of the

NADS facility. Access to simulator data is controlled through permissions established on a per-study basis.

If we write a report or article about this study, or share the study data set with others, we typically describe the study results in a summarized manner so that you cannot be identified by name.

IS BEING IN THIS STUDY VOLUNTARY?

Taking part in this research study is completely voluntary. You may choose not to take part at all. If you decide to be in this study, you may stop participating at any time. If you decide not to be in this study, or if you stop participating at any time, you won't be penalized or lose any benefits for which you otherwise qualify.

Can Someone Else End my Participation in this Study?

Under certain circumstances, the researchers might decide to end your participation in this research study earlier than planned. This might happen if you fail to operate the research vehicle in accordance with the instructions provided, or if there are technical difficulties with the driving simulator.

WHAT IF I HAVE QUESTIONS?

We encourage you to ask questions. If you have any questions about the research study itself, please contact: Dawn Marshall at 319-335-4774. If you experience a research-related injury, please contact Dawn Marshall at 319-335-4774.

If you have questions, concerns, or complaints about your rights as a research subject or about research related injury, please contact the Human Subjects Office, 105 Hardin Library for the Health Sciences, 600 Newton Rd, The University of Iowa, Iowa City, IA 52242-1098, (319) 335-6564, or e-mail irb@uiowa.edu. General information about being a research subject can be found by clicking "Info for Public" on the Human Subjects Office web site, http://hso.research.uiowa.edu/. To offer input about your experiences as a research subject or to speak to someone other than the research staff, call the Human Subjects Office at the number above.

This Informed Consent Document is not a contract. It is a written explanation of what will happen during the study if you decide to participate. You are not waiving any legal rights by signing this Informed Consent Document. Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Subject's Name (printed): ____

Do not sign this form if today's date is on or after EXPIRATION DATE: 07/30/17.

______________________________ ______________________
(Signature of Subject) (Date)

Statement of Person Who Obtained Consent

I have discussed the above points with the subject or, where appropriate, with the subject's legally authorized representative. It is my opinion that the subject understands the risks, benefits, and procedures involved with participation in this research study.

______________________________ ______________________
(Signature of Person Who Obtained Consent) (Date)

Appendix C: Simulator Experiment Demographic and Driving Questionnaire

Participant number: Date:

DEMOGRAPHIC AND DRIVING QUESTIONNAIRE

As part of this study, it is useful to collect information describing each participant. The following questions ask about your basic demographic information, health, driving frequency and patterns. Please read each question carefully. If something is unclear, ask the research assistant for help. Your participation is voluntary and you may skip any questions that you do not want to answer.

Background Information

1) What is your birth date? ______/______/______
Month Day Year

2) What is your gender?

❒ Male
❒ Female

3) What is your marital status? (Check only one)

❒ Single
❒ Married
❒ Domestic Partnership
❒ Separated or Divorced
❒ Widowed

4) What was <u>your</u> total household income last year? (Check only one)

❒ 0 - $20,000
❒ $20,000 - $29,999
❒ $30,000 - $39,999
❒ $40,000 - $49,999
❒ $50,000 - $59,999
❒ $60,000 - $69,999
❒ $70,000 - $79,999
❒ $80,000 or more

5) What is your present employment status? (Check only one)

❒ Unemployed
❒ Retired
❒ Work part-time
❒ Work full-time
❒ None of the above

6) What type of work do you do (e.g., teacher, law enforcement official, homemaker)?

____

7) Of which ethnic origin(s) do you consider yourself? (Check all that apply)

❒ American Indian/Alaska Native
❒ Asian
❒ Black/African American
❒ Hispanic/Latino
❒ Native Hawaiian/Other Pacific Islander
❒ White/Caucasian
❒ Other

8) What is the highest level of education that you have completed? (Check only one)

❒ Primary School
❒ High School Diploma or equivalent
❒ Technical School or equivalent
❒ Some College or University
❒ Associate's Degree
❒ Bachelor's Degree
❒ Some Graduate or Professional School
❒ Graduate or Professional Degree

Participant number: Date:

Driving Experience

9) How old were you when you started to drive? _____ years of age

10) On average, how many days in a week (out of 7 days) do you drive?
❒ 0 ❒ 1 ❒ 2 ❒ 3 ❒ 4 ❒ 5 ❒ 6 ❒ 7

11) How many work-related miles did you drive in the last year? (Check only one)
❒ Under 2,000
❒ 2,000 - 7,999
❒ 8,000 - 12,999
❒ 13,000 - 19,999
❒ 20,000 or more

12) What speed do you typically drive on the highway when the speed limit is 55 miles per hour?
❒ Below 45
❒ 45 - 49
❒ 50 - 54
❒ 55
❒ 56 - 60
❒ 61 - 64
❒ 65 - 69
❒ 70 - 74
❒ Above 74

13) What speed do you typically drive on the highway when the speed limit is 65 miles per hour?
❒ Below 55
❒ 55 - 59
❒ 60 - 64
❒ 65
❒ 66 - 70
❒ 71 - 74
❒ 75 - 79
❒ 80 - 84
❒ Above 84

14) What speed do you typically drive on the highway when the speed limit is 70 miles per hour?
❒ Below 60
❒ 60 – 64
❒ 65 - 69
❒ 70
❒ 71 – 74
❒ 75 - 79
❒ 80 - 84
❒ Above 84

15) Have you ever participated in any driving training program (e.g., Graduated Driver Licensing program, CDL Truck Training Schools)?
❒ No
❒ Yes (Please describe) ____

____

Personal Vehicle

16) What type of automobile do you drive most often?

Year — Make (e.g., Ford, Toyota) — Model (e.g., Escort, Celica)

___ ___ ___ ___ ___________________________ ______________________________

17) Which of the following Advanced Driver Assistance Systems (ADAS) features does your automobile have? (Check all that apply)

❒ None of these
❒ Adaptive Cruise Control (ACC)
❒ Lane Departure Warning (LDW)
❒ Lane Change Assistance
❒ Forward Collision Avoidance System
❒ Intelligent Speed Adaptation or Intelligent Speed Advice (ISA)
❒ Automotive Night Vision
❒ Adaptive Light Control
❒ Automatic Parking
❒ Blind Spot Detection (BSD)
❒ Driver Drowsiness Detection
❒ Hill Descent Control (HDC)
❒ Others
Please list: ____

And how often you use these ADAS features when you are driving?
❒ Never ❒ Rarely ❒ Sometimes ❒ Often ❒ Always

18) How many vehicles are in your household? _________________________

Violations and Accidents

19) Within the past five years, how many moving violations have you received? __________

20) Within the past five years, have you received a ticket for any of the following? (Please check No or Yes for each)

	No	Yes
Speeding	❒	❒
Going too slowly	❒	❒
Failure to yield right of way	❒	❒
Disobeying traffic lights	❒	❒
Disobeying traffic signs	❒	❒
Using cellphone while driving	❒	❒
Driving without using the seatbelt	❒	❒
Following another car too closely	❒	❒
Driving while intoxicated	❒	❒
Other (please specify) ___________________________________		

Participant number: Date:

21) In the past five years, how many times have you been the driver of a car involved in a crash?

❒ 0 (Go to question 23)
❒ 1
❒ 2
❒ 3
❒ 4 or more

Please provide the following information about the last crash.

	No	Yes
Was another vehicle involved?	❒	❒
Was a pedestrian involved?	❒	❒
Were you largely responsible for this accident?	❒	❒
Did you go to driver's rehabilitation?	❒	❒

Weather Condition: ______________________
Month/Year: ______________________
Brief Description: ______________________
____

22) In the past five years, how many times have you been the driver of a car involved in a rear-end crash?

❒ 0 (Go to question 23)
❒ 1
❒ 2
❒ 3
❒ 4 or more

Please provide the following information about the last rear-end crash.

	No	Yes
Was another vehicle involved?	❒	❒
Was a pedestrian involved?	❒	❒
Were you largely responsible for this accident?	❒	❒
Did you go to driver's rehabilitation?	❒	❒

Weather Condition: ______________________
Month/Year: ______________________
Brief Description: ______________________
____

Motion sickness

23) How often do you experience motion sickness? (Circle only one)
0 1 2 3 4 5 6 7 8 9 10
Never Always

24) How severe are your symptoms when you experience motion sickness (Circle only one)
0 1 2 3 4 5 6 7 8 9 10
None Severe

25) Have you taken any prescription or over-the-counter medication in the past 48 hours?
❒ No
❒ Yes (Please list all) ______________________

26) Have you consumed any alcohol or other drugs in the past 24 hours?
❒ No
❒ Yes (Please list all) ____

Other Studies

27) Have you participated in other driving studies?

❒ No (End of questionnaire)
❒ Yes (please provide details for each study you have participate in below)

Study 1
What vehicle was used for this study? (Check only one)

❒ Actual car - only
❒ Simulator - only
❒ Both - actual car and simulator

Brief Description:
____
____
____

Study 2
What vehicle was used for this study? (Check only one)

❒ Actual car - only
❒ Simulator - only
❒ Both - actual car and simulator

Brief Description:
____
____
____

Appendix D: Simulator Experiment Post Drive Questionnaire

Study: **WASD**
Participant: _________
Date: _________

POST-DRIVE QUESTIONNAIRE

Please answer the following questions. You may skip any questions that you do not wish to answer.

1. Did you know what sort of event the warning was trying to alert you to before you saw the other vehicle?

2. How easily and quickly could you interpret this warning? (Please circle a number 1-5)

Very Easily/Quickly				*Very Difficult/Slowly*
1	*2*	*3*	*4*	*5*

3. How useful was the warning to you in this situation? (Please circle a number 1-5)

Very Useful				*Not Useful At All*
1	*2*	*3*	*4*	*5*

4. How distracting was this warning? (Please circle a number 1-5)

Not Distracting At All				*Very Distracting*
1	*2*	*3*	*4*	*5*

5. Would you pay to have this type of system installed in your vehicle? If yes, how much?

Appendix E: Simulator Experiment Wellness Survey

Study: <u>WASD</u>
Participant: ________
Date: ________

WELLNESS QUESTIONNAIRE

<u>Directions</u>: Circle one option for each symptom to indicate whether that symptom applies to you <u>right now</u>.

1. General Discomfort.................... None .... Slight .... Moderate ....Severe
2. Fatigue ....None .... Slight .... Moderate ....Severe
3. Headache ....None .... Slight .... Moderate ....Severe
4. Eye Strain ....None .... Slight .... Moderate ....Severe
5. Difficulty Focusing ....None .... Slight .... Moderate ....Severe
6. Salivation Increased ....None .... Slight .... Moderate ....Severe
7. Sweating ....None .... Slight .... Moderate ....Severe
8. Nausea ....None .... Slight .... Moderate ....Severe
9. Difficulty Concentrating ....None .... Slight .... Moderate ....Severe
10. *"Fullness of the Head" ....None .... Slight .... Moderate ....Severe
11. Blurred Vision ....None .... Slight .... Moderate ....Severe
12. Dizziness with Eyes Open ....None .... Slight .... Moderate ....Severe
13. Dizziness with Eyes Closed ......None .... Slight .... Moderate ....Severe
14. **Vertigo ....None .... Slight .... Moderate ....Severe
15. ***Stomach Awareness ....None .... Slight .... Moderate ....Severe
16. Burping ....None .... Slight .... Moderate ....Severe
17. Vomiting ....None .... Slight .... Moderate..........Severe
18. Other __________________ ......None .... Slight .... Moderate..........Severe

* Fullness of the head is an awareness of pressure in the head.

**Vertigo is experienced as loss of orientation with respect to vertical upright.

***Stomach awareness is a feeling of discomfort which is just short of nausea.

Appendix F: Simulator Experiment Realism Survey

Study: __WASD__
Participant: __________
Date: __________

REALISM QUESTIONNAIRE

For each of the following items, circle the number that best indicates how closely the simulator resembles an actual car in terms of appearance, sound, and response. If an item is not applicable, circle NA.

	General Driving	Not at all Realistic					Completely Realistic	
1	Response of the seat adjustment levers	0	1	2	3	4	5	6	NA
2	Response of the mirror adjustment levers	0	1	2	3	4	5	6	NA
3	Response of the door locks and handles	0	1	2	3	4	5	6	NA
4	Response of the fans	0	1	2	3	4	5	6	NA
5	Response of the gear shift	0	1	2	3	4	5	6	NA
6	Response of the brake pedal	0	1	2	3	4	5	6	NA
7	Response of accelerator pedal	0	1	2	3	4	5	6	NA
8	Response of the speedometer	0	1	2	3	4	5	6	NA
9	Response of the steering wheel while driving straight	0	1	2	3	4	5	6	NA
10	Response of the steering wheel while driving on curves	0	1	2	3	4	5	6	NA
11	Feel when accelerating	0	1	2	3	4	5	6	NA
12	Feel when braking	0	1	2	3	4	5	6	NA
13	Ability to read road and warning signs	0	1	2	3	4	5	6	NA
14	Appearance of car interior	0	1	2	3	4	5	6	NA
15	Appearance of signs	0	1	2	3	4	5	6	NA
16	Appearance of roads and road markings	0	1	2	3	4	5	6	NA
17	Appearance of rural scenery	0	1	2	3	4	5	6	NA
18	Appearance of intersections	0	1	2	3	4	5	6	NA
19	Appearance of other vehicles	0	1	2	3	4	5	6	NA
20	Appearance of rear-view mirror image	0	1	2	3	4	5	6	NA
21	Sound of the car	0	1	2	3	4	5	6	NA
22	Sound of other vehicles	0	1	2	3	4	5	6	NA
23	Overall feel of the car when driving	0	1	2	3	4	5	6	NA
24	Overall similarity to real driving	0	1	2	3	4	5	6	NA
25	Overall Appearance of driving scenes	0	1	2	3	4	5	6	NA

Study: __WASD__
Participant: ___________
Date: ___________

	Situational Driving	Not at all Realistic						Completely Realistic	
26	Feel of driving straight while going 25 mph	0	1	2	3	4	5	6	NA
27	Feel of driving straight while going 55 mph	0	1	2	3	4	5	6	NA
28	Feel of driving on a curved road while going 25 mph	0	1	2	3	4	5	6	NA
29	Feel of driving on a curved road while going 55 mph	0	1	2	3	4	5	6	NA
30	Feel of accelerating from a stopped position	0	1	2	3	4	5	6	NA
31	Feel of braking to a stop	0	1	2	3	4	5	6	NA
32	Ability to stop the vehicle	0	1	2	3	4	5	6	NA
33	Ability to respond to other vehicles	0	1	2	3	4	5	6	NA
34	Ability to keep straight in your lane	0	1	2	3	4	5	6	NA
35	Ability to respond at intersections	0	1	2	3	4	5	6	NA

Appendix G: Simulator Experiment Debriefing Statement

Debriefing Statement
Thank you very much for participating in this study. Your participation was very valuable to us. We know you are very busy and appreciate the time you devoted to participating in this study.

There was some information about the study that we were unable to discuss with you prior to the drive, because doing so may have impacted your actions and thus skewed the study results.

In this study, we were interested in understanding your reactions to various types of aftermarket safety device systems, particularly Intersection Movement Assist, Left Turn across Path, or Emergency Electronic Brake Lights. You were told that we were studying differences among drivers across the US; however, in reality, one of the three systems was simulated and data about your reaction to the warning was collected. It is true that people in another location in the US are participating in a related study.

We hope this clarifies the purpose of the research, and the reason why we could not tell you all of the details about the study prior to your participation.

It is very important that you do not discuss this study with anyone else until the study is complete. Our efforts will be greatly compromised if participants come into the study knowing its true purpose and how their reactions are being examined. To this end, we would ask that you not discuss any of the details of the study until April 15, 2017.

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National Highway
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