# Safety, Operational, and Energy Impacts of In-vehicle Adaptive Stop Displays Using Connected Vehicle Technology

CVI UTC

## CONNECTED VEHICLE/INFRASTRUCTURE UNIVERSITY TRANSPORTATION CENTER (CVI-UTC)

MORGAN STATE UNIVERSITY

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# Safety, Operational, and Energy Impacts of In-vehicle Adaptive Stop Displays Using Connected Vehicle Technology

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Submitted by:


Virginia Tech Transportation Institute
3500 Transportation Research Plaza
Blacksburg, VA 24061

Program Director:

**Dr. Thomas Dingus**
Director Virginia Tech Transportation Institute
Director National Surface Transportation Safety Center for Excellence
Newport News Shipbuilding Professor of Engineering at Virginia Tech
tdingus@vtti.vt.edu
(540) 231 – 1501

Name of Submitting Official:

**Alexandria M. Noble**
Graduate Research Assistant
anoble@vtti.vt.edu
(540) 231 – 1500



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# Disclaimer



# Connected Vehicles-Infrastructure UTC

The mission statement of the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) is to conduct research that will advance surface transportation through the application of innovative research and using connected-vehicle and infrastructure technologies to improve safety, state of good repair, economic competitiveness, livable communities, and environmental sustainability.

The goals of the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) are:

- Increased understanding and awareness of transportation issues
- Improved body of knowledge
- Improved processes, techniques and skills in addressing transportation issues
- Enlarged pool of trained transportation professionals
- Greater adoption of new technology

# Abstract

Un-signalized intersections create multiple opportunities for missed or misunderstood information. Stop sign-controlled intersections have also been shown to be a source of delay and emissions due to their frequent, often inappropriate use. By using connected vehicle technology, it is possible to place electronic stop signs at more conspicuous locations that can communicate with the in-vehicle systems. Then, if a conflict is imminent at an intersection, the vehicle's system alerts the driver, thus reducing the probability of missed information, as well as decreasing the amount of unnecessary delay, fuel consumption, and emissions by only prompting a stop when a conflict is present. Before implementing any new technology, it is important to assess it from both a transportation engineering and human factors standpoint to determine the value of such a system.

The objective of this study was to assess perceived benefits of an adaptive in-vehicle stop display and to determine if there were any negative safety implications with the use of this system. This was accomplished through a test track experiment with 49 participants. These drivers were presented with a standard R1-1 stop sign on the in-vehicle display, as well as an experimental sign, which informed them to proceed through the intersection with caution. Results indicate the implementation of this technology reduces delay, decreases fuel consumption, and does not instigate any safety decrements.

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# Background

## Overview

Intersections are defined as locations where vehicles are required to cross paths to proceed along their intended route; they are prime areas for the occurrence of vehicle crashes. In recent years, the general trend of highway crashes has steadily declined largely due to aggressive public awareness campaigns and more stringent enforcement of safe driving practices by state and local law enforcement. Despite these reductions in overall fatal crash involvement, there is a significantly less marked decline in the occurrence of fatal crashes at stop and yield controlled intersections. In 2012, 683,000 crashes occurred at stop sign-controlled intersections, with 2,434 of those crashes being fatal and composing 5.3% of all fatal traffic incidents in the United States [1]. According to crash statistics from the National Highway Transportation Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS) database, the most frequently occurring pre-crash event in 2011 was crossing over, or running, the stop/yield sign, comprising exactly 50% of all fatal stop/yield sign related crashes that year.

According to the Manual on Uniform Traffic Control Devices for City Highways and Streets (MUTCD), traffic control devices "notify road users of regulations and provide warning and guidance needed for the safe, uniform, and efficient operation of all elements of the traffic stream" [2]. The MUTCD also states that for a traffic control device to be effective, it should perform the following functions: fulfill a need; command attention; convey a clear, simple meaning; command respect of road users; and give adequate time for proper response.

The conditions under which a multi-way stop sign control is implemented generally fall into two categories. First, at low volume intersections, such as in rural environments, a stop sign may be installed for the sake of perceived safety. Second, at low to medium volume intersections, such as in urban environments, a stop sign may be installed where traffic volume is heavy enough to warrant some sort of control but not heavy enough to warrant a traffic signal. Stop signs, often used to control speed in areas of perceived risk, unfortunately have low compliance rates. It is critical for roadway safety that they must command attention and respect from the road user, but this is seldom the case.

## Unintended Consequences of the Misuse and Overuse of Stop Signs

Stop signs often have unintended consequences associated with their use, many of which can be addressed and corrected by using adaptive stop displays instead. Additionally, misuse of traffic control devices promotes a lack of respect for them, thus an overall reduced rate of compliance.

**Reduced Compliance**. Stop signs have extremely low full compliance rates when compared to other forms of traffic control, and these rates seem to have decreased over time. A 1989 study by the Federal Highway Administration (FHWA) showed that only 16 years after the introduction of stop signs, they had less than a 50% full compliance rate [3]. Overall, the study examined 31,212 vehicles at 142 sites: 67.6% of those observations resulted in a violation, while only 1.3% of that 67.6% resulted in a traffic conflict. The most recent stop sign compliance study by *Trinkaus et al.* was conducted in the New York metropolitan area at the same four "T" junction intersections located in a residential community. In 1996, the final year of the nine-year study, 99% of drivers did not stop at the stop signs assessed in the study. During this same study period, full stops declined from 37% to 1% [4]. In a study of driver's violation rates at intersections to develop an algorithm to determine violators, it was found that 36% of drivers in the sample never slowed below 3.4 m/s (5 mph) [5], or a rolling stop. While by law these acts should be classified as violations, their frequency suggests that rolling stops are intentional; drivers were cognizant of the signs yet made a conscious decision to proceed through the intersection anyways.

**Delay**. The magnitude of the delay incurred at stop signs depends on the type of junction, traffic volumes, and turn percentages. Delay at multi-way stops signs results from a set of complex interactions between the traffic flows on all approaches to the intersection. The delay experienced on any given approach leg of an intersection is predominately influenced by flow on that approach and the flows on conflicting and opposite approaches. Turning percentages are also believed to play a role in the performance of four-way stop-controlled intersections. According to Chan et al., an increase in right turns at these intersections decreases delay, although an increase in left turn percentage does not alter the level of service or capacity of an intersection [6]. Furthermore, unnecessary delays arise from vehicles stopping at an intersection when no conflict is present, which adds to overall travel times.

**Speeding**. A commonly held public belief is that stop signs provide some measure of speed control. While this may be true at an intersection where a stop sign is located, studies nationwide have shown that speeds within a block of a stop sign are either unaffected or in some cases actually increased. In 1976, a study was conducted on the impact of stop sign installation on speed, indicated that while the difference in average speeds was not significant after installation of a stop sign, vehicle speeds tended to slightly increase, possibly as the driver attempted to make up for lost time [7].

**Fuel Consumption and Emissions**. There is a direct correlation between fuel consumption and emission: the more fuel a vehicle uses, the more emissions it produces. Stop signs increase fuel consumption by requiring drivers to stop even when another vehicle is not present at the intersection. In the United States alone, the annual estimate for fuel wasted due to unnecessary stops is somewhere between $1.587\times10^9$ and $2.489\times10^9$ gallons while greenhouse gas emissions is approximately $25.7\times10^6$ tons[8]. Emissions and fuel consumption are highly dependent on traffic volume and the vehicle mix. The Texas State Department of Highways and Public Transit found that approach volume has a strong effect on emissions and fuel consumption for in-bound travel lanes. Additionally, a higher percentage of tractor-trailers increases emissions and fuel consumption [9].

## Crash Causation at Stop-controlled Intersections

Crashes are a function of the vehicle, the driver, and the environment. Because stop-controlled intersections have their own set of unique safety considerations, they are different from signalized intersections and highway driving.

**Road Characteristics**. Intersections by their very nature create multiple conflict points between vehicles, pedestrians, and bicyclists. At a typical four-way stop-controlled intersection, there are 32 vehicle-to-vehicle conflicts and 16 vehicle-to-pedestrian conflicts [10].

***Intersection Geometry***. According to the National Cooperative Highway Research Program (NHCRP) report on *Geometric Design Consistency on High-Speed Rural Two Lane Roadways,* the angle at which the two intersecting roadways cross greatly affects the safe operation of the intersection. Intersections with large or small crossing angles increase the conflict area, limit visibility, increase the turning area needed for large vehicles, and increase the time of exposure within the intersection for crossing vehicles [11].

Excessive driveway access at or near un-signalized intersections can be confusing to drivers and may create vehicle-to-vehicle conflicts. The *AASHTO Policy on Geometric Design of Highways and Streets* defines the upstream functional area of an intersection as a variable distance influenced by: (a) distance traveled during perception-reaction time, (b) deceleration distance while the driver maneuvers to a stop, and (c) the amount of queuing time at the intersection. Limiting driveways within the functional area of an intersection improves the safety of an intersection by reducing both driver workload and the number of additional conflict points [12].

Drivers who collide with oncoming traffic despite stopping their vehicles can sometimes be attributed to sight-distance obstructions as demonstrated in Figure 1. Reduced sight distance at un-signalized intersections for approaching drivers or for stopped drivers on the approach leg plays a factor in stop-controlled intersection crashes.

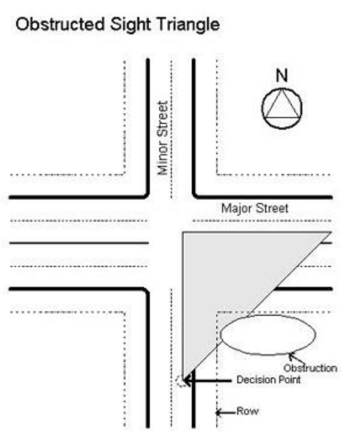



**Figure 1: Obstructed sight lines contribute to driver indecision [14]**

***Traffic Control Device Maintenance and Conspicuity***. Traffic signs are an important transportation tool that communicates regulatory, warning, and guidance information to drivers along the roadway. Signs that are inappropriately designed or misused can have unintended consequences for the drivers of motor vehicles, such as confusion or missed messages, which is a direct result of insufficient funds, negligence, and poor maintenance.

Traffic control asset management is now an important issue for state and local transportation agencies because FHWA has proposed minimum retro-reflectivity standards for traffic signs. There is little data on how different types of sheeting materials deteriorate over time; it is difficult to determine what role these factors have in the frequency of replacing traffic signs when considering climate, geographic region, and the sign's orientation.

The *Maintenance of Signs and Sign Supports: A Guide for Local Highway and Street Maintenance Personnel* provides checklists for an adequate inventory management program as well as suggestions for preventative maintenance for common problems afflicting traffic signs. Sign cleaning, vegetation control, anti-theft measures, and support adjustments are among their suggestions to keep these devices fully operational [15]. Also, as trees and brush can block the view of traffic control devices especially during the spring and summer months, the *Vegetation Control for Safety, A Guide for Local Highway and Street Maintenance Personnel* recommends that any vegetation blocking or obscuring stop or yield signs must be cut immediately [16]. Finally, because stop signs are often knocked over or rotated out of place by large trucks, run off road crashes, and environmental factors, by using a proper and through inventory management program, missing signs can be replaced and knocked down signs can be re-erected.

Given the lack of data on environmental factors, the best information that state agencies have to consider is the typical warranty life of the retro-reflective sheeting as provided by the manufacturer. The expected sign life and years of warranty are linked but not equal. Once a traffic sign has exceeded its retro-reflective ability, it loses its utility in night driving and low visibility situations and must be replaced.

**Table 1. ASTM Retro-Reflective Sheeting Warranty [17]**

| ASTM D4956 Type | Years of Warranty |
|---|---|
| I and II | 7 |
| III and IV | 10 |
| VII, VIII, IX, X | 12 |

The expected life of the stop sign is used in blanket replacement techniques, which is a common sign replacement strategy due to its ease of execution. The replacement of stop signs using a blanket replacement technique can be performed in a strategic or spatial fashion [17]. In the spatial technique, all road sign types slated for replacement in that time frame are replaced, regardless of their age.

The main benefit to this common blanket replacement strategy is that if every sign is replaced in a given time period, in theory, its retro-reflectivity levels should not fall below the useful levels. However, this method is extremely wasteful, particularly at beginning of the municipalities' use of retro reflective signage. Sometimes signs are replaced during their service periods due to vandalism or other environmental factors and then subsequently replaced before their useful life is up.

Stop signs frequently need to be replaced due to intentional vandalism (e.g., paintballs, eggs, paint, guns, etc.) or the effects of nature (e.g., tree sap, dirt, water damage, etc.). According to a North Carolina State University study conducted for the North Carolina Department of Transportation (NCDOT), 4.7% of signs are replaced each year due to damage and poor night time visibility and 2.4% are replaced due to vandalism for a total replacement rate of 6.9% [18]. It also determined a visual inspection cost of $0.55 per sign. However in Minnesota County, MN their inspection cost using a reflectometer was determined to be $2.80 per sign. Accuracy between the two methods varied from 54% to 83% [19].

#### Driver Related Factors.

***Perception and Search Error***. Older drivers generally have difficulty detecting, reading, and understanding traffic signs. They are also at a particular disadvantage at night if the brightness is high as irradiation makes a sign more difficult to read. Older drivers also require far more contrast between sign messages and its background.

A report in 2008 discovered failure to yield crashes occurred most often when drivers were turning left and more frequently at stop signs than at signalized intersections. Among drivers 80 and older, search errors predominated in failure to yield crashes. Search errors also were a large factor in failure to yield crashes among drivers ages 35-54, but their search errors were due more often to distraction [20].

***Inexperience***. Novice drivers have not been exposed to the many complex situations that can arise while operating a motor vehicle. Teen drivers have a tendency to take their eyes off the road longer than more experienced drivers when performing driving-related tasks or engaging in distractive activities. Inexperience is a risk factor in crashes mainly because competence for safe driving is largely a mental rather than a physical activity. However, new drivers can learn to manage a vehicle effectively within a short time frame. Safe and competent driving requires the ability to perceive hazards and having the ability to make sound judgments on mitigating hazards by defensive driving. These mental processes are only strengthened with years of exposure.

***Decision Making***. The primary factors that influence decision making in general are knowledge of risks, appreciation of the potential tradeoffs between risks and benefits, focus on the most likely outcomes, and perceived alternatives to taking the risk. Teen drivers, much like adult drivers, have a tendency to overestimate their confidence in control over risk [21]. While a teen who believes they can handle hazardous situations has confidence in their driving skills, their concern for safety decreases. Since the teen driver is also less experienced than the average adult driver is, the optimistic bias is particularly hazardous for teen drivers.

Stop sign compliance relies on the internal control of "rule following," which may be described as a statement of contingencies [22]. As illustrated by a modified example from *Human Factors for*

*Highway Engineers*, the rule "stop if there is a stop sign" may be translated as a statement of the contingency: if there is a stop sign (discriminative stimulus) and a driver does not stop (response), they may crash into another vehicle (punishing consequence). As demonstrated in the real world with the prevalence of stop sign violations where rule following is not supported by the natural contingencies, the control of behavior may transfer from the rule to those contingencies.

An objective of the adaptive stop display is to increase the reliability of the rule by only requiring drivers to stop when it is necessary.

***Information Processing***. Driver characteristics, associated with the immersion and understanding of information, govern the driver's abilities to derive implications for the current situation and the decisions required for appropriate execution. Given the difficulties in maintaining the integrity of road signs, gaps exist that can lead to an absence of information and contribute to inappropriate decision-making and crashes. A large US in-depth study found that in 70% or more cases involved human error as a causal factor of a crash occurring at an un-signalized intersection [23]. Of these, about 40% indicated difficulties in perception or information processing as contributing factors. Because driving is a time sensitive task, there is a finite amount of time to identify relevant information, make the decision of the best course of action, and then execute. When information is missing, often drivers do not fill in those gaps until they have encroached on another vehicle's right of way.

**Table 2. Human Causal Factors in Traffic Accidents [23]**

| Factor | Percentage |
|---|---|
| Improper lookout | 18-23 |
| Inattention | 10-15 |
| Speeding | 8-17 |
| Internal distraction | 6-9 |
| False assumption | 5-8 |

***Driver Visual Search***. The ability of a driver to scan the environment for hazards is important when approaching an intersection and making the decision whether to stop or proceed. Human vision alone extends about 180° in the horizontal direction, yet by age 70 the range reduces to about 140°. The addition of head and eye movements allows for a much wider field of view. Useful field of view (UFOV) includes the total visual field from which target characteristics can be acquired when head and eye movements are excluded. The extent of the UFOV depends on how well the driver can divide their attention, ignore distractions, and select relevant information. UFOV reduces with increasing driver age, increasing vehicle speed, heavy traffic, inclement weather, and high task demand. In stressful driving conditions, a driver may fail to scan the entire road environment, thus missing critical information and putting them at risk for conflicts.

Crundall et al. showed that as driving becomes more dangerous, the pattern of visual search becomes more focused and drivers are more likely to miss certain information. This is especially true in peripheral vision with inexperienced drivers [25]. It was also noted by Crundall that although novice and experienced drivers have similar detection rates for identifying near hazards, the novices' ability declines the further away a hazard is relative to the vehicle. As drivers gain experience, they become more adept to scanning the road and at ignoring information that is irrelevant to the driving task [25]. In a study by Romoser et al., differences between older (mean age = 77) and younger drivers (mean age = 35) on obstructed stop-controlled intersection approaches were significantly different when they were within two seconds from entering the intersection [26]. It appears that there are no physiological or cognitive explanations between the older driver's failures to scan intersections for hazards when there are no distractions present. It is possible that they may have developed a habit of not scanning the intersection, which may cause them to not take action though they are physically able to do so.

The roadway environment also has an impact on driver scanning behavior. Eye movements change from narrow scanning and looking just ahead of the vehicle to sampling more widely as driving experience increases [27]. Where a driver looks depends upon the driving situation; such as, for example, when there is no traffic, about half of the glances are straight ahead. Driving on a two way road has shown an increase in the variance of horizontal fixation location for more experienced drivers when compared to other road types [28]. Data from driver eye fixations suggest drivers feel comfortable looking inside a vehicle for about one second on average, though it is noted that in such cases as that of contemporary in-vehicle systems, up to 1.5 seconds is commonplace [29].

***SEEV Model***. The SEEV (Salience, Effort, Expectancy, and Value) Wicken's model is a model of selective attention [30].The parameters of SEEV demonstrate how visual and mental attention are affected by the environment. With a decrease in information conspicuity, there is an increased effort in obtaining the same level of information than if the stimulus had been more salient. For example, if a stop sign is conspicuous enough to be seen by a driver where appropriate action could be taken, the expectancy of any repercussion for violating the stop sign is inherently low. The value of information from a traditional stop sign is generally low for many drivers: its value is contingent on the presence of some form of repercussion such as a collision or a ticket.

Relocating stop signs to adaptive in-vehicle displays could accommodate for the shortcomings of traditional stop signs. When coupled with an auditory alert, the probability of missed information is lower than compared to other traditional methods. A reduced visual search field for the information is also introduced as the relevant information is presented inside the vehicle, thus narrowing the area of search. The expectancy and value of the information presented to the driver will vary as a function of the driver's trust in the system, their degree of experience with the system, and situational factors such as level of opposing traffic (probability of conflict).

Ideally, the most valuable information is more obvious in any design. However, at stop-controlled intersections, the most valuable information (the stop sign) may be obstructed by vegetation or missing entirely; other indicators of potential hazards could be obstructed by poor sightlines. An adaptive stop display inside the vehicle allows for the potential of additional benefits including reduced frequency of missed information and higher levels of conspicuity.

When any change is made to a traffic sign, especially those which are so ingrained into drivers' minds, such as stop signs, an evaluation of the perceptions and reactions of naïve people must be considered. According to Dewar and Olson, as cited by Salvendy [31] the traffic control device must attract the driver's attention (conspicuity), be easily read or interpreted (comprehension), and disseminate information quickly, within 1 or 2 seconds. While adaptive in-vehicle signs have great potential, they must be properly designed and tested to ensure that there are no unintended safety repercussions in terms of driver comprehension or distraction.

### Objective

The primary aim of this research was to determine if any safety decrements result from replacing typical static stop signs with an in-vehicle adaptive stop display. The presence of a safety decrement was determined by extended gaze duration off road, frequent in-vehicle glances, and decreased scanning of the environment, or relying overmuch on the system.

## Method

The research questions posed were studied with an on-road mixed subject Latin-square design test studying drivers from high-risk age groups. Participants approached an uncontrolled intersection under various levels of traffic. The state of an in-vehicle display (IVD) was predetermined based on the scenario presented to the participant; traffic levels also varied with scenario.

The data collected was used to answer the following research questions about the overall IVD impact on driving behavior and safety:

1. What are the potential savings in terms of implementation and maintenance costs?
2. What is the driver's cost of delay?
3. What is the driver's cost of fuel consumption?
4. What is the societal cost of $CO_2$ emissions?
5. Does stopping behavior of drivers using the adaptive display differ significantly from a traditional stop sign? If so, could these differences compromise safety?
6. Do drivers proceed through the intersection when permitted in a way that appears averse to risk (e.g. decelerating on their approaching)?
7. Do drivers respond in a way that is averse to risk when a display malfunction occurs?

### Sign Study

At the onset of this research, an assessment was conducted on sign characteristics for use in-vehicle adaptive stop displays. There are currently no standards on the shape and colorings of in-vehicle regulatory signs, a need that must be addressed given the growth and improvement of connected vehicle technology. Instead of focusing on a particular standard, this study considered optimizing IVD's ability to convey the appropriate message. Ninety-four participants completed an online survey. Each responder was randomly given one of three versions of the survey, all of which asked the same questions about different displays. Results indicated the wording on the display matters more to users than the shape or colors used in the display. For a complete report on the background, method, and conclusion of the Sign Study, see Appendix S.

## Participant Recruitment

The Virginia Tech Transportation Institute (VTTI) maintains a database of potential participants organized by age and gender. Forty-nine participants were recruited for this study from the targeted high-risk age ranges of 18 to 25 and 55 years old and above, with a nearly equal distribution of males and females. Any previous involvement in a VTTI study was also considered in participant selection but did not disqualify anyone. Many participants had not participated in any VTTI study previously.

All participants were required to complete the screening and orientation tasks for eligibility to participate in the study. They were compensated at a rate of $30 per hour; if the experiment ended early, the participants were paid a pro-rated amount.

## Testing Environment

The Virginia Smart Road was used as the primary testing environment for this study. Participants drove an instrumented experimental vehicle on the Smart Road under varying traffic and sign conditions.

**The Smart Road**. This private test-track facility is a 2.2-mile two-lane roadway built to highway specifications. The Smart Road has four "turn around" so experimental vehicles can quickly change direction without having to traverse the length of the road. Dispatchers control access to the roadway via an electronic gateway that makes the test facility a safe location to conduct research. Here, researchers are able to conduct experiments that would not be possible or safe on the open roadway.

The Smart Road has a full sized intersection with a high-speed and low-speed approach, which allows for flexibility of studies conducted on the road. During this particular study, the four-way intersection was used as the only location for participant interaction with confederate vehicle traffic and in-vehicle alert distribution. North and southbound approaches were used for collecting data on participant stopping behavior; all four legs of the intersection were used for confederate vehicle to interact with participants.

**Research Vehicle**. Participants drove a 2008 White Chevy Tahoe, shown in Figure 2, on the test track.

**Figure 2. Experimental vehicle.**

The experimental vehicle was equipped with anti-lock brakes, traction control, and airbags for the safety of the participant and in-vehicle researchers. An emergency passenger side-brake was added so the lead researcher could stop the vehicle if needed.

The data acquisition system (DAS) gathers and records data streams asynchronously, allowing each sensor to operate at its optimal collection rate, accurately recording all relevant kinematic and driver performance data for subsequent analysis. For this study, it was positioned in the back of the vehicle out of the participant's view in an unobtrusive location. The DAS hardware was contained in custom housing and was wired to interface with the vehicle controller area network (CAN) through the OBD port.

The DAS records data at millisecond precision at the data collection rate native to sensor on a high performance sensor suite. The configuration used for this study is presented below:

- Four digital video cameras views
- Forward camera view
- Driver face view
- Display view
- Accelerator/brake pedal view
- Accelerometers (three axes)
- Gyroscopes (three axes)
- GPS receiver
- Experimenter interface
- Audio
- Vehicle network data

Data was collected on an encrypted 256 GB solid state hard drive for each participant and subsequently uploaded to a secure server at VTTI. A NovaTel differential GPS unit was used to provide precise coordinates of the test vehicle for proximity calculations. A Savari On Board Equipment (OBE) unit was the Dedicated Short Range Communication (DSRC) transceiver.

A laptop was used for the experimenter interface and was plugged directly into the DAS via an Ethernet cable (see Figure 3). The interface software, SOLEye allowed for the manual input of participant demographic information along with trial specifications such as number, alert type, and proximity to center of the intersection where the alert would be administered.

**Figure 3. Experimenter interface and SOLEye program.**

**Confederate Vehicles**. During the on road procedure, participants interacted with vehicles driven by trained researchers from VTTI. Varying vehicle sizes were selected due to the large size of the experimental vehicle; the confederate vehicles are shown in Figure 4. All confederate drivers received many hours of supervised training prior to driving on the Smart Road with a participant.

**4(a). Large confederate vehicle.**

**4(b). Mid-size confederate vehicle.**

**4(c). Small confederate vehicle.**

**Figure 4. Confederate vehicles.**

Confederate drivers communicated with the experimental vehicle researcher via two-way radios with a headset to coordinate their carefully choreographed scenarios. They also communicated with one another privately using a second two-way radio on a separate channel that served as a notification system for surprise events between the research vehicle and the confederate drivers.

## Participant Screening and Orientation

**Screening Tasks**. During initial phone interviews, participants confirmed they held a valid United States driver's license, had no pre-existing medical conditions that would prohibit them from taking part in this study, and delivered the appropriate age and gender demographics. Those willing who met the preliminary age and health criteria were scheduled to participate in the study.

**Orientation Tasks**. At the time of the test, participants were instructed to arrive at VTTI where they would be greeted in the lobby by a researcher and escorted to a participant screening room. There, they then completed the following tasks: an Informed Consent form (see Appendix B); a W-9 tax form (see Appendix C); a Snellen vision test; the Ishihara color blindness test; and a general hearing test. The vision test ensured all participants had the corrected acuity of at least 20/40 as prescribed by Virginia law. See Appendix D for the script used by researchers for participant orientation.

**Pre-Drive Survey**. Participants also completed a preliminary survey during orientation, which gathered demographic information, driving experience, their primary vehicle type, experience with active safety systems/advanced in-vehicle technology, experience and feelings toward connected vehicle technology, and behaviors at stop signs. See Appendix E for the script used by researchers for participant orientation to the vehicle.

## Vehicle Orientation

After completing all orientation materials, participants were acclimated to the specifics of the research vehicle. They were also informed of the in-vehicle adaptive stop display and its purpose. Researchers ensured that participants were familiar and comfortable with the vehicle and its components prior to driving on the Smart Road (see Appendix F).

**In-Vehicle Adaptive Display**. The in-vehicle adaptive display was a five-inch HD TFT LCD monitor, positioned so it was slightly offset from the vehicle's steering wheel and plugged in the HVAC system (see Figure 5). This is considered a high head-down display and was selected due to its proximity to the driver's field of view. In this study, the change in display and associated auditory alert was triggered by the driver crossing a geo-specific threshold and activating a pre-determined sign state. However, in real world application the state of the sign will adapt based on traffic conditions using a DSRC network and additional connected vehicle systems.


**Figure 5. In-vehicle adaptive display location.**

**Visual Display**. The stop display was an image of the standard R1-1 stop sign [2] on a black background. Participants saw the stop display when a stop was necessary. The Proceed with Caution (PWC) display, developed by VTTI in an earlier stage of this research (see Appendix S), was also displayed on a black background. Participants saw the PWC display when they were advised to proceed vigilantly through the intersection rather than stopping completely (see Figure 5.)


6(a). Stop display.


6(b). PWC display.

**Figure 6. Stop display 6(a) and PWC display 6(b) were shown to drivers during the on-road portion of the study.**

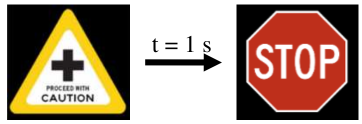
In the interim between presentations of relevant information, the display shown in Figure 7 was placed on the screen to maintain the authority of the traffic control displays.


**Figure 7. Interim display.**

**Auditory Alert**. An auditory alert coupled with the display of the in-vehicle traffic control device (TCD) notified the participant that information had appeared on the screen. The auditory alert that occurred during normal display functionality contained seven pulses with a pulse width of 62 ms, inter-pulse interval of 39 ms, and a frequency of 1500 Hz (Alert 1). In the case of an emergency switch, the auditory alert began with Alert 1 then switched to a signal that contained five pulses with a pulse width of 1690 ms, inter-pulse interval of 26 ms, and a frequency of 740 Hz (Alert 2).

**Description of Sign States**. Table 3 gives a description of events surrounding the presentation of each sign shown on the IVD.

**Table 3. Summary of Sign and Alert Pairings**

| Sign State | Image | Alert Pairing |
|---|---|---|
| STOP |  | Alert 1 |
| Proceed with Caution (PWC) |  | Alert 1 |
| Switch |  | Alert 1 then Alert 2 |
| Blackout | VirginiaTech. Transportation Institute | No Auditory Alert |

## On-Road Procedure

**Orientation Tasks**. After vehicle orientation, the experimenter took the research vehicle's front seat while the participant took the driver's seat and proceeded to the Smart Road. They completed an orientation lap to familiarize themselves with turnarounds, uphill and downhill starting points, the intersection prior to the onset of data collection, and ease any uncertainty of driving an unfamiliar vehicle on an unfamiliar road. Participants then received more information about connected vehicle technology and how it related to the study. Conditions set forth in the test were designed to imitate situations that drivers might experience in the real world when using this technology. Finally, participants were instructed to maintain a the maximum speed limit of 35 mph, keep the vehicle in 3$^{rd}$ gear on intersection approaches, and place the vehicle in park if they stopped for an extended period.

**Scenario Tasks**. All participants completed a series of 21 uniquely crafted scenarios and encountered those experimental conditions in a pre-determined order that varied in a modified Latin-Square design. These maneuvers were designed to imitate situations one may experience in the real world while using this technology, including interactions with varying levels of traffic and equipment malfunctions or failures. The lead researcher gave the following instructions to participants prior to every scenario:

1. Proceed toward the intersection at about 35 mph.
2. Follow the onscreen prompt.
3. Follow the lead researcher's navigational instructions after passing through the intersection.

## Normal Driving Conditions: Scenario Descriptions

Under normal driving conditions participants would approach the intersection from one of two marked start locations on the Smart Road. Between zero and three other [confederate] vehicles would also approach the intersection keeping pace with the subject vehicle. Diagrams of the scenarios that the subject vehicle experienced are shown in Appendix T.

## Violation of Expectations: Scenario Descriptions

**Surprise**. In the "surprise" scenario, one leg of the intersection was blocked with a visual obstruction— in this case, a collapsible fence with privacy slats, blocking a confederate vehicle from sight (Figure 8). As the participant approached the intersection, the confederate vehicle received notification from the lead researcher when the participant vehicle was approximately 35 m from the stop bar (Figure 8). Then, the confederate vehicle drove partially into the intersection in view of the participant vehicle (Figure 9) and stopped (Figure 11).

**Figure 8. Confederate vehicle behind visual obstruction.**


**Figure 9. Participant view on approach (35 m behind stop bar).**


**Figure 10. Confederate vehicle encroaching on participant vehicle.**


**Figure 11. Final stopping location for confederate vehicle.**

**Switch**. In the "switch" case, the in-vehicle display unit initially gave the participant the PWC display; then 0.10 sec. following, the display switched to stop with a different auditory alert. Switch cases occurred both with and without traffic conditions present.


Figure 12. Participant view of intersection on approach.


Figure 13. Cross traffic for switch case.

This scenario was intended to simulate a system malfunction and was tested in particular to determine driver behavior in case of error. For example, in real-world application, drivers could receive one command and then receive another command on the same approach a short time later. If drivers are not able to stop prior to entering the intersection or are careless about how they proceed, there lies the potential for serious safety implications.

**Blackout**. In the "blackout" case, the display provides no visual or auditory stimulus to the participant: they were left to make a decision regarding whether or not to proceed through the intersection. Two confederate vehicles approached the intersection to create a conflict situation for the participant.


**Figure 14. Participant view of intersection on approach with confederate vehicles approaching directly and on the left.**

## Data Mining Effort for Driver Behavior at Traditional Stop Signs

Data for a traditional static stop sign was collected through a data mining effort of the 100-Car Naturalistic Driving Study (26), which tracked the behavior of the drivers of 100 vehicles equipped with video and sensor devices for over one year. During that time, the vehicles drove nearly 2,000,000 miles and yielded 42,300 hours of data. The 241 participant drivers were involved in 82 crashes, 761 near-crashes, and 8,295 critical incidents. The data mining effort undertaken in this study involved a partial dataset that contained kinematic data and video of the participant and their surroundings. Stop-controlled intersections from the 100-Car database were previously identified from the 100-Car database for CICAS-V Subtask 3.2 [32] using coordinates provided by the Virginia Department of Transportation (VDOT).

The data mining effort resulted in 426 observations occurring at traditional static stop signs at five different intersections (Figure 15). Observations of driver behavior in the 100-Car study were compared to driver behavior using the adaptive stop display.

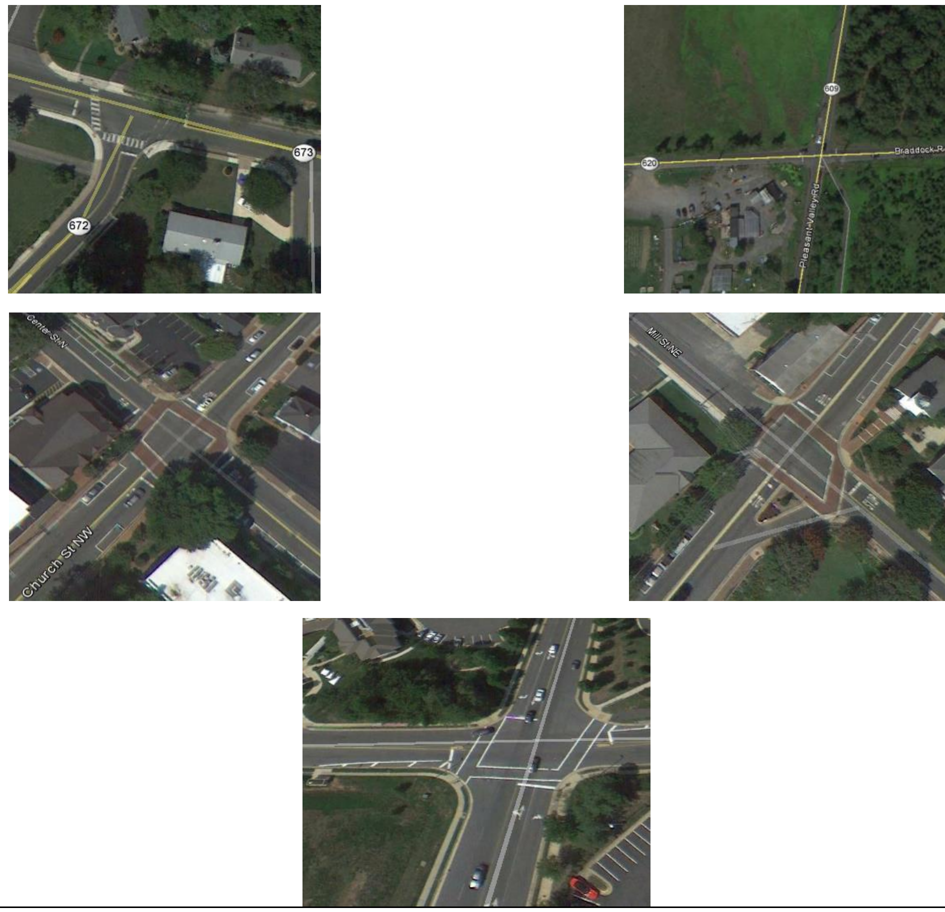



**Figure 15. Intersections used for comparison to adaptive display.**

### Participant Post-Test Debriefing

After finishing all the experimental trials, participants returned to the building where they were debriefed, completed post-drive questionnaires, and received answers to any questions they had. They were compensated for their time and asked not to discuss any specifics of the study with anybody.

## Results

### Driving Behavior and Implications for Safety

This analysis determined if the use of the adaptive stop display resulted in driving behavior that was significantly different from that of a typical stop-controlled intersection. Data from the 100-Car study was used as the baseline measurement of driver stopping behaviors at stop-controlled intersections. Any difference in driving behavior was of interest to researchers in determining how the change in behavior impacts driver safety at intersections.

**Adaptive Stop Display Compliance**. A full stop is defined by the *ITE Manual of Transportation Engineering Studies* as a complete cessation of movement no matter however brief [33]. In addition, the vehicle should stop with the front bumper somewhere between 15 m before or 2 m after the stop bar. For the purpose of this study, a rolling stop was defined as a vehicle reaching a minimum speed of 4.5 m/s (or 10 mph) or less while still in motion prior to passing through the intersection. A full violation was defined as a vehicle reaching a minimum speed that is greater than 4.5 m/s prior to passing through the intersection [5].

It was discovered that the adaptive stop display had a full compliance level of 62.11% while traditional stop signs had a full compliance level of 12.44%. The rate for full violations (crossing the stop bar at a speed greater than 4.5 m/s [10 mph]) was 1.17 % for the adaptive stop display and 39.67% for traditional stop signs. The prevalence of rolling stops between the two traffic control devices was comparable, occurring 36.72% of the time with the adaptive stop display and 47.89% of the time for traditional stop signs [$\chi^2$ (2,N = 682) = 225.45, p < 0.0001].

A chi-square test indicated a statistically significant difference tending toward more compliant behavior for the adaptive stop display when compared to the traditional stop sign (Figure 15).

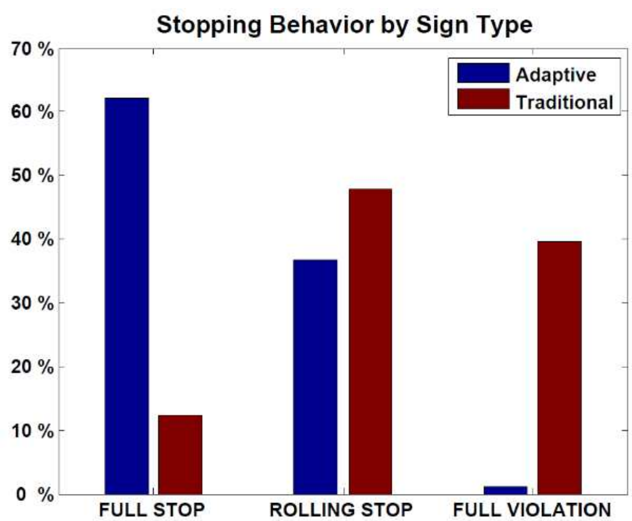



**Figure 16. Stopping behavior by compliance type.**

**Location of Braking Onset**. Participant braking behavior for the in-vehicle adaptive stop display was compared to that of drivers stopping at a traditional static stop sign. An acceleration rate of -0.075 g was used as the threshold for detection to ensure the participant was actively pressing the brake and no other phenomena was causing the vehicle's apparent deceleration.

An analysis of variance indicated no statistically significant difference between sign type in the distance relative to the stop bar where braking begins *[F (1,649) = 0.0568, p = 0.57]* (Table 4).

**Table 4. Location of Braking Onset (m)**

| Sign Type | N | Mean | Std Dev | Min | Max |
|---|---|---|---|---|---|
| ADAPTIVE | 147 | 54.73 | 5.97 | 41.49 | 147 |
| TRADITIONAL | 335 | 51.87 | 23.52 | 0.51 | 335 |

**Location of Stop**. An analysis of variance indicated a statistically significant difference between location of stop and sign type *[F (1, 210) = 73.72, p<0.0001]*. Tukey's Honest Significant Difference (HSD) test showed a significant difference between the mean stopping locations for the adaptive stop display *(N=159, M=2.71, S= 3.34)* and the traditional stop sign *(N=53, M=7.51, S= 4.04)*.

51% of the events in the traditional stop sign group had a final stop location greater than or equal to 7.5 m behind the stop bar, indicating more than half of the people in the 100-Car subset stopped behind at least one lead vehicle but did not stop when they approached the stop bar.

**Inappropriate Stops**. Participants in the adaptive stop display study committed thirteen inappropriate stops beyond the stop bar (greater than 2 m); the mean stopping location was 4.22 m. Most of these events occurred during the first three exposures to the system, particularly the first time, with only two instances occurring in later scenarios. The same participant committed those two inappropriate stops with a mean stopping location of 3.5 m beyond the stop bar. All participants except one committed only one inappropriate stop, although one participant contributed four inappropriate stops to the overall number (see Figure 17.)

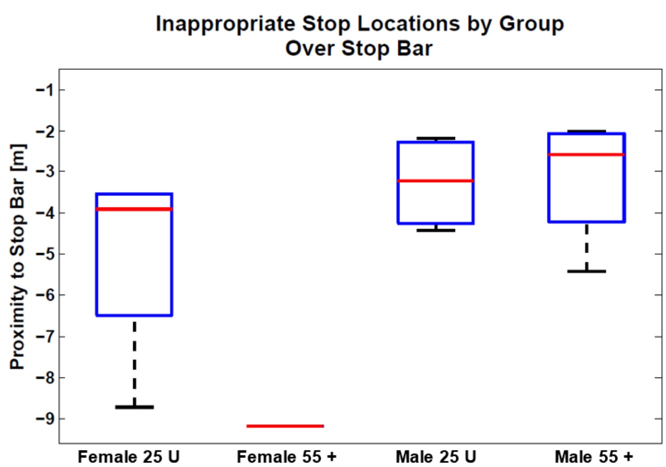



**Figure 17. Inappropriate stop location by age and gender.**

## Risk Aversion Using Proceed with Caution Display

This analysis determined how drivers proceeded through the intersection while using the adaptive stop display when the IVD indicated they were permitted to do so. The desired response was drivers complying with the display and proceeding through the intersection; however, a modest change in speed was also desirable as drivers should also be assessing their surroundings.

**Proceeding vs. Stopping at Intersection**. Participants were presented with the PWC display without any prior instruction on what to take when the alert appeared. Over the course of all exposures to the display, 95.7% of participants proceeded through the intersection while only 4.3% of participants stopped.

A chi-square analysis indicated traffic level had a significant influence *[$\chi 2$ (3, N = 1029) = 10.917, p = 0.012]* on whether or not a participant decided to stop or go when they received the PWC display (Table 5).

**Table 5. Frequency of Stop/Go Behavior by Traffic Level**

| TRAFFIC | Frequency | Percent | Number of Exposures |
|---|---|---|---|
| 0 | 3 | 6.8% | 2 |
| 1 | 25 | 56.8% | 12 |
| 2 | 6 | 13.6% | 3 |
| 3 | 10 | 22.7% | 2 |

**Minimum Speed**. Traffic level influenced the minimum speed attained by participants [F (3,971) = 14.01, p < 0.0001]. A Tukey's HSD test indicated a statistically significant difference between the minimum speeds of all traffic levels compared to behavior when three other vehicles were present at the intersection (Table 6).

**Table 6. Minimum speed (m/s) × Traffic Level**

| TRAFFIC | N | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| 0 | 144 | 6.48 | 3.95 | 0.37 | 15.28 |
| 1 | 563 | 6.18 | 3.80 | 0.24 | 16.24 |
| 2 | 190 | 5.62 | 4.16 | 0.19 | 16.95 |
| 3 | 88 | 7.81 | 4.47 | 0.85 | 16.56 |

An analysis of variance was conducted on the location relative to the stop bar where the minimum speed occurs; traffic was found to have a statistically significant influence *[F (3,971) = 14.01, p < 0.0001]* (Table 7).

**Table 7. Proximity to Stop Bar (m) Where Minimum Speed Occurs × Traffic Level**

| TRAFFIC | N | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| 0 | 144 | -5.39 | 11.50 | -21.30 | 32.69 |
| 1 | 563 | -2.58 | 10.64 | -23.26 | 63.75 |
| 2 | 190 | 0.09 | 8.61 | -14.70 | 33.95 |
| 3 | 88 | 1.07 | 7.20 | -13.83 | 20.82 |

Though participants had a higher minimum speed with an increase in traffic, their time to intersection (TTI) was higher (see Table 8). This indicated that in a situation requiring more time to assess the hazards of an environment, they were more cautious and slowed prior to proceeding through the intersection.

$$TTI = \frac{Proximity\ to\ Stop\ Bar\ [m]}{Minimum\ Speed\ \left[\frac{m}{s}\right]} \qquad (1)$$

**Table 8. Driver TTI × Traffic Level**

| TRAFFIC | N | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| 0 | 144 | -1.87 | 4.41 | -43.70 | 2.91 |
| 1 | 563 | -0.78 | 2.00 | -17.07 | 14.00 |
| 2 | 190 | -0.38 | 1.54 | -5.79 | 5.10 |
| 3 | 88 | 0.17 | 0.89 | -1.86 | 4.16 |

**Mean Acceleration Prior to Crossing the Stop Bar**. Traffic level *[F (3,971) = 42.03, p <0.0001]* had an influence on mean acceleration prior to crossing the stop bar. When coupled with minimum speed and TTI findings, participants generally decelerated when the level of traffic increased, indicating drivers were avoiding risks when proceeding through the intersection. (see Table 9).

**Table 9. Mean Acceleration Prior to Crossing Stop Bar (g)**

| TRAFFIC | N | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| 0 | 144 | -0.11 | 0.06 | -0.29 | 0.04 |
| 1 | 563 | -0.13 | 0.07 | -0.25 | 0.05 |
| 2 | 190 | -0.17 | 0.05 | -0.26 | -0.04 |
| 3 | 88 | -0.08 | 0.05 | -0.18 | 0.02 |

## Driver Performance with Abnormal Display Functionality

It was important to test not only how users reacted to the adaptive display when it functioned properly, but perhaps more importantly when it did not perform as expected. A collection of scenarios were developed to simulate assorted equipment malfunctions drivers could experience in the real world when using this technology; their kinematic and behavioral response was recorded and analyzed.

**Surprise**. The participant approached the intersection under the conditions of the "surprise" scenario: a confederate vehicle that had been blocked from sight drove partially into the path of the participant as they traveled through the intersection.

***Participant Stopping Behavior upon Encroachment***. 57.14% of drivers did not stop upon encroachment. However, a chi-square test of independence was performed to examine the relation between the prevalence of hard braking events (acceleration < -0.5 g) and the stop/go behavior of the participants to determine if a stop action was taken by the drivers that did not stop. Results indicated a statistically significant difference between the occurrence of hard braking events for participants who proceeded through the intersection and those that did not [$\chi^2$ (1, N=49) =10.46, p=0.0012] (Table 10).

**Table 10. Chi-Square for Stop/Go Behavior and Hard Braking**

| | GO | STOP | Total |
|---|---|---|---|
| Hard Brake Event | 7 | 15 | 22 |
| | 14.29% | 30.61% | 44.90% |
| No Hard Brake | 21 | 6 | 27 |
| | 42.86% | 12.24% | 55.10% |
| Total | 28 | 21 | 49 |
| | 57.14% | 42.86% | 100% |
| Statistic | DF | Value | p |
| $\chi^2$ | 1 | 10.46 | 0.0012 |

Of the hard braking events recorded, 30.6% of participants were vigilant enough to react in time to the encroachment with hard braking. 12.2% of participants were able to stop without a hard braking event; 14.3% of participants made an attempt to stop with a hard braking event, but were ultimately unsuccessful. Many of these participants also attempted lateral collision avoidance maneuvers in addition to their hard braking behavior.

**Switch**. The participant approached the intersection under the conditions of the "switch" scenario: they initially received a PWC display that switched quickly to stop.

***Participant Violation Commission on Switch***. A chi-square test was performed on the frequency of the participants who stopped and did not stop when information on the IVD changed when traffic was present and when traffic was not present. The data from the chi-square test indicated no statistically significant difference between the two scenarios [$\chi^2$ (1, N = 98) = 0.3908, p =0.5319] (See Table 11.).

**Table 11. Frequency of Violations on Switch**

| | Frequency | Percent |
|---|---|---|
| GO | 37 | 37.76% |
| STOP | 61 | 62.24% |

*Location of Minimum Speed*. **An analysis of variance on the distance relative to the stop bar where the participant had achieved their minimum speed indicated no statistically significant difference between stopping behavior, age, gender, or traffic volume [F (4, 97) = 1.93, p = 0.0112]. The descriptive analysis of the minimum speed shows that on average participants who proceeded through the intersection (GO Group) achieved their minimum speed closer to the stop bar (see Table 12 and**

Table 13).

**Table 12. Location of Minimum Speed (m)**

| BEHAVIOR | N | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| GO | 37 | 0.12 | 3.32 | -8.45 | 8.10 |
| STOP | 61 | 2.13 | 5.99 | -5.80 | 26.63 |

**Table 13. Minimum Speed (m/s)**

| BEHAVIOR | N | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| GO | 37 | 1.03 | 0.96 | 0.19 | 5.39 |
| STOP | 61 | 0.00 | 0.00 | 0.00 | 0.00 |

The required deceleration parameter represents the calculated, constant deceleration required to stop at the stop bar based on the vehicle's current speed and proximity.

$$RDP = \frac{V^2}{2 \times R \times g}$$

$$RDP = Required\ deceleration\ parameter\ [g]$$
$$V = Minimum\ Speed\ [m/s]$$
$$R = Instantaneous\ proximity\ to\ the\ stop\ bar\ [m]$$
$$g = Gravitational\ acceleration\ constant\ [9.81\ m/s^2] \quad (2)$$

About half of the participants who proceeded through the intersection would have been able to stop the vehicle without hard braking (deceleration < 0.5g) based on their Required Deceleration Parameter (RDP). The remaining participants had already crossed the stop bar by the time their minimum speeds had been achieved (Table 14).

**Table 14. RDP Summary Statistics for GO Group**

| RDP | Min. Speed Location | N | Mean | Min. | Max. |
|---|---|---|---|---|---|
| RDP > 0 | Behind Stop Bar | 18 | 0.14 | 0.00 | 0.48 |
| RDP < 0 | In Front of Stop Bar | 19 | -0.02 | -0.06 | -0.001 |

The majority was able to stop the vehicle prior to crossing the stop bar, or would have been able to if the need presented itself.

**Blackout**. The participant approached the intersection under the conditions of the "blackout" scenario: the IVD provided no visual or auditory stimulus to the participant, forcing them to rely on their own judgment of whether or not to proceed through the intersection. Two confederate vehicles approached the intersection to create a conflict situation for the participant. In this analysis, driver response to the situation of oncoming traffic coupled with a lack of information will be analyzed through kinematic measures. Driving behavior will be further analyzed through eye glance analysis in a later section.

***Stop/Go Behavior***. When no auditory or visual information was displayed to the participant, only 4.08% (2) of participants came to a complete stop behind the stop bar while 95.92% (47) of drivers proceeded through the intersection. Due to the low number of participants who stopped, inferential statistics cannot be completed on this information.

***Cautionary Behavior of Participants***. Participants who stopped completely before the stop bar were removed from the data set in order to analyze stop bar crossing speed.

**Table 15. Summary Statistics on Maximum Speed**

| Variable | N | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| D2SB (m) | 46 | 63.72 | 30.54 | -14.85 | 76.90 |
| Speed (m/s) | 46 | 15.60 | 0.83 | 13.84 | 18.13 |
| Accel. (g) | 46 | -0.01 | 0.04 | -0.12 | 0.13 |

**Table 16. Summary Statistics on Minimum Speed**

| Variable | N | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| D2SB (m) | 46 | 6.43 | 12.75 | -13.52 | 45.62 |
| Speed (m/s) | 46 | 11.00 | 5.00 | 0.25 | 17.12 |
| Accel. (g) | 46 | 0.02 | 0.02 | -0.04 | 0.06 |

This shows participants did not consistently demonstrate the desired level of risk-averse behavior in the absence of a stimulus.

### Potential Infrastructure and Implementation Costs

In the absence of a national stop sign inventory, VDOT data cited by Cottrell et al. [34] was used instead as a surrogate for the United States. By using the functional classifications of the roadways in Virginia as dictated by VDOT [35] the approximate number of stop signs in the state could be calculated. Then by taking the number of stop signs per mile and the length of roadways by functional classification as dictated by the Bureau of Transportation Statistics [36] the estimated number of stop signs in the United States was calculated. Using the previously mentioned parameters and the method outlined in Appendix U we can believe that there are roughly 14,896,156 stop signs in the United States.

The estimated annual cost to install and maintain all stop signs on only secondary rural roads in the United States is illustrated in Table 17. These costs assume a blanket replacement method is used, and that 50% the municipalities in the country use a visual inspection method while the remaining 50% use the retro-reflectometer method. This assumes that the stop sign material used in a given network is Type III or above prismatic retro-reflective material and the cost of installation and material is $255 USD per stop sign [37]. The cost of a full network install using these parameters is $3,798,519,780.00; Table 17 shows the costs of the Blanket Replacement and 4% replacement methods.

**Table 17. Thirty Year Stop Sign Cost for Secondary Roads**

| Activity | Cost [$\$\times10^8$] |
|---|---|
| Blanket Replacement (15 year) | $37.54 |
| 4% Replacement | $22.52 |
| *Total* | *$60.06* |

63% of these costs are a result of the blanket replacement technique that is, replacing stop signs that may not have a deficiency as well as other inherent flaws of stop signs such as low compliance, unnecessary stops, and visual obstruction. It is possible that a cheaper way exists to achieve a more desirable outcome in terms of compliance and funds expended.

### Connected Vehicle Technology Costs

Twelve automotive sector panelists from a mixture of automakers, Tier 1 suppliers, and wireless communications suppliers participated in a Delphi study conducted by the Michigan Department of Transportation (MDOT) about connected vehicle technologies [38]. Panelists responded to a series of open-ended and multiple choice questions as well as true/false statements about their insights on a broad range of topics including communication technologies for various applications, possible governmental influence, and the years in which various levels of DSRC deployment would be reached. They were also asked about the deployment cost and alternatives to embedded communications equipment. Findings from the MDOT Delphi study determined the estimate cost per vehicle for manufactures to add DSRC hardware as embedded equipment inside the vehicle would be $175 in 2017 and about $75 in 2022. Additionally, the estimated cost per vehicle for consumers would be $350 in 2017 and $300 in 2022.

The 2010 *ITS Unit Costs Database* [39] detailed the operating and maintenance costs for the constituents of the adaptive stop display system. The cost of the system components was projected to the deployment year of 2014 to account for the projected decrease in price of certain components; those projected capital and operational costs for system components are listed in Table 18. These costs were projected to the year 2014, from 1995 or 2003 as shown in the ITS Unit Costs Database. Since the market penetration of connected vehicle technology likely will not have reached a level sufficient for the practical implementation of the adaptive stop display until well after 2020, it is difficult to estimate the change in price of the individual components over such an extended period.

**Table 18. Projected Adaptive Stop Display System Component Costs for 2014 [$USD]**

| Component | Capital Costs | | Operation & Maintenance Costs | |
|---|---|---|---|---|
| | Low | High | Low | High |
| 1 | $177.91 | $355.82 | $0.42 | $0.84 |
| 2 | $18.48 | $36.97 | $0.02 | $0.03 |
| 3 | $92.41 | $184.83 | $0.08 | $0.15 |
| 4 | $197.86 | $296.80 | — | — |
| 5 | $295.72 | $406.62 | $1.86 | $2.56 |
| 6 | $110.90 | $184.83 | $0.27 | $0.46 |
| 7 | $103.50 | $203.31 | $0.16 | $0.29 |
| **System Cost** | **$996.79** | **$1,669.16** | **$2.81** | **$4.33** |

The "lifetime" in years of the constituents of the onboard system is relatively low when compared to traditional traffic control systems, such as 20 years for a traffic signal. However, considering that at this time the onboard equipment is in the prototype phase, the lifetime of the in-vehicle equipment may be improved. Table 19 gives a description and estimated lifetime of the different components of the adaptive stop display.

**Table 19. Adaptive Stop Display Component Description**

| Part # | Component Name | Life (yr.) | Description |
|---|---|---|---|
| 1 | Communication Equipment | 7 | Wireless data transceiver. (DSRC) |
| 2 | In-Vehicle Display | 7 | In-vehicle display/warning interface. Software is commercial off-the-shelf (COTS) merchandise. |
| 3 | GPS/DGPS | 7 | Global Positioning System/Differential Global Positioning Systems. |
| 4 | GIS [a] | 7 | Geographical Information System (GIS) software for performing route planning. |
| 5 | Sensors for Lateral Control | 7 | Includes lane sensors in vehicle and lateral sensors millimeter microwave radar. |
| 6 | Sensors for Longitudinal Control | 7 | Longitudinal sensors millimeter microwave radar. |
| 7 | Intersection Collision Avoidance Processor [a] | 7 | Software/processor for infrastructure transmitted information, interface to in-vehicle signing and audio system, software and processor to link to longitudinal and lateral vehicle control modules based on input signal from vehicle intersection collision warning equipment package. Software is COTS. |

[a] *denotes software*

According to the Bureau of Transportation Statistics, there were 253,108,389 registered vehicles in 2011 [40]. The estimates in Table 20 were used to determine the expense of adding the necessary ITS components to all of these registered vehicles to make them usable in the adaptive stop display scenario. By analyzing their initial cost and need for maintenance over the seven year life cycle, it was determined that this would cost approximately $\$34.37\times10^{10}$ (see Table 20).

**Table 20. Life Cycle Cost of Adaptive Stop Display System for All Registered Vehicles in the United Sates (7 years)**

| Activity | Cost [$\$\times10^{8}$] |
|---|---|
| Initial Cost | $3,373.88 |
| Operating and Maintenance | $63.26 |
| *Total* | *$3,437.14* |

According to the assumptions, per individual driver, the cost of obtaining and maintaining this system is $1,357.97 (see Table 21).

**Table 21. Life Cycle Comparison Using Unit Cost Values**

| | Adaptive Stop Connected Vehicle | Stop Sign |
|---|---|---|
| Capital | $1,332.98 | $250.00 |
| Maintenance | $24.99 | $562.16 |
| *Total* | *$1,357.97* | *$812.16* |

Given the $350 cost to consumer assumption provided by the MDOT Delphi study, the connected vehicle solution appears more practical. Table 22 shows the costs of the connected vehicle system implementation using the Delphi anticipated consumer costs. The Delphi study considers that the connected vehicle technology will be able to leverage the resources available from other components within the vehicle. For example, the display and transceiver will be in the vehicle to perform other functions in a connected environment, and therefore only a fraction of the total cost of each component needs to be considered in the overall cost of the application.

**Table 22. Adaptive Stop Display Compared to Traditional System using Delphi Consumer Costs**

| | Adaptive Stop Connected Vehicle | Stop Sign |
|---|---|---|
| Capital | $350.00 | $250.00 |
| Maintenance | $24.99 | $562.16 |
| *Total* | *$374.99* | *$812.16* |

## Cost of Delay Incurred

This analysis determined the associated cost per user and cumulative delay incurred at traditional stop-controlled intersections when compared to an intersection in a connected vehicle environment where an adaptive stop display could be used. Since unnecessary stops are a significant source of delay at un-signalized intersections, eliminating them should reduce the amount of delay incurred by the driver.

**Assumptions**. The analysis of delay and the subsequent analyses on fuel consumption and emissions relied on a few assumptions. Envision a rural major collector at junction with another major rural collector with an annual average daily traffic (AADT) of 1,950 vehicles. Peak hour distributions allow for the assessment of delay as a function of intersection volume fluctuations resulting from daily demand increases on intersection capacity (Table 23).

**Table 23. Peak Hour Distributions**

| Hour Start | Hour Stop | Percent AADT | Hour Start | Hour Stop | Percent AADT |
|---|---|---|---|---|---|
| 0:00 | 1:00 | 1.20% | 12:00 | 13:00 | 6.20% |
| 1:00 | 2:00 | 0.80% | 13:00 | 14:00 | 6.00% |
| 2:00 | 3:00 | 0.50% | 14:00 | 15:00 | 6.10% |
| 3:00 | 4:00 | 0.40% | 15:00 | 16:00 | 6.20% |
| 4:00 | 5:00 | 0.50% | 16:00 | 17:00 | 7.80% |
| 5:00 | 6:00 | 1.00% | 17:00 | 18:00 | 9.30% |
| 6:00 | 7:00 | 2.50% | 18:00 | 19:00 | 6.10% |
| 7:00 | 8:00 | 7.70% | 19:00 | 20:00 | 5.20% |
| 8:00 | 9:00 | 5.60% | 20:00 | 21:00 | 3.80% |
| 9:00 | 10:00 | 5.00% | 21:00 | 22:00 | 3.10% |
| 10:00 | 11:00 | 5.20% | 22:00 | 23:00 | 2.50% |
| 11:00 | 12:00 | 5.50% | 23:00 | 0:00 | 1.80% |

Given the relatively low service time required for both traditional and adaptive controls, low intersection volume queuing was not considered in this calculation because the intersection was always at a utilization rate less than one. By using turn movement percentages from the NHCRP as listed in Table 24 [41] and incorporating a monetary cost of road, the values displayed in

Table 25 show the user value of time, turn volumes, and monetary allocations for delay incurred.

**Table 24. Turn Movement Percentages**

| Movement | Percent |
|---|---|
| Left Turn | 10% |
| Right Turn | 20% |
| Straight | 70% |

**Table 25. User Value of Time**

| Class | VTTS/HR | PCT._MIX |
|---|---|---|
| Personal Local | $12.00 | 0.95 |
| Business Local | $22.90 | 0.05 |

**Quantification of Delay**. Delay was quantified from both test track data and naturalistic data using the epoch onset of 36 m from the stop bar and end point of 30 m beyond. This distance was selected given the required stopping braking distance for the study's speed limit (35 mph).

The delay incurred by the driver is calculated in a stepwise fashion by a ratio of their current travel speed and dividing it by the speed limit (presumed desired speed). The delay equation that was used in the computation of driver delay incurred for the traditional stop sign and the adaptive stop display is shown below:

$$d = \Delta t \sum_{t=0}^{N} (1 - \frac{v_t}{v_f}) \qquad (3)$$

$d = total\ delay\ for\ entire\ trip\ for\ a\ specific\ vehicle\ [s]$

$\Delta t = Analysis\ increment\ duration\ [s]$

$v_t = Vehicle\ speed\ at\ any\ instant\ "t"\ [m/s]$

$v_f = Facility\ free\ flow\ speed\ [m/s]$

Initial participant exposures to the adaptive stop display were removed from the analysis to better represent the system's use after they had acclimated to the system. The delay incurred by turning maneuver is shown in Table 26.

**Table 26. Delay for Adaptive Display and Traditional Stop Signs**

| Sign | Nav. | Delay [s.] | Sign | Nav. | Delay [s.] | Sign | Nav. | Delay [s.] |
|---|---|---|---|---|---|---|---|---|
| A-PWC | L | 9.76 | A-STOP | L | 18.20 | TRADITIONAL | L | 14.87 |
| A-PWC | R | 4.89 | A-STOP | R | 10.36 | TRADITIONAL | R | 11.82 |
| A-PWC | S | 2.90 | A-STOP | S | 10.07 | TRADITIONAL | S | 12.46 |

For the purpose of this analysis, the proportion of PWC to stop displays is 60% - 40%. Table 27 shows the estimated hourly cost of delay per movement. A marked difference appears in the time savings between use of the adaptive stop display and the traditional stop sign.

**Table 27. Total Cost of Delay**

| Turning Movement | Adaptive | Traditional | Difference |
|---|---|---|---|
| Left | $401.03 | $755.83 | ***$354.80*** |
| Right | $216.12 | $600.80 | ***$384.68*** |
| Straight | $176.06 | $633.42 | ***$457.36*** |

Figure 18 shows the greatest potential for user savings occurs during the peak hours when travel demand is at its highest.

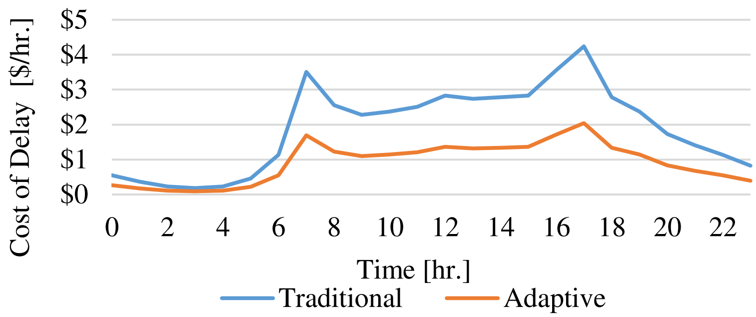



**Figure 18. User cost of delay by hour.**

The cumulative savings of the peak hours (between 7:00 AM and 7:00 PM) comprises 82% of the time savings. Figure 19 demonstrates the cumulative cost of delay when the adaptive stop display is compared to the traditional stop sign throughout the entire day.

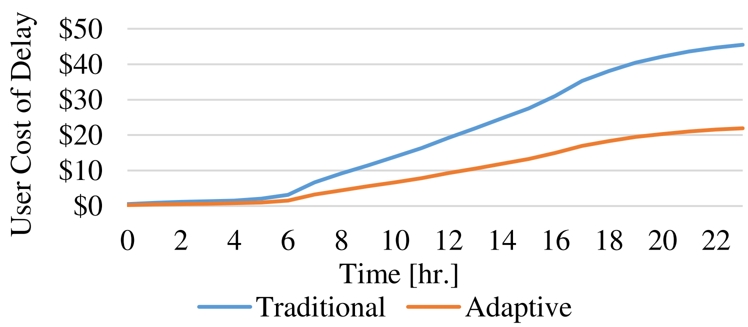



**Figure 19. Cumulative cost user delay.**

The savings potential of the adaptive stop display compared to an all-way stop-controlled intersection depends on a number of additional factors. This would be best explored through a full simulation to test the system under varying volume levels; however, that particular analysis did not fit the scope of this research.

## Fuel and Emissions Costs Associated with Delay

Since there was no statistically significant difference in driver braking behavior between the traditional stop sign data and adaptive display test track data, it is safe to assume that the rate of fuel consumption for the traditional stop sign and the adaptive stop display are the same. Fuel consumption and emissions are measured as a function of delay incurred and multiplied by the fuel consumption rate that was collected via the test vehicle's CAN. For this analysis, recall the constraints of the assumed intersection.

**Fuel Costs**. In the year 2013, the estimated cost of fuel in the United States was $3.87 per gallon, or $1.02 per liter [42]. The total delay incurred for vehicles at the intersection is multiplied by the rate of fuel consumption on average for each movement, per hour. The total daily fuel consumption as a result of the delay incurred at the intersection is shown in Figure 20.

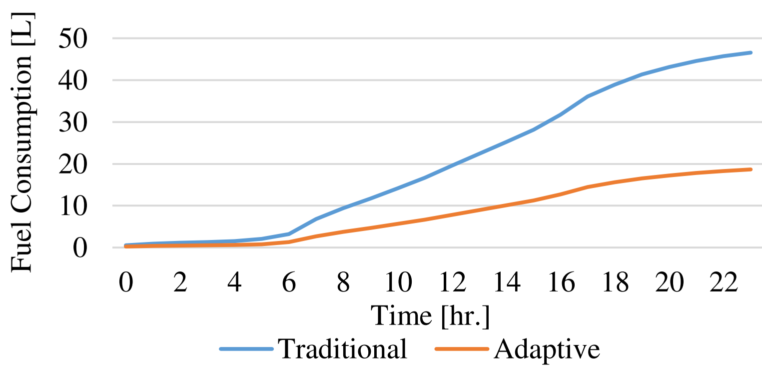



**Figure 20. Delay induced daily fuel consumption.**

The amount of fuel consumed as a result of delay is 46.59 L at this particular intersection when it is controlled by a traditional stop sign. However, when it is controlled the adaptive stop display, the amount of fuel consumed is 18.64 L, resulting in a daily savings of $28.51 in fuel since less delay is incurred in the adaptive system.

**Emissions Costs**. In the year 2010, the estimated societal cost of $CO_2$ emissions from fuel was equivalent to $0.011 $/kg (39); this cost also had a projected discount rate of 5% for average use of gasoline. When this data was projected to a 2014 present worth, there was a societal benefit in reduction of $CO_2$ emissions equal to $0.88.

It is likely that the societal cost of carbon emissions will grow at *i = 3% per annum* to account for the introduction of legislation and other factors that could reduce the societal cost of carbon emissions in the future. When assuming this and the consistency of the intersection volume and use for the next 45 years, the modeled intersection experiences a large increase in emissions costs passed on to society over time.

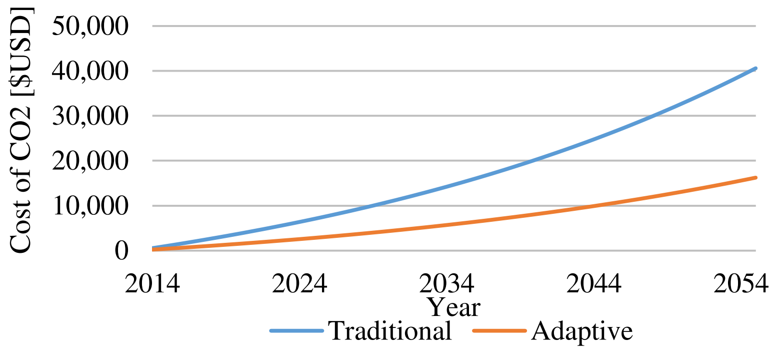



**Figure 21. Cumulative cost of $CO_2$ emissions to society over time.**

The annual cost of delay induced $CO_2$ that is passed on to society if the intersection were controlled by adaptive stop display compared to traditional stop signs is $24,349.14. While this number seems small, it is important to remember that this is only a model of one approach leg at one stop-controlled intersection.

## Is the IVD a Distraction?

**Number of Glances to the IVD**. The mean glance frequency over time follows a power series (see Figure 22.)

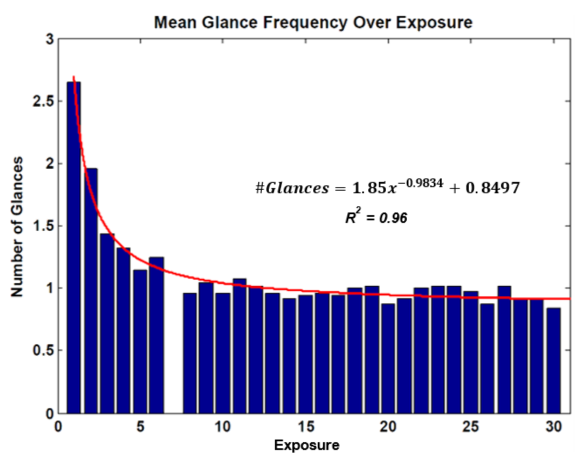



**Figure 22. Mean glance frequency over exposure to the IVD.**

When the system functions properly, as the number of exposures to the IVD tends towards infinity, the average number of glances to the IVD is approximately 0.85 glances (one glance) [$F$ (307, 1124) = 3.44, $p < 0.0001$]. The first six exposures to the IVD were considered an orientation or exposure period for the participants. Identical analyses were conducted for all statistical tests including and excluding this initial exposure period. All results discussed in this report from herein will be of the data subset that excludes this initial learning period.

On average, the mean glance frequency to the IVD for a given display state per intersection approach is shown in Table 28.

**Table 28. Mean Glance Frequency to IVD by Sign State**

| Sign | N | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| **Blackout** | 29 | 2.03 | 1.21 | 1 | 6 |
| **PWC** | 810 | 1.16 | 0.41 | 1 | 4 |
| **Stop** | 143 | 1.87 | 1.00 | 1 | 6 |
| **Surprise** | 48 | 1.13 | 0.33 | 1 | 2 |
| **Switch** | 96 | 2.54 | 1.13 | 1 | 6 |

The mean number of glances to the IVD was less than two in the cases when the IVD functioned normally, as well as during the surprise scenario. When the display malfunctioned, the mean number of glances was greater than two: since participants glanced at the IVD more frequently during malfunctions, their total eyes off road time (TEORT) increased.

The main effect traffic level has a statistically significant influence on mean number of glances *[F (3, 1124) = 112.22, p < 0.0001*]. Traffic is defined as the number of vehicles approaching the intersection in addition to the participant vehicle and can have an integer value between 0 and 3. A Tukey's post hoc test shows that participants looked at the IVD more frequently when there was no traffic at the intersection than when compared to any other level of traffic. Likely less time is spent looking at the IVD when the traffic volume, or probability of incursion, increases.

**Table 29. Mean Number of Glances to IVD by Traffic Level**

| TRAFFIC | N | Mean | Std Dev |
|---|---|---|---|
| **0** | 98 | 2.31 | 1.23 |
| **1** | 732 | 1.33 | 0.67 |
| **2** | 204 | 1.23 | 0.63 |
| **3** | 92 | 1.19 | 0.42 |

The age and gender of the driver has a statistically significant influence on the mean number of glances made to the IVD *[F (3, 1124) = 3.35, p = 0.0187].* Younger women have the fewest mean number of glances to the display than any other group (*N = 288, M = 1.278, SD = 0.746*).

**Mean Glance Duration to IVD**. Participant glances to the display lasted on average less than half a second per glance, except for the surprise scenario. The average glance duration was not long enough to be considered a distraction. The mean glance duration to the IVD is shown in Table 30.

**Table 30. Mean Glance Duration to IVD by Sign States**

| Sign | N | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| **Blackout** | 29 | 0.40 | 0.15 | 0.13 | 0.80 |
| **PWC** | 809 | 0.49 | 0.22 | 0.13 | 1.60 |
| **Stop** | 143 | 0.48 | 0.28 | 0.13 | 1.85 |
| **Surprise** | 48 | 0.58 | 0.19 | 0.27 | 1.07 |
| **Switch** | 96 | 0.47 | 0.29 | 0.17 | 2.24 |

An analysis of variance was conducted for mean glance duration. The statistically significant main effects that were found to influence the mean glance duration were exposure *[F (23, 1127) = 1.77,* *p = 0.0147]* and age *[F (1, 1127) = 13.02, p = 0.0003]*. Post hoc testing of exposure indicated that while it played a part in the outcome of the glance duration, there was not an individual pair of exposures that contributed to the differences at the 95% confidence level.

**Change in Glance to Display Behavior Based on Vehicle Speed and Location**. To assess the appropriateness of the duration of glances, an analysis was conducted on the kinematic variables that influence the duration of glances to the IVD, over the course of the intersection approach as well as the characteristics of the maximum glance on display kinematic factors. The key kinematic variables included in this analysis are the speed of the vehicle and the vehicle's proximity to the stop bar. This added context to the measure of glance duration and assist in determining appropriateness of IVD use.

***Kinematic Influence on Glance Duration***. An analysis of variance was used for each display type to determine what factors influence glance duration. The speed of the vehicle and its proximity to the intersection are significant safety factors and should be considered in the discussion of distractibility potential and safety implications. The statistically significant model inputs are listed below in Table 31 Table 31*[F (21, 1104) = 25.09, p < 0.0001]*.

**Table 31. Significant Variables of Kinematic Influence on Display Glance Duration**

| Source | DF | Mean Square | F | p |
|---|---|---|---|---|
| **Sign** | 4 | 0.33 | 4.78 | 0.0008 |
| **Age** | 1 | 0.94 | 13.45 | 0.0003 |
| **Traffic** | 3 | 0.33 | 4.77 | 0.0026 |
| **D2SB** | 1 | 4.38 | 62.63 | <.0001 |
| **Speed** | 1 | 5.70 | 81.53 | <.0001 |

According to the regression output the interactions cannot be treated any differently than zero. The main effects of the general linear regression coefficients were found to all have a statistically significant influence on the glance duration to the IVD.

With each meter increase away from the stop bar (prior to crossing) the glance duration increased by 0.01 seconds; conversely with each unit (m/s) increase in the vehicle's speed, the glance duration decreased by 0.04 seconds. Since proximity relative to the stop bar and speed are (ideally) inversely correlated, doing an analysis on the kinematic factors influencing maximum glance duration allows for a little more insight.

***Kinematic Factors and Maximum Glance on Display Duration***. The speed and location relative to the stop bar were analyzed with several other factors to determine if drivers were using the display in a way that may compromise their safety (Table 32).

**Table 32. ANOVA Kinematic Factors on MGOD**

| Source | DF | Mean Square | F | p |
|---|---|---|---|---|
| **Sign** | 4 | 0.967 | 9.97 | <.0001 |
| **Gender** | 1 | 0.568 | 5.85 | 0.0157 |
| **Age** | 1 | 4.895 | 50.46 | <.0001 |
| **Sign × Gender** | 4 | 0.277 | 2.86 | 0.0227 |
| **Sign × Age** | 4 | 0.769 | 7.92 | <.0001 |
| **Gender × Age** | 1 | 0.421 | 4.33 | 0.0376 |
| **Sign × Gender × Age** | 4 | 0.608 | 6.27 | <.0001 |
| **D2sb** | 1 | 1.807 | 18.62 | <.0001 |
| **Speed** | 1 | 9.458 | 97.49 | <.0001 |

A separate regression determined the influence of proximity to stop bar, vehicle, speed, and the significant independent variables and interactions from the previous regression on MGOD duration. An analysis of the significance of the individual regression coefficients indicated the following main effects impact the maximum glance on display in a way that is significantly different from zero: with each unit increase in speed, maximum glance duration to the display decreases by 0.053 seconds. The maximum glance duration to the display increased by 0.006 seconds with each meter further away from the stop bar prior to crossing. Younger participants looked at the display with a maximum glance 0.255 seconds less than older drivers. Female participants looked at the display for their longest glance 0.187 seconds longer than males.

Based on the analysis of glance durations within a contextual framework, the IVD does not appear to be a distraction or cause significant safety concerns.

**Driver Scanning and Awareness**. While it may be helpful for a driver to check the speedometer while approaching an intersection, the value of the information obtained by scanning for traffic and assessing potential hazards is greater. It is important to consider the percentage of time spent making meaningful glances against the percentage of time not spent making meaningful glances when thinking of intersection approaches.

***No Glances to the IVD***. There were 110 cases of 1,480 (7.43%) where participants did not look at the display, most of which occurred during the PWC display. However, when analyzed as a function of exposure, the blackout display was comparatively high, although the lack of auditory and visual stimulus for that scenario would indicate that reaction.

**Table 33. Summary of No Glance to IVD Conditions × Sign State**

| Sign | Count | Percent by Total | Percent by Exposure |
|---|---|---|---|
| **Blackout** | 20 | 20.20% | 40.82% |
| **PWC** | 72 | 72.73% | 8.16% |
| **Stop** | 4 | 4.04% | 2.72% |
| **Surprise** | 1 | 1.01% | 2.04% |
| **Switch** | 2 | 2.02% | 2.04% |

If the display does not function correctly, it does not appear that a driver neglecting to look at the IVD a poses a safety decrement. In the absence of auditory and visual information from the IVD, drivers can easily revert to scanning traffic for hazards in lieu of looking at the IVD for direction.

***Glance Allocation***. The average mean glance duration to any location is less than one second; the glance duration also has a standard deviation of less than one second. This indicates that drivers were making relatively short glances to their surroundings and the IVD upon approaching the intersection. (See Table 34.)

**Table 34. Glance Characteristics**

| Location | Label | N | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|---|
| **Display** | MEAN DURATION | 1156 | 0.64 | 0.62 | 0.00 | 7.41 |
| | NUM GLANCES | 1156 | 1.28 | 0.85 | 0.00 | 6.00 |
| | PCT | 1156 | 0.08 | 0.06 | 0.00 | 0.46 |
| **Left** | MEAN DURATION | 1156 | 0.81 | 0.77 | 0.00 | 5.87 |
| | NUM GLANCES | 1156 | 1.85 | 1.39 | 0.00 | 8.00 |
| | PCT | 1156 | 0.11 | 0.10 | 0.00 | 0.56 |
| **Right** | MEAN DURATION | 1156 | 0.69 | 0.87 | 0.00 | 8.28 |
| | NUM GLANCES | 1156 | 1.45 | 1.35 | 0.00 | 8.00 |
| | PCT | 1156 | 0.08 | 0.09 | 0.00 | 0.48 |

The mean glance frequency is significantly influenced by the sign, location, and exposure, as well as gender and traffic level *[F (107, 3507) = 12.10, p<0.0001]*. The mean glance duration to the IVD after the initial six exposures and the surprise scenario is significantly influenced by the main effects of sign, location, exposure, turning maneuver, and gender *[F (104, 3363) = 10.34, p <0.0001]*. The mean glance duration was influenced by the location of the glance and traffic level *[F (2, 3363) = 11.85, p<0.0001]*. The mean scanning-related glance duration by exposure is shown in Figure 24; the mean scanning-related glance frequency by exposure is shown in Figure 24.

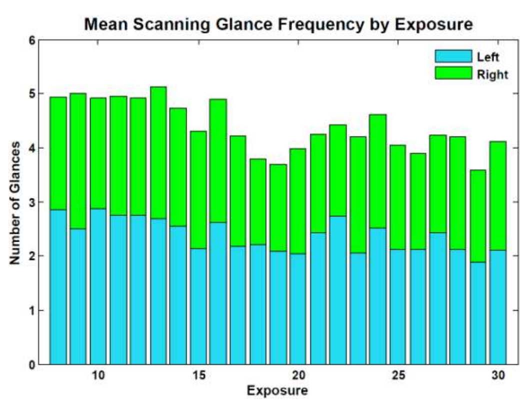



**Figure 23. Glance frequency to road location × exposure.**

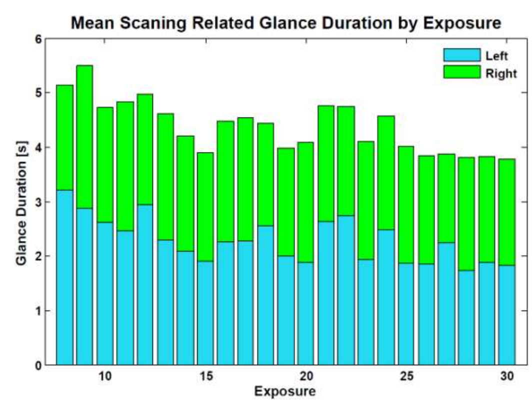



**Figure 24. Glance duration to road location × exposure.**

There is a marginal yet noticeable increase in driver mean glance duration to the left with an increase in traffic volume (Figure 25). There is also an apparent increase in glance frequency to the left with an increase in traffic level (Figure 26).

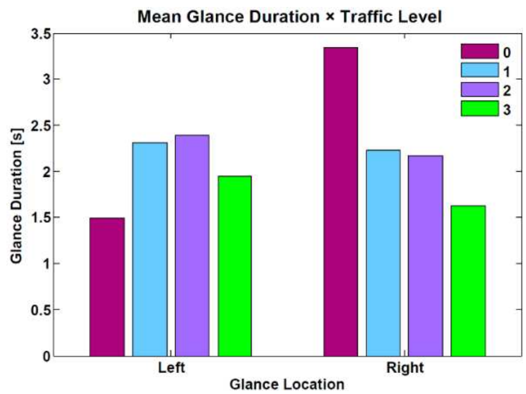



**Figure 25. Glance duration × traffic interaction.**

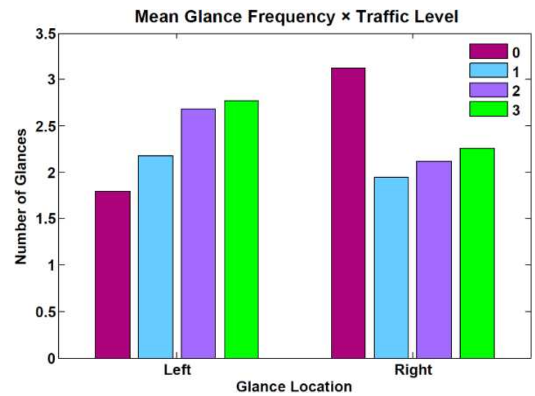



**Figure 26. Glance frequency × traffic interaction.**

A Tukey's post hoc analysis was conducted on the interactions between the glance location and traffic level and the dependent variables of glance duration and number of glances. The post hoc test shows that participant glance duration to the left is different from all other glance durations. There is no difference between right glance duration and display glance duration when there is traffic present. However, when no traffic is present, the duration of glances to the right is significantly lower than glances to the display and to the left. The post hoc test conducted on the number of glances and the interactions between the glance location and traffic level indicates a trend in the number of glances as it relates to traffic level. The number of glances to the right is not different except in the situations where traffic levels are high.

Generally, as traffic level increases, the number of glances to the environment increases, while the number of glances to the IVD decreases. These changes in scanning behavior indicate that drivers are not becoming complacent with the IVD but are actively assessing their surroundings and determining the appropriate course of action.

## Discussion

### Influence on Driving Behavior

The key difference between traditional stop signs and the adaptive stop display is compliance and location of braking onset. Participants reacted to the adaptive stop display in a way that allowed them to come to a controlled stop without instigating a panicked response. The adaptive stop display has a significantly higher compliance rate when compared to traditional stop signs, especially when compared to literature relating the compliance of static stop signs in real world conditions. Table 35 demonstrates the change in compliance with traditional stop signs over time since their introduction to the transportation system in 1915. However, it is important to note that vast differences exist between closed test track conditions, naturalistic driving studies, and field data collection. In theory, the addition of an auditory alert and in-vehicle visual cue allows drivers to be more prepared for the stop since they lack the deficiencies of a traditional stop sign. (see Table 35).

**Table 35. Comparison of Compliance among Studies**

| Study | Full Stop | Rolling Stop | Full Violation |
|---|---|---|---|
| Noble et al. (2014)[a] | 61% | 47% | 2% |
| Dingus et al. (2005)[b] | 5% | 37% | 48% |
| Trinkaus (1996)[c] | 1% | 2% | 97% |
| Dyar (1977) [c] | 12% | 60% | 28% |
| Beaublen (1976) [c] | 22% | 48% | 30% |
| Leisch (1963) [c] | 17% | 69% | 14% |
| Hanson (1960) [c] | 20% | 69% | 11% |
| Eliot (1935) [c] | 38% | 42% | 20% |
| Fisher (1935) [c] | 45% | 34% | 21% |
| Morrison (1931) [c] | 47% | 42% | 11% |

[a] – Adaptive stop display – Closed test track
[b] – Traditional stop signs – Naturalistic driving study
[c] – Traditional stop signs – Traffic counts [43]

The location relative to the stop bar where braking began was not statistically different between the adaptive stop display and the traditional stop signs, an expected observation since the alert presentation timing was based on the stopping sight distance calculations. Generally, drivers using the adaptive stop display were able to stop at a location behind the stop bar or half a car length beyond, indicating a controlled stop was readily achieved. Some participants had trouble on their initial exposure to the system and stopped on average 4.22 m beyond the stop bar, suggesting that system exposure leads to learning. Only one participant using the adaptive stop display habitually stopped beyond the stop bar (4 out of 6 times); it was not assessed whether or not that participant also stopped beyond the stop bar with a traditional control in place.

Stop bar crossing speeds demonstrated a statistically significant difference but only for the full violation level. However, there were minimal differences in the rolling stop crossing speeds between the two types of signs. While this could be a potential safety concern in real world application, it could be easily mitigated with user education prior to use of the technology.

95.7% of participants proceeded through the intersection when the PWC display appeared. They also attained their minimum speed further from the stop bar when traffic increased. This indicates they became more cautious when the situation called for a change in behavior and did not blindly following the display. They decelerated from the onset of the alert until the stop bar, which allowed them more than enough time to stop the vehicle if needed. This analysis indicates drivers actively lower their level of risk as hazards present themselves in terms of traffic presence. Furthermore, driver TTI increased as traffic levels increased, which indicates in a situation requiring more time to assess the hazards in the environment, drivers were more cautious and slowed prior to proceeding through the intersection.

During the “surprise” scenario, 57.14% of participants stopped or attempted to stop via hard braking but were ultimately unsuccessful. Upon encroachment, 42.86% of participants did not stop or attempt to stop. During the “switch” scenario, 37.76% of participants failed to stop regardless of whether or not traffic was present. Upon assessing the RDP values for participants who failed to stop and achieved a minimum speed behind the stop bar (about 50%), those participants would have been able to bring the vehicle to a complete stop at the stop bar without hard braking. This indicates they were in control of the vehicles and made the decision to proceed through the intersection. It did not appear that drivers were being careless or in any way increasing their risk through their response to scenario.

The “blackout” malfunction scenario appears to pose the greatest hazard to drivers. However, demand characteristics associated with the experimental design may have influenced the participant’s reaction to the blackout scenario in particular. Despite those factors, 95.92% of participants failed to stop and crossed the stop bar at a speed higher than that achieved when prompted by the PWC display. This indicates they were behaving in a risky way, though they might not have been aware of their carelessness.

## Distraction and Glance Behavior

The findings from these analyses indicate that participants were able to adapt to the new display quickly and did not have any substantial issues in acclimating beyond those first six exposures. The differences in use between older and younger drivers seem to be negligible: younger participants glanced at the adaptive stop display slightly fewer times when the vehicle was in motion and had a maximum glance duration 0.25 seconds shorter than older drivers. While the differences between the two age groups are statistically significant, it does not seem to be practically significant.

Salience in the Wicker’s SEEV model is the extent to which the area of interest stands out from the background or the environment (40). Participants tended to not allocate their attention to the adaptive stop display when it did not stand out to them (e.g., there was no change in the visual appearance of the sign state and no auditory alert administered). As demonstrated in

Table 33, the “blackout” scenario yielded the highest relative number of missed glances (40.8%). In general, the glance allocation findings align well with the Wicken’s SEEV model, as the driver’s visual search indicates the level of vigilance was not compromised by the addition of the adaptive stop display.

The increased salience of having the auditory pre-emption along with the display inside the vehicle instead of outside of the vehicle allowed for a much lower rate of change blindness. For example, if the driver did not look at the adaptive stop display, perhaps they deemed the information on the display unimportant, perhaps due to observations of their environment (e.g., other vehicles activating their turn signals in advance, not perceiving a conflict, etc.). This is supported by the observation that many of the non-display glances for the PWC display occurred on right turns. The change blindness that did occur during these right turns happened during the scenarios where non-conflicting movements were permitted to enter the intersection at the same time, which may correlate to a high task load because participants were not informed prior to the start of the study that this type of movement would happen (see Table 36).

**Table 36. PWC Right Turn – No Display Glance under Different "Workload"**

| Non-Conflicting Movements | Count | Percent by Total | Percent by Exposure |
|---|---|---|---|
| Not Permitted | 2 | 4.44% | 2.04% |
| Permitted | 43 | 95.56% | 14.63% |

The average number of glances to the adaptive stop display as a function of exposure to the system decreased following a power series ($y = 1.85\boldsymbol{x}^{-0.9834} + 0.8497$) where y = number of glances to the display. The number of glances decreases rapidly over the course of the first seven exposures to the system and levels out at about one glance to the display per exposure. Factors found to influence the number of glances IVD in a statistically significant way were traffic level, display type, and the age and gender of the participant.

The 2008 report *Relative Risks of Secondary Task Induced Driver Distraction* [44]classifies this type of glance duration and number of glances away from the roadway as a relatively simple secondary task. While it analyzes tasks that require visual and manual attention from the driver, this display only truly requires one of those modalities and for a short duration.

Driver glance frequency to the display seems to increase when their expectations are violated, (e.g. the display shows the driver a PWC and then a stop sign, or nothing at all, as seen in Table 28). However, the mean glance durations have minimal difference; the only clear outlier is the scenario where the driver is shown a PWC sign and another vehicle subsequently enters the intersection from behind a visual obstruction, as seen in Table 30.

The driver's attention allocation to the IVD is relatively low. The driver is able to look at the display and gather the necessary information from the IVD quickly and return to their primary task. The duration of driver gaze to the forward location decreases with an increase in traffic volume. There is a marginal but noticeable increase in driver mean glance duration to the left with an increase in traffic volume, as seen in Figure 25. There is an apparent increase in glance frequency to the left with an increase in traffic level, as seen in Figure 26. This indicates drivers may believe there is more task relevant information to be found at these locations than in the vehicle on the display, which when functioning appropriately, will only change state once. This finding is substantiated by Werneke et. al [45] who found that under high traffic density, drivers made more glances to the left side of the intersection than when traffic density was lower.

The display types have a statistically significant influence on the percent glance allocation except for the surprise case. Blackout accounted for the most significant percentage of eyes on display time increase, followed by switch. This is something to be considered prior to deployment: when the system malfunctions and violates expectations, attention is taken away from the roadway.

Regardless of the state of the IVD, driver's scanning behavior does not vary in a statistically significant way between the display types.

The kinematic factors affecting the glance duration show that drivers are using the display appropriately: the amount of time that drivers have their eyes off the road decreases proportionately with closing distance to the stop bar and with an increase in speed. Drivers shortly allocate their attention to the IVD to assess the state of the traffic control device and then return their gaze to the forward roadway to scan for any potential conflicts and hazards.

The protective effects of having a traffic control in the vehicle appear to be high. Drivers have a lower likelihood of change blindness, or experiencing the "looked, but did not see" phenomena currently afflicting public roads. Neither the concern of driver vigilance nor the concern of driver complacency appears to be validated by the data. Drivers are assessing their environment noticeably with an increase in traffic level. Over time, the percentage of intersection approach time where the driver's eyes are off road or on the IVD stabilize to a low, reasonable percentage when compared to their eyes on road time.

## Conclusions

The objective of this research was to assess several key benefits of an in-vehicle adaptive stop display system and to determine if there were any negative safety implications associated with its use. This proof of concept study demonstrates that many of the concerns associated with connected vehicle technology are minimal or non-existent in the test track environment, which provides reason to believe that this would extend to the public road setting as well.

The performance of participants using the adaptive stop display indicates no difference in stopping behavior in terms of driver input when compared to a traditional stop sign. However, the increased level of compliance to the stop display is something that should be noted; participants were not missing valuable information and were more willing to stop when using the adaptive stop display. When participants were presented with the PWC display, they exhibited more risk-averse behaviors that were appropriate when responding to situational changes that required higher levels of attention, such as an increase in traffic.

Risk aversion with the adaptive stop display during malfunctions depended heavily on the mode of failure. Due to the dynamic nature of the display, participants were able to respond to changing information by maneuvering the vehicle safely, bringing it to a complete stop if they felt it was necessary. However, without a visual stimulus, or if an unexpected vehicle encroached on the participant's right-of-way from behind a visual obstruction, they responded with more risky maneuvers.

Prior to application, researchers must ensure the system is highly reliable. They must also implement a widely applied education program on appropriate use of the in-vehicle adaptive stop display. Drivers should also be educated on proper response to each of the failure modes since this study discovered a wide range of responses to system failures. Educating the user will yield decreased variance in the behavior across drivers, which ideally will increase driver safety.

### Safety Implications

Results indicate that response to the in-vehicle adaptive stop display does not pose any more of a hazard to drivers than checking the speedometer or the time. Participants were generally able to learn how to use the display quickly. Additionally, the number of glances to the display decreased to about one glance per intersection approach after the first six to eight exposures to the system. Scanning behaviors increased during situations of higher traffic levels, which was a sign that they were not relying totally on the system and still sought information from their surroundings before committing to proceeding through the intersection.

Overall, adaptive stop display compliance was substantially higher than that of traditional stop signs as analyzed in the 100-Car study. The stopping behavior for the traditional stop signs and the adaptive display shows no statistically significant difference in terms of location of braking onset, indicating drivers were able to stop at the traditional stop signs but chose not to.

Compliance with the adaptive stop display was not influenced by participant demographics. Many inappropriate stops over the stop bar occurred during the first three exposures to the system with the majority occurring in the first exposure. All participants except for one committed only one inappropriate stop; however, one participant contributed four inappropriate stops to the overall number. This implies that drivers would be more likely to stop appropriately with more education on the purpose of the system, though the stopping behavior of participants in the test track study at a traditional stop sign was not analyzed.

### Influence on Mobility, Fuel Consumption, and Emissions

The feasibility and practicality of these solutions is entirely contingent on how connected vehicles are introduced into the market. As stated in *Longitudinal Study of ITS Implementation: Decision Factors and Effects* [46] it is important to identify the potential economic impacts of this technology in order to appropriately assess the benefits of this technology. However, what is mentioned briefly, but perhaps what is most important in the report, is the role of the consumer in the connected vehicles market place.

It is likely that the state of connected vehicles technology will continue to press ahead, and the costs of instrumenting vehicles and infrastructure will become a more palatable alternative to the current static infrastructure that is in place today. However, without a 100% connected driving environment, the benefits of the connected vehicle system are not being optimized, and such system like adaptive stop displays, and adaptive traffic lights would not be able to work in a purely vehicle-to-vehicle (V2V) environment, but would rely on additional costly infrastructure.

The potential for savings that can be passed on the consumer is a multi-tiered issue that cannot be taken lightly. In the adaptive Stop display application, it is largely dependent on the driver's willingness to comply with this type of device in a non-test track environment, the volumes of the intersection on the approach leg, and the probability of a conflict occurring at the intersection. Additionally, in a fully implemented application, there are more factors to consider in the system architecture.

The system would need to have multiple fail-safes and redundancies. While DSRC is able to see around corners for the most part, there are still some instances, in which the system's ability to communicate becomes sparse. Urban canyons can propagate signals further than expected or cause the DSRC to become less efficient that it would be in an open sky environment, due to null points, as documented by *Vehicle Infrastructure Integration* [47]. A null point is the result of a radio signal taking multiple paths from the source to the destination, at certain distances the signals destructively interfere. This null point can cause the radio signal strength to drop below the threshold of detectability of transceiver, resulting in lost data. Emerging technologies such as beamforming and geo-routing to counteract these issues.

There is a potential for reducing delay, fuel consumption, and emissions in a connected vehicle environment when using adaptive stop displays. Yet the possible savings that could be passed on to consumers is a multi-tiered issue, which must be given much scrutiny. A real world application requires a consideration of many more factors in the system architecture, some of which are overlooked in transportation engineering today while some have never been a prior issue. For example, in the adaptive stop display application, time savings depend largely on the driver's willingness to comply with the device. However, in a non-test track environment, time savings may depend on the traffic volumes of the intersection on the approach leg or the probability of a conflict occurring at the intersection. These factors would be best analyzed through a series of simulations under varying traffic volumes to assess the system and determine where inefficiencies arise.

## Recommendations and Considerations for Future Use

The in-vehicle adaptive stop display would be best suited for typical stop-controlled intersection locations where traffic volumes are relatively low. The feasibility of this system is contingent upon how connected vehicles are introduced into the open market; additionally, it is important to identify the potential economic impacts of this technology to assess the benefits of its use. The impact on the consumer in terms of upfront out-of-pocket costs and maintenance is also important to consider when discussing the implementation of any new technology. To date, all connected vehicle technology from the DSRC transceivers to the Road Side Equipment (RSE) are prototypes of what could be used in the future. As these innovations evolve, the technology will eventually become less expensive to purchase upfront and maintain with a longer lifecycle.

It is expected that the state of connected vehicles technology will progress, thus making the costs of instrumenting vehicles and infrastructure a more palatable alternative to the current static infrastructure in place today. However, without a 100% connected driving environment the benefits of the connected vehicle system cannot be optimized: such a system like the adaptive stop display would not work properly in a purely V2V environment and would rely on additional infrastructure.

The system architecture requires multiple fail-safes and redundancies to ensure the safety of the driver and reliability of the transmitted information. Full system development will involve a more thorough analysis of the in-vehicle adaptive stop display system in a variety of conditions.

Connected vehicle technology and the application of the in-vehicle adaptive stop display have the potential to tackle some of the biggest problems facing the transportation industry today. The adaptive stop display has demonstrated in closed test track studies that it has the potential to reduce driver delay and the excessive use of fuel caused by unnecessary stops at un-signalized intersections. Additionally, moving the traffic control device into the vehicle does not cause drivers to become complacent or adopt any behaviors that may be detrimental to their safety or the safety of others.

# References


1. National Highway Traffic Safety Administration, *Traffic Safety Facts 2012*. 2012. p. 230.
2. MUTCD, *Manual on Uniform Traffic Control Devices for Streets and Highways*. 2009, Federal Highway Administration: Washington, DC.
3. Pietrucha, Martin T. , Opiela,Kenneth S. , Knoblauch,Richard L. ,Crigler, Kristy L. , *MOTORIST COMPLIANCE WITH STANDARD TRAFFIC CONTROL DEVICES*. 1989, FHWA. p. 156.
4. Trinkaus, John, *STOP SIGN COMPLIANCE: A FINAL LOOK.* Perceptual and Motor Skills, 1997. **85**(1): p. 217-218.
5. Doerzaph, Zachary R., *Development of a Threat Assessment Algorithm for Intersection Collision Avoidance Systems*, in *Industrial and Systems Engineering*. 2007, Ph.D. Thesis Virginia Polytechnic Institute and State University: Blacksburg, VA. p. 222.
6. Chan, Y. P., L. J. Flynn, and K. J. Stocker, *VOLUME-DELAY RELATIONSHIP AT 4-WAY-STOP CONTROLLED INTERSECTIONS - A RESPONSE-SURFACE MODEL.* ITE JOURNAL-INSTITUTE OF TRANSPORTATION ENGINEERS, 1989. **59**(3): p. 27-34.
7. Beaubien, Richard F., *Stop Signs for Speed Control?* Insitute for Transportation Engineers, 1976.
8. Zhang, Neil, Zhang, Wei-Bin, Li, Jinquan, Zhang, Kevin, *Unsignalized Intersections: Can ITS Offer Improved Efficiency and Safety?*, in *14th International IEEE Conference on Intelligent Transportation Systems*. 2011: Washington, DC.
9. Lee, Fong-Ping, Lee, Clyde E. , Machemehl, Randy B., Copeland, Charlie R. ,Jr. , *SIMULATION OF VEHICLE EMISSIONS AT INTERSECTIONS* 1983, Texas State Depratment of Highways and Public Transportation
10. Bared, Joe, *Evaluation of Sign and Marking Alternatives for Displaced Left-Turn Lane Intersections*. 2009.
11. Wooldridge, Mark D., Fitzpatrick, Kay, Harwood, Douglaw W., Potts, Ingrid B., Elefteriadou, Lilly, Torbic, Darren J., *Geometric Design Consistency on High-Speed Rural Two Lane Roadways*, in *NCHRP Report 502*. 2003: Washington, DC.
12. American Association of State Highway and Transportation Officials, *A Policy on Geometric Design of Highways and Streets, 6th Edition*. 2011, AASHTO: Washington, DC. p. 907 pp.
13. Retting, Richard A., Weinstein, Helen B., Solomon, Mark G., *Analysis of Motor-vehicle Crashes at Stop Signs in Four U.S. Cities.* Journal of Safety Research, 2003. **34**: p. 485-489.
14. Iowa LTAP. *Providing drivers with a clear, adequate line of sight*. TECHNOLOGY NEWS 2005.
15. McGee, Hugh W., *Maintenance of Signs and Sign Supports: A Guide for Local Highway and Street Maintenance Personnel*. 2010: Washington, DC.
16. Eck, Ronald W. , McGee, Hugh W. , *Vegetation Control for Safety, A Guide for Local Highway and Street Maintenance Personnel*. 2008. p. 50.
17. Carlson, Paul J and Matt S Lupes, *Methods for maintaining traffic sign retroreflectivity*. 2007.
18. Rasdorf, W.J., North Carolina. Department of Transportation. Research, Analysis Group, Construction North Carolina State University. Department of Civil, and Environmental Engineering, *Designing an Efficient Nighttime Sign Inspection Procedure to Ensure Motorist Safety*. 2006: North Carolina Department of Transportation, Research and Analysis Group.

19. Preston, H., K.C. Atkins, M. Lebens, and M. Jensen, *Traffic Sign Life Expectancy*. 2014, Minnesota. Department of Transportation. Research, Library Services,,.

20. Braitman, Keli A., Bevan B. Kirley, Susan Ferguson, and Neil K. Chaudhary, *Factors leading to older drivers' intersection crashes.* Traffic injury prevention, 2007. **8**(3): p. 267-274.

21. Shope, Jean Thatcher, *Adolescent Motor Vehicle Crash Risk: What's Needed to Understand and Reduce the Risk?* The Journal of Adolescent Health : Official Publication of the Society for Adolescent Medicine, 2010. **46**(1): p. 1-2.

22. Fuller, Ray Santos J. A., *Human factors for highway engineers*. 2002, Amsterdam; New York: Pergamon.

23. Treat, J.R., N.S. Tumbas, S.T McDonald, D. Shinar, R.D Hume, R.E Mayer, R. L. Stansifer, N.J. Castellan, *Tri-Level Study of the Causes of Traffic Accidents: Final Report - Volume I,* 1977, Institute for Research in Public Safety- Indiana University: Bloomington, Indiana.

24. Crundall, David, Peter Chapman, Nicola Phelps, and Geoffrey Underwood, *Eye movements and hazard perception in police pursuit and emergency response driving.* Journal of Experimental Psychology: Applied, 2003. **9**(3): p. 163-174.

25. Crundall, David E, Underwood, Geoffrey, *Effects of Experience and Processing Demands on Visual Information Acquisition in Drivers.* Ergonomics, 1998. **41**(4): p. 448 - 458.

26. Romoser, Matthew R. E., Alexander Pollatsek, Donald L. Fisher, and Carrick C. Williams, *Comparing the glance patterns of older versus younger experienced drivers: Scanning for hazards while approaching and entering the intersection.* Transportation Research Part F: Traffic Psychology and Behaviour, 2013. **16**(0): p. 104-116.

27. Mourant, Ronald R., Rockwell, Thomas H., *Strategies of Visual Search by Novice and Experienced Drivers.* Human Factors, 1972. **14**(4): p. 325-335.

28. Underwood, G., Crundall, D., Chapman, P., *Selective Searching While Driving: the Role of Experience in Hazard Detection and General Surveillance.* ERGONOMICS, 2002. **45**(1): p. 1-12.

29. Dewar, Robert E. and Paul L. Olson, *Human factors in traffic safety*. 2007, Tucson, AZ: Lawyers & Judges Pub. Co.

30. Wickens, Christopher D., Juliana Goh, John Helleberg, William J. Horrey, and Donald A. Talleur, *Attentional Models of Multitask Pilot Performance Using Advanced Display Technology.* Human Factors: The Journal of the Human Factors and Ergonomics Society, 2003. **45**(3): p. 360-380.

31. Salvendy, G., *Handbook of Human Factors and Ergonomics, 4th Edition*. 2012: Wiley.

32. Sudweeks, Jeremy , Neale, Vicki L., Wiegand, Kendra, Bowman, Jodi , Perez, Miguel A. , Maile, Michael A. , *Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V) – Phase I Final Report*. 2008.

33. Robertson, H. Douglas., Hummer, Joseph E., Nelson, Donna C. , *Manual of transportation engineering studies*, ed. I.o.T. Engineers. 1994, Englewood Cliffs, N.J.: Prentice Hall.

34. Cottrell Jr, Benjamin H and Lance Eric Dougald, *Evaluation of Retroreflective Material on Stop Sign Posts in Virginia*. 2009.

35. Virginia Department of Transportation. *Virginia's Highway System*. 2015 [cited 2015 6/25]; Available from: http://www.virginiadot.org/about/vdot_hgwy_sys.asp.

36. Office of the Assistant Secretary for Research and Technology - Bureau of Transportation Statistics. *Public Road Length, Miles by Functional System: 2012*. 2014 [cited 2014 5/22];

Available from: http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/state_transportation_statistics/state_transportation_statistics_2014/index.html/chapter1/table1-1.

37. MnDot Research Services Section, *Traffic Sign Maintenance/Management Handbook*. 2014.

38. Michigan Department of Transportation Center for Automotive Research, *Connected Vehicle Technology Industry Delphi Study* 2012.

39. Research and Innovative Technology Administration RITA, *ITS Unit Costs Database*. 2010.

40. Beningo, Steven, Chambers, Matthew, Ford, Chester, Notis, Kenneth, Liu, Mindy, *National Transportation Statistics*. 2014.

41. Bonneson, James A and Michael D Fontaine, *Engineering study guide for evaluating intersection improvements*. 2001.

42. Davis, SC, SW Diegel, and RG Boundy, *Transportation Energy Data Book. 2010: Oak Ridge National Laboratory.* ORNL, 2014. **6985**.

43. Dyar, Richard, *An Analysis of Driver Observance of STOP Signs*. 1977.

44. Dingus, Thomas A. and Sheila G. Klauer, *The Relative Risks of Secondary Task Induced Driver Distraction*, in *SAE Technical Paper Series*. 2008: Detriot, Michigan.

45. Vollrath, Mark, Totzke, Ingo, *In-Vehicle Communication and Driving: An attempt to Overcome Their Interference*. 2000, University of Wuerzburg: Wuerzburg, Germany. p. 7.

46. Shah, Vaishali, Carolina Burnier, Drennan Hicks, Greg Hatcher, Liz Greer, Doug Sallman, William Ball, Katie Fender, and Dan Murray, *Longitudinal Study of ITS Implementation: Decision Factors and Effects*. 2013.

47. Andrews, Scott, Cops, Michawl, *Final Report: Vehicle Infrastructure Integration Proof of Concept Technical Description -Vehicle* 2009.

# APPENDIX A - INITIAL SCREENING QUESTIONNAIRE

**Initial Contact Participant Screening Questionnaire**

Eligible: Yes No

Name ______________________________ Male/Female

Phone Numbers ______________________________

Best Time to Call ______________________________

Screener ______________________________

**Note to Researcher:**

Initial contact between participants and researchers may take place over the phone. If this is the case, read the following Introductory Statement, followed by the questionnaire. Regardless of how contact is made, this questionnaire must be administered verbally before a decision is made regarding eligibility for this study. Once this questionnaire is completed, remove this cover sheet and file separately from the screening questions.

**Introductory Statement:**

After prospective participant calls or you call them, use the following script to guide you through the screening interview.

*Hello. My name is _____ and I am a researcher at the Virginia Tech Transportation Institute in Blacksburg, VA. I am recruiting participants for a driving study that will take place on the Smart Road. I obtained your contact information from the VTTI internal participant database.*

*The purpose of the study is to see how people react to the new technology of an adaptive stop/yield sign. This study will look at how drivers react to and use this sign design, to see if further research is needed on the sign concept or design. If you choose to participate, you will drive a test vehicle on the Smart Road while navigating the Smart Road intersection and obeying the in-vehicle sign,* *maintaining a specific speed. You will be driving the vehicle, however an experimenter will be with you at all times while you are driving. The vehicle is equipped with cameras that allow us to collect data. The cameras, however, are very small and are placed out of the way.*

*The study consists of two distinct parts. The first is filling out the necessary paperwork, and performing simple vision tests. If these are passed, you will perform the driving portion of the study. The driving portion will consist of driving an experimental vehicle on a Smart Road for approximately <u>one and a half hours</u>. The study takes up to <u>two hours</u>. Participants are paid $30.00 per hour. Does this sound like something you would be interested in doing?*

If they indicated that, they are <u>not</u> interested:

*Thank you for your time.*

If they indicated that, they are interested:

*That's great. I would like to ask you some questions to see if you are eligible to participate.*

**Questions**

1. *Do you have a valid driver's license?* (Criterion for participation: the response must be *Yes*)

   □ Yes □ No

2. *Please note that for tax recording purposes, the fiscal and accounting services office at Virginia Tech (also known as the Controller's Office) requires that all participants provide their social security number to receive payment for participation in our studies. You do NOT need to provide it now, but are you willing to provide us with your social security number?*

   □ Yes □ No

3. *What is your age?* ________ (Criterion for participation: must be 18-25 or 50+ at time of experiment)

4. *Have you had any moving violations in the past 3 years? If so, please explain each case.*

□ Yes (Criterion for participation: the driver must not have more than two moving violations in the past 3 years)
Description: ________________________________________________

□ No

5. *Do you have normal hearing and vision?* (Criterion for participation: subject must have normal hearing and vision or corrected to normal).

□ Yes □ No

6. *Are you able to drive an automatic transmission vehicle without assistive devices or special equipment?* (Criterion for participation: the driver must be able to drive an automatic transmission vehicle without assistive devices)

□ Yes □ No

*(Females only) Are you currently pregnant?*

□ Yes □ No

If YES--*While being pregnant does not disqualify you from participating in this study, you are encouraged to talk to your physician about your participation to make sure that you both feel it is safe. If you like, we can send you a copy of the consent form to discuss with your physician.*

7. *Have you been involved in any accidents within the past 3 years? If so, please explain.* (Criterion for participation: the driver must not have caused an accident in the past 3 years.)

□ Yes ________________________________________________

□ No

8. *Do you have a history of any of the following? If yes, please explain.*

Heart Condition □ No
□ Yes________________________________

Stroke ☐ No
☐ Yes________________________________

Brain tumor ☐ No
☐ Yes________________________________

Head injury ☐ No
☐ Yes________________________________

Epileptic seizures ☐ No
☐ Yes________________________________

Respiratory disorders ☐ No
☐ Yes________________________________

Motion sickness ☐ No
☐ Yes________________________________

Inner ear problems ☐ No
☐ Yes________________________________

Dizziness, vertigo, or other balance problems

☐ No
☐ Yes________________________________

Diabetes ☐ No

☐ Yes________________________________

Migraine, tension headaches ☐ No
☐ Yes________________________________

(Criterion for participation: subject cannot have lingering effects of heart condition, brain damage from stroke, tumor, head injury, recent concussion, or infection. Cannot have had epileptic seizures within 12 months, uncontrolled current respiratory disorders, motion sickness, inner ear problems, and dizziness, vertigo, and balance problems, uncontrolled diabetes for which insulin is required, chronic migraine or tension headaches.)

9. *Are you currently taking any medications on a regular basis that impair your ability to drive?*

(Criterion for participation: subject cannot currently be taking any substances that may interfere with driving ability, cause drowsiness or impair motor abilities.)

*10. Are you eligible for employment in the United States? (Driver must be eligible for employment in the US)*

□ Yes □ No

*11. How often do you drive*?

□ Less than 2 times per week

□ 2 to 4 times per week

□ more than 4 times per week

(Criterion for participation: Participants must drive at least 2 times per week)

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**Note to Researcher:**

If a response to any of the first 12 questions does not meet its criterion, read the following:

*Unfortunately you are not eligible for this particular study. Thank you for your time. Would you like to be called for future studies?*

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Criteria for Participation

**1. Must hold a valid driver's license.**

**2. Must not have more than two moving violations in the past three years.**

**3. Must have normal (or corrected with contacts to normal) hearing and vision.**

**4. Must be able to drive an automatic transmission vehicle without assistive devices.**

**5. Must not have caused an injurious accident in the past three years.**

**6. Cannot have lingering effects of heart condition, brain damage from stroke, tumor, head injury, recent concussion, or infection. Cannot have had epileptic seizures within 12 months, uncontrolled current respiratory disorders, motion**

**sickness, inner ear problems, dizziness, vertigo, balance problems, uncontrolled diabetes for which insulin is required, chronic migraine or tension headaches.**

**7. Cannot currently be taking any substances that may interfere with driving ability, cause drowsiness or impair motor abilities.**

**8. Must be eligible for employment in the U.S.**

**9. Participants must fall in the age range of <18-25 or 50+> years old**

**10. Must drive at least 2 times per week.**

# APPENDIX B - INFORMED CONSENT FOR TEST TRACK

**VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY**
***Informed Consent for Participants of Investigative Projects***

**Title of Project**:
SAFETY AND HUMAN FACTORS OF ADAPTABLE STOP DISPLAYS USING CONNECTED-VEHICLE INFRASTRUCTURE

**Investigators**: Tom Dingus, Alexandria Noble, Gabrielle Laskey, Mohamad Raseem Farook

## I. THE PURPOSE OF THIS RESEARCH PROJECT

In the past, only static signs have been used at un-signalized intersections. These signs are used to regulate or control the flow of traffic through an intersection. They do not change when traffic conditions change.
The purpose of this study is to see how people react to the new technology of an adaptive stop/yield sign. The sign consists of an electronic in-cab display that changes with traffic patterns and time of day. This study will look at how drivers respond to this sign to see if further research is needed. The project will also look at the sign's impact on fuel savings and delay.
It is important that this technology is tested with drivers in a controlled environment to identify any safety concerns related to this new type of sign.

## II. PROCEDURES

During the course of this experiment, you will be asked to perform the following tasks:

1) Read this Informed Consent Form and sign it if you agree to participate.
2) Show the experimenter your valid driver's license.
3) Complete some vision tests and an informal hearing test.
4) Drive an instrumented vehicle on the Smart Road, navigating the Smart Road intersection and obeying the in-vehicle sign, maintaining a specific speed. The speed limit will be 35 miles per hour. The experimenter will inform you of the speed limit before each task and provide navigational instruction. While you are in the vehicle, digital video will be recorded, including your face. An experimenter will be with you throughout the study. Other vehicles will be on the Smart Road to simulate real traffic conditions.
5) Complete written questionnaires.

It is important for you to understand that we are not evaluating you or your performance in any way. You are helping us to evaluate in-vehicle technology and how easy it is to use while driving. The opinions you have will help us determine appropriate guidelines for new in-vehicle interfaces. The information and feedback that you provide is very important to this project. Today's total experiment time last up to 2 hours.

## III. RISKS

The tasks described here are believed to pose no more than minimal risk to your health or well-being. The risks of driving the test vehicle on the Smart Road for this experiment are similar to that of driving an unfamiliar vehicle during daylight hours while using unfamiliar technology. You may become bored or fatigued due to the length of the study.

While the risk of participation in this study is considered to be no more than that encountered in everyday driving, if you are pregnant you should talk to your physician and discuss this consent form with them before making a decision about participation.

Please be aware that events such as equipment failure, changes in the test track, stray or wild animals entering the road, and weather changes may require you to respond accordingly. If at any point in the session the experimenter believes that continuing the session would endanger you or the equipment, he/she will stop the testing.

In the event of an accident or injury in an automobile owned or leased by Virginia Tech, the automobile liability coverage for property damage and personal injury is provided. The total policy amount per occurrence is $2,000,000. This coverage (unless the other party was at fault, which would mean all expense would go to the insurer of the other party's vehicle) would apply in case of an accident for all volunteers and would cover medical expenses up to the policy limit. For example, if you were injured in an automobile owned or leased by Virginia Tech, the cost of transportation to the hospital emergency room would be covered by this policy.

Participants in a study are considered volunteers, regardless of whether they receive payment for their participation; under Commonwealth of Virginia law, worker's compensation does not apply to volunteers; therefore, if not in the automobile, the participants are responsible for their own medical insurance for bodily injury. Appropriate health insurance is strongly recommended to cover these types of expenses. For example, if you were injured outside of the automobile owned or leased by Virginia Tech, the cost of transportation to the hospital emergency room would be covered by your insurance.

The following precautions will be taken to ensure minimal risk to you:

1. An experimenter will be you at all times to monitor your driving and will ask you to stop if he/she feels the risks are too great to continue.
2. You may take breaks or decide not to participate at any time.
3. You will be required to maintain a specific speed for each given task. The experimenter will inform you of the speed before each task is performed. The maximum speed limit on the road for this study will be 35 miles per hour miles per hour. The testing will take place on a closed, controlled test track.
4. The experimenter will be present while you are driving. As long as you are driving the research vehicle, it remains your responsibility to drive in a safe and legal manner.
5. You will be required to wear your lap and shoulder belt restraint system while in the car. The vehicle is equipped with a driver's side and passenger's side airbag supplemental restraint system, fire extinguisher, and first aid kit. The experimenter will also have a cell phone.
6. In the event of a medical emergency, or at your request, VTTI staff will arrange medical transportation to a nearby hospital emergency room. You may elect to undergo examination by medical personnel in the emergency room.
7. All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to you in any foreseeable case.

8. Testing will be cancelled in the event of poor weather resulting in the use of windshield wipers beyond an intermittent speed or if the pavement is or becomes icy.
9. You do not have any medical condition that would put you at a greater risk, including but not restricted to history of neck/spine injury, epilepsy, balance disorders, lingering effects of head injuries and stroke, and advanced osteoporosis.

## IV. BENEFITS

While there are no direct benefits to you from this research, you may find the experiment interesting. No promise or guarantee of benefits is made to encourage you to participate. Participation in this study will contribute to the improvement of future in-vehicle technology by increasing safety and providing insight to designing in-vehicle technology so that it is better understood by drivers. This study is aimed to reduce future crashes at intersections by determining how drivers perceive and react to this new type of traffic control device.

## V. EXTENT OF ANONYMITY AND CONFIDENTIALITY

The data gathered in this experiment, including video, vehicle, and questionnaire data, will be treated with confidentiality. Shortly after participation, your name will be separated from your data. A coding scheme will be employed to identify the data by participant number only (e.g., Participant No. 1). You may elect to have your data withdrawn from the study if you so desire, but you must inform the experimenters immediately of this decision so that the data may be promptly removed.

The data collected in this study may be used in future VTTI transportation research projects. IRB approval will be obtained prior to accessing the data for other projects.

It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

## VI. COMPENSATION

You will be paid $30.00 per hour for participating. You will be paid at the end of the session in cash. If you choose to withdraw before completing all scheduled experimental tasks, you will be compensated for the portion of time of the study for which you participated rounded to the nearest half-hour.

You will be asked to provide researchers with your social security number for the purposes of being paid for your participation. For tax recording purposes, the fiscal and accounting services office at Virginia Tech (also known as the Controller's Office) requires that all participants provide their social security number or Virginia Tech I.D. number to receive payment for participation in our studies.

## VII. FREEDOM TO WITHDRAW

As a participant in this research, you are free to withdraw at any time without penalty. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated. Furthermore, you are free not to answer any question or respond to experimental situations without penalty. If you choose to withdraw during the study session, please inform the experimenter of this decision and he/she will drive you back to the building.

## VIII. APPROVAL OF RESEARCH

This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University. This form is valid for the period listed at the bottom of the page.

## IX. PARTICIPANT'S RESPONSIBILITIES

If you voluntarily agree to participate in this study, you will have the following responsibilities:

1. To follow the experimental procedures as well as you can.
2. To wear your seat and lap belt.
3. To adhere to a 35 mph (maximum) speed limit on the Smart Road for this experiment.

Check all that apply:

- ☐ I am not under the influence of any substances or taking any medications that may impair my ability to participate safely in this experiment.
- ☐ I am in good health and not aware of any health conditions that would increase my risk including, but not limited to lingering effects of a heart condition.
- ☐ I have informed the experimenter of any concerns/questions I have about this study.
- ☐ I understand that digital video including my image will be collected as part of this experiment.

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- ☐ If I am pregnant, I acknowledge that I have either discussed my participation with my physician, or that I accept any additional risks due to pregnancy.

**XI. PARTICIPANT'S PERMISSION**

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. **If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.**

| | | |
|---|---|---|
| Participant's name (Print) | Signature | Date |
| Researcher's name (Print) | Signature | Date |

Should I have any questions about this research or its conduct, I may contact:
Dr. Tom Dingus @ (540) 231-1501, or by email: TDingus@vtti.vt.edu
Alexandria Noble @ (302) 299-9160, or by email: anoble@vtti.vt.edu

If I should have any questions about the protection of human research participants regarding this study, I may contact: Dr. David Moore, Chair of the Virginia Tech Institutional Review Board for the Protection of Human Subjects, telephone: (540) 231-4991; email: moored@vt.edu;

# APPENDIX C - Participant Debriefing Form

**Participant Time In/ Time Out Form**

Thank you for your collaboration and interest in this study. The time that you have taken to assist us today is greatly appreciated. The results of this evaluation process will help to identify any safety concerns related to this new type of connected vehicle technology. This research project will also examine the technologies impact, if any on fuel savings and delay.

We appreciate your cooperation to keep the details of this study confidential.

If you have any questions please do not hesitate to contact us. Alex Noble will be glad to answer all your questions related to this evaluation process.

Study Date: ______ / ______ / ______

Study Start Time: ______ : ______ AM PM

Study End Time: ______ : ______ AM PM

Total Time: ______________

Total Payment* ______________

______________________________ ______ - ____ - ______

*Participant Printed Name* *Social Security Number*

______________________________ ______________

*Participant Signature* *Date*

______________________________ ______________

*Researcher Signature* *Date*

*Please note that payments you receive in accordance with this research are considered taxable income. If payment exceeds $600.00 in any one calendar year, Virginia Tech is required to file a 1099 form with the IRS. For amounts less than $600.00, you are responsible for reporting additional income, but no 1099 tax forms will be filed with the IRS.

# APPENDIX D - IN-BUILDING EXPERIMENTER PROTOCOLS

## In Building Experimenter Responsibilities

### Before Participant Arrives

1. Ensure all required paperwork is printed and ready to go **PRIOR TO PARTICIPANT ARRIVAL**
2. Print scenario order sheets for confederate drivers
3. Get keys and small radios together for confederate drivers; leave them in box in Gabrielle's office.
4. Get your large radio from the control room and have the headset with you to get on the road.
5. Make sure you have multiple pens/pencils for taking notes and for the participant to use

### General Responsibilities

1. Maintain a professional attitude.
2. Treat the participant with respect.
3. Be early
4. Be alert and attentive

## Participant Prep Protocols

1. **Prior to the participant's arrival, make sure that all the needed forms are available.**
2. **Set up the subject prep room**
    - **Pencils available**
    - **Vision Tests available**
    - **Room is clean**
3. **Greet Participant**
4. **Record the time that the participant arrived on the debriefing form**
5. **Show driver's license.**

*Before we begin, it is required for me to verify that you have a driver's license. Would you please show me your license?*

- Must be a **valid (Check expiration date)** Class A driver's license to proceed with the study. Out of state is fine.
- Document on the Orientation Form that you have verified a valid driver's license.

6. **Briefly explain purpose of the research**

- **The purpose of this study is to see how people react to the new technology of an adaptive sign.**
- **This sign would combine both in an electronic in-cab display unit that changes with traffic patterns and time of day.**

- **This study will look at how drivers react to and use this sign design, to see if further research is needed on the sign concept or design, or if another type of solution would be better instead.**
- **It is important that this technology is tested with drivers in a controlled environment to identify any safety concerns related to this new type of sign.**
- **This research project will also examine the sign's impact, if any on fuel savings and delay.**

**7. Informed consent**

*Now I have some paperwork for you to fill out. This first form tells you about the study, what your job is, and any safety risks involved in the study. We have two copies of this form and they are identical. Please read through the document. If you have any questions, please feel free to ask. Before you sign, we want to make sure you understand and consent to participating in the study. We want to make sure all your questions have been answered. So please get all your questions clarified before you sign the document.*

- Give the participant the form
- Answer questions
- Have participant sign and date 2 informed consent forms
- You need to also sign and date the 2 informed consent forms.
- Make sure that all applicable checkboxes are marked
- Print the participant's name on the front page of the consent form that we keep.
- DO NOT write the participant number anywhere on the form.
- Give the participant a copy of the informed consent.

**8. Tax Form**

To complete the W-9, the participant must fill out the following in the box:

- Name
- Address
- Social security number
- Check "individual"
- Complete "For Individuals Only" box
- Sign and date at the bottom

**9. Vision Test**

*Follow me and I will go through the vision test with you.*

***a) The first test is the Snellen eye chart test.***

- Take the participant over to the eye chart test area.
- Line up their toes to the line on the floor (20 feet).
- Participants can leave on their glasses if they wear them for driving.

**Procedure:** *Look at the wall and read aloud the smallest line you can comfortably read.*

- If the participant gets every letter on the first line they try correct have them try the next smaller line. Continue until they miss a letter. At that time, record the one that they were able to read in full (line above).
- If they get the first line they attempt incorrect, have them read the previous line. Repeat as needed until they get one line completely correct. Record this acuity on the Orientation Form.
- **Participant must have 20/40 or better vision using both eyes to participate in the study.**

***b) The second test is an Ishihara Color Vision Test***

- Have participant look at the book at the distance indicated by the rod (rod touches their nose.
- Record answers in the blanks on the **"Study Checklist"** sheet.

10. **Informal Hearing Test**

*I'm going to say four sentences, please repeat each sentence back to me after I say it. Do you have any questions before we start?* <when administering this test, the experimenter should sit where s/he would in the vehicle. For example, if the experimenter will be in the passenger seat, s/he should sit to the right of the participant-both facing forward> Person administering the test should sit 24 inches from the driver on their right.

- A car is approaching in the left lane.
- Please turn left at the next intersection.
- The vehicle is riding smoothly.
- The car ahead of me has his high-beams on.

- Document the number of sentences repeated correctly on the **"Study Checklist"**.
- Participant must be able to repeat all 4 sentences in order to participate in the study.

**11. Administer the Pre Drive Questionnaire**

- Check to make sure no pages left blank

**12. Ask the participant if s/he would like to use the restroom before going to the road**

**13. File all completed forms into appropriate binders**

- Consent Form
- Tax Form
- Orientation Form

# APPENDIX E - ON ROAD EXPERIMENTER PROTOCOLS

## On Road Experimenter Responsibilities

1. You are in charge of the safety of the participant. If a scenario appears to be going wrong, hit the passenger side brake or call it off entirely. **DO NOT RISK THE SAFETY OF THE PARTICIPANT IN ORDER TO COLLECT DATA!**
2. You are responsible for notifying confederate vehicles of when scenarios are about to begin without informing the participant you are doing so. You are also in charge of discretely giving the confederate vehicles audio signals of when to go.

### General Responsibilities

1. Maintain a professional attitude.
2. Treat the participant with respect.
3. Be early
4. Follow all Smart Road safety Protocols
5. Follow proper Smart Road radio protocols
6. Be alert and attentive while on the road

## In-vehicle Protocols

*--- Prior to participant arrival ---*

**1. Set up the Data Collection System**

1. **Turn on laptop and enter passwords**
2. **After logged in to Windows, enter SOLEye application**
3. **Connect laptop to Ethernet cable near passenger seat [might need to wait for connection]**
4. **Click connect to SOL button on upper left side of application window**
5. **Application should then load settings for ASY. If an error message is received, turn off the car and exit SOL.**
6. **Wait for the DAS to turn off (open car door to turn off power in vehicle) after about 5 minutes turn car back on and repeat steps 4 and 5.**
7. **If you still receive errors contact HEL team.**

At no time during the study should you turn off the vehicle

--- After completion of participant screening and assessment ---

**2. Take participant out to the vehicle**

1. Vehicle will be parked out in the front of the building
2. Participant should not chew gum, and should not have food or drink in the vehicle

3. Ask participant to mute/power off their cell phone if they have one.

3. **Orient participant to the vehicle**
    1. Power seat: when sitting in seat controls are on the left side of the seat
    2. Steering wheel: can be positioned forward, backward, up, and down
    3. Power mirrors: controls are on driver side door panel
    4. Windshield wipers: automatic sensor does exist, but wipers can be manually activated or changed
    5. **Explain to participant that they will not need nor should they use the cruise control**
4. **Ask participant to drive to the Smart Road, making sure all passengers have their seat belts buckled.**
    1. **Radio dispatch that study has one car entering the road**

*For this study you will be asked to drive a vehicle on the Smart Road. Your primary task, or what you should pay the most attention to, is the driving task.*

*Do you have any questions before we go down to the Smart Road?* (Answer any questions.) *Okay, we will head down to the road now. We will be down there for approximately 2 hours. If you feel that you need a break, please let me know and we will drive back to the building.*

5. **Proceed to the T1 training area**
    1. **Instruct them to put the vehicle in park → a cone will be set up to mark the position**
    2. **Explain that this is the training area that we will be using throughout the study**

6. **Orient participant to the Smart Road**
    1. **Allow participant to drive a lap up and down the Smart Road pointing out key features such as the Intersection, Zero Crown, T2 turn around (downhill turn) and Start Cone (T1 turn or the uphill turn), etc. Also use this time to mention to participants other studies may be using the road as it is in high demand by many notable companies (i.e. GM, Google).**
7. **Orient the participant to the study**
    - This study is to determine if people accept a new technology the "adaptive" display.
    - The display in this study will change based on traffic conditions, time of day, etc.
    - We will be running scenarios on the Smart Road to simulate conditions one might encounter at a real intersection.

**8. Orient participant to technology to be tested**

- This study involves testing connected vehicle technology. Connected vehicle technology may be available in the near future, and its main purpose will be to reduce the number of car crashes on public roads.
- The technology works by allowing vehicles to send messages via wireless communication to equipment installed on the side of the road (Road Side Equipment or RSE). The vehicles are constantly sending a signal to the RSE sharing important information such as speed and relative position.
- When multiple vehicles are equipped with this capability, the units on the side of the road can give the driver information that they might find useful, particularly about the location of other drivers on the road.
- In this study we will be testing an in-vehicle display which relies on this V2I technology.
- These scenarios we will be going through today are designed to imitate situations you may experience in the real world using this technology.
- During our study today, you will see an intersection on the Smart Road that has no working traffic lights, and no stop signs or yield signs like you would see at a typical intersection controlling traffic. Instead, the technology will 'talk' to the roadside unit and you will receive information on the display that advises your course of action for the intersection.
- Stop signs require the motorist to stop and ensure that it is safe to proceed through the intersection.

**8. List Remaining Tasks and Instructions as necessary**

*Instruct participant*

- *Approaches should be done in 3rd gear.*
- *<proceed toward intersection at about 35 mph>*
- *<follow the on screen prompt>*
- ***Provide with navigational instructions (turn left, turn right, etc.) at the intersection***

**9. Check with Participant about halfway through and see if they need a break**

**10. Instruct Participant to Return to Building**

**11. Complete post drive survey**

**12. Pay Participant**

- **Thank them for their time**

- **Ask them to sign payment log**

**13. Provide participant with debriefing/payment form**

- **Make sure form is completed and signed before giving to participant**

# APPENDIX F - PRE-DRIVE SURVEY

VirginiaTech Transportation Institute

**Pre-Drive Survey** Participant Number: ____________

Age: ________

Gender: ________

Number of Years Driving: ________

1. What is your primary vehicle?

| Make | Model | Year |
|---|---|---|
| | | |

2. Please list other vehicles that you drive regularly.

| Make | Model | Year |
|---|---|---|
| | | |
| | | |
| | | |

3. Does your primary vehicle have any of the features listed below? Please indicate yes or no. Please ask if you need an explanation of any of these features.

| Feature | Yes | No |
|---|---|---|
| Adaptive Cruise Control | | |
| Heads-Up Display | | |
| Navigation System | | |
| Lane Departure Warning System | | |
| Rear Vision Camera | | |
| Park Assist | | |
| Cross-Traffic Alerting System | | |
| Bluetooth | | |
| Forward Collision Alerts | | |
| Tire Pressure Monitoring System | | |

4. Which of the following features have you experienced before, either in your primary vehicle or another vehicle you drove in the past?

| Feature | Experienced | Have Not Experienced |
|---|---|---|
| Adaptive Cruise Control | | |
| Heads-Up Display | | |
| Navigation System | | |
| Lane Departure Warning System | | |
| Rear Vision Camera | | |
| Park Assist | | |
| Cross-Traffic Alerting System | | |
| Bluetooth | | |
| Forward Collision Alerts | | |
| Tire Pressure Monitoring System | | |

5. Have you heard of Vehicle-to-Vehicle and/or Vehicle-to-Infrastructure communication?
   - ☐ Yes
   - ☐ No

If yes, what are your general feelings towards this technology?

6. Have you ever been involved in a crash at a stop-controlled or yield-controlled intersection?
   - ☐ Yes
   - ☐ No
7. On the following scale, how often do you come to a complete stop at a stop sign?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Only when I must | | Half of the time | | Every time |

8. What is your opinion on the frequency of stop sign usage by the DOT to control traffic?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Extremely Overused | | Used just right | | Extremely Underused |

9. How effective do you believe stop signs are at controlling traffic at intersections?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Extremely Ineffective | | Neutral | | Extremely Effective |

10. If a stop sign were to adapt to current traffic conditions, ***how much would you trust it***?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not at all | | About half of the time | | Every time |

11. If the stop sign were to adapt to current traffic conditions, ***how much more likely would you be to obey the sign over a typical static sign***?

| 1 | 2 | 3 | 4 | 5 |
| --- | --- | --- | --- | --- |
| Not at all | | About half of the time | | Obey it every time |

# APPENDIX G - POST- DRIVE SURVEY

**Post-Drive Survey** Participant Number: ___________

1. What is your immediate impression of the adaptable stop sign?

2. How useful would this be in the real world at an intersection where crossing traffic wa obstructed by an object or limited sight distance?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not Very Useful | | Neutral | | Very Useful |

3. I believe that this display is useful in areas with limited sight distance or with obstructions.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Strongly Disagree | | Neutral | | Strongly Agree |

4. The message provided by the sign was clear.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Strongly Disagree | | Neutral | | Strongly Agree |

**If rated 4 or lower, what was unclear?**

5. The sign changed with enough time for me to react safely.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Strongly Disagree | | Neutral | | Strongly Agree |

6. Would this type of sign change your driving behavior at stop controlled intersections?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not at all | | Neutral | | All of the time |

7. If this technology were available in your next vehicle purchase would you have it installed?

   ☐ Yes

   ☐ No

8. If yes, approximately how much would you be willing to pay for it? : $____________

9. Could you describe any concerns, suggestions for improvement, or any other comments you might have for adaptable stop in-cab display unit?

## APPENDIX H - VIRGINIA TECH W-9 TAX FORM

Participants were instructed to complete only the highlighted portions of this tax document.

Virginia Tech
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

**VENDOR REGISTRATION**
Substitute Form W-9
Mail, e-mail or Fax completed form to:
201 Southgate Center, Blacksburg, VA 24061
W9@vt.edu Phone: (540) 231-2544/Fax: (540) 231-7221

Legal Name: ______________________
*(as it appears on your tax return)*

Trade Name: ______________________
*(DBA)*

| Mail PURCHASE ORDERS and BIDS to: | | Mail PAYMENTS to: | |
|---|---|---|---|
| | | | |
| PO Telephone # *(preferably toll free)* | PO Fax # *(preferably toll free)* | Email address: | |
| | | AP email address: | |

| Taxpayer Identification Number: | | |
|---|---|---|
| **Employer Identification Number(EIN):** | AND/OR | **Social Security Number (SSN):** |

**Entity Type (one MUST be checked)**

- ☐ Corporation
- ☐ Government Entity
- ☐ Non-Profit Organization
- ☐ LLC
  - If "LLC" is checked, type MUST be marked below:
  - ☐ Disregarded (D)
  - ☐ Partnership (P)
  - ☐ Corporation (C)
- ☐ Partnership
- ☐ Sole Proprietor
- ☒ Individual (see below)

**For Individuals ONLY:**
____ I am a U.S. Citizen, **or**
____ I have been granted permanent residency (green card holder), **or**
____ I am a Resident Alien for tax purposes and have contacted the international tax specialist at 540-231-3754 or jakunz@vt.edu to discuss additional documentation that is required by federal law.

Business Classification Type (check ALL that apply): *for descriptions see: http://www.purch.vt.edu/Vendor/class.html*

☐ Large Business ☐ Small Business ☐ Minority owned Business ☐ Women Owned Business ☐ Other

**Certification: Under penalties of perjury, I certify that:**
(1) The number(s) shown on this form is my correct taxpayer identification number(s) (or I am waiting for a number to be issued to me), ***and*** (2) The organization entity and all other information provided is accurate, ***and*** (3) I am not subject to backup withholding either because I have not been notified that I am subject to backup withholding as a result of a failure to report all interest or dividends, or the Internal Revenue Service has notified me that I am no longer subject to backup withholding.

You must cross out item (3) above if you have been notified by IRS that you are currently subject to backup withholding because of underreporting interest or dividends on your tax return.

______________________ ______________________
*Authorized Signature* *Title*

______________________ ______________________ __________
*Printed or Typed Name* *Phone Number* *Date*

# APPENDIX I - NUMBER OF GLANCES TO IVD OVER ALL EXPOSURES ANOVA TABLE

| Source | DF | Sum of Squares | Mean Square | F | p |
|---|---|---|---|---|---|
| **Model** | 334 | 772.896 | 2.314 | 2.84 | <.0001 |
| **Error** | 1,074 | 875.333 | 0.815 | | |
| **Corrected Total** | 1,408 | 1,648.229 | | | |

| Source | DF | Mean Square | F Value | p |
|---|---|---|---|---|
| SIGN | 3 | 14.863 | 18.24 | <.0001 |
| EXPOSURE | 29 | 2.474 | 3.04 | <.0001 |
| GENDER | 1 | 0.331 | 0.41 | 0.5240 |
| AGE | 1 | 0.758 | 0.93 | 0.3350 |
| NAV | 2 | 0.014 | 0.02 | 0.9830 |
| TRAFFIC | 3 | 1.163 | 1.43 | 0.2333 |
| SIGN×EXPOSURE | 62 | 0.593 | 0.73 | 0.9434 |
| SIGN×GENDER | 3 | 0.570 | 0.70 | 0.5528 |
| SIGN×AGE | 3 | 1.515 | 1.86 | 0.1348 |
| SIGN×TRAFFIC | 1 | 0.535 | 0.66 | 0.4181 |
| EXPOSURE×GENDER | 29 | 0.314 | 0.39 | 0.9987 |
| EXPOSURE×AGE | 29 | 0.350 | 0.43 | 0.9966 |
| EXPOSURE×NAV | 46 | 0.183 | 0.23 | 1.0000 |
| EXPOSURE×TRAFFIC | 65 | 0.369 | 0.45 | 0.9999 |
| GENDER×AGE | 1 | 1.997 | 2.45 | 0.1178 |
| GENDER×NAV | 2 | 0.246 | 0.30 | 0.7399 |
| GENDER×TRAFFIC | 3 | 0.097 | 0.12 | 0.9486 |
| AGE×NAV | 2 | 0.134 | 0.16 | 0.8487 |
| AGE×TRAFFIC | 3 | 0.504 | 0.62 | 0.6030 |
| NAV×TRAFFIC | 1 | 0.140 | 0.17 | 0.6781 |
| SIGN×GENDER×AGE | 3 | 1.188 | 1.46 | 0.2244 |
| EXPOSURE×GENDER×AGE | 29 | 0.948 | 1.16 | 0.2531 |
| GENDER×AGE×NAV | 2 | 0.075 | 0.09 | 0.9126 |
| GENDER×AGE×TRAFFIC | 3 | 0.022 | 0.03 | 0.9941 |

# APPENDIX J - NUMBER OF GLANCES TO IVD AFTER INITIAL EXPOSURE ANOVA TABLE

| Source | DF | Sum of Squares | Mean Square | F | p |
|---|---|---|---|---|---|
| **Model** | 307 | 374.654 | 1.220 | 3.44 | <.0001 |
| **Error** | 817 | 290.146 | 0.355 | | |
| **Corrected Total** | 1,124 | 664.800 | | | |

| Source | DF | Mean Square | F Value | p |
|---|---|---|---|---|
| SIGN | 3 | 14.863 | 41.85 | <.0001 |
| EXPOSURE | 23 | 0.621 | 1.75 | 0.0163 |
| GENDER | 1 | 0.178 | 0.50 | 0.4786 |
| AGE | 1 | 0.212 | 0.60 | 0.4397 |
| NAV | 2 | 0.212 | 0.60 | 0.5500 |
| TRAFFIC | 3 | 1.163 | 3.27 | 0.0206 |
| SIGN×EXPOSURE | 62 | 0.593 | 1.67 | 0.0013 |
| SIGN×GENDER | 3 | 0.570 | 1.60 | 0.1870 |
| SIGN×AGE | 3 | 1.515 | 4.27 | 0.0053 |
| SIGN×TRAFFIC | 1 | 0.535 | 1.51 | 0.2201 |
| EXPOSURE×GENDER | 23 | 0.251 | 0.71 | 0.8422 |
| EXPOSURE×AGE | 23 | 0.305 | 0.86 | 0.6553 |
| EXPOSURE×NAV | 46 | 0.183 | 0.52 | 0.9969 |
| EXPOSURE×TRAFFIC | 65 | 0.369 | 1.04 | 0.3947 |
| GENDER×AGE | 1 | 1.384 | 3.90 | 0.0487 |
| GENDER×NAV | 2 | 0.246 | 0.69 | 0.5010 |
| GENDER×TRAFFIC | 3 | 0.097 | 0.27 | 0.8438 |
| AGE×NAV | 2 | 0.134 | 0.38 | 0.6864 |
| AGE×TRAFFIC | 3 | 0.504 | 1.42 | 0.2356 |
| NAV×TRAFFIC | 1 | 0.140 | 0.40 | 0.5296 |
| SIGN×GENDER×AGE | 3 | 1.188 | 3.35 | 0.0187 |
| EXPOSURE×GENDER×AGE | 23 | 0.202 | 0.57 | 0.9482 |
| GENDER×AGE×NAV | 2 | 0.075 | 0.21 | 0.8107 |
| GENDER×AGE×TRAFFIC | 3 | 0.022 | 0.06 | 0.9800 |

# APPENDIX K - Mean Glance Duration to IVD- All Exposures ANOVA Table

| Source | DF | Sum of Squares | Mean Square | F | p |
|---|---|---|---|---|---|
| **Model** | 334 | 43.379 | 0.130 | 1.80 | <.0001 |
| **Error** | 1,074 | 77.352 | 0.072 | | |
| **Corrected Total** | 1,408 | 120.731 | | | |

| Source | DF | Mean Square | F Value | p |
|---|---|---|---|---|
| SIGN | 3 | 0.008 | 0.11 | 0.9527 |
| EXPOSURE | 29 | 0.125 | 1.74 | 0.0093 |
| GENDER | 1 | 0.137 | 1.91 | 0.1675 |
| AGE | 1 | 0.564 | 7.83 | 0.0052 |
| NAV | 2 | 0.105 | 1.46 | 0.2336 |
| TRAFFIC | 3 | 0.091 | 1.27 | 0.2841 |
| SIGN×EXPOSURE | 62 | 0.045 | 0.62 | 0.9903 |
| SIGN×GENDER | 3 | 0.034 | 0.47 | 0.7021 |
| SIGN×AGE | 3 | 0.032 | 0.44 | 0.7224 |
| SIGN×TRAFFIC | 1 | 0.018 | 0.24 | 0.6220 |
| EXPOSURE×GENDER | 29 | 0.054 | 0.75 | 0.8237 |
| EXPOSURE×AGE | 29 | 0.051 | 0.70 | 0.8798 |
| EXPOSURE×NAV | 46 | 0.057 | 0.79 | 0.8443 |
| EXPOSURE×TRAFFIC | 65 | 0.059 | 0.82 | 0.8412 |
| GENDER×AGE | 1 | 0.013 | 0.18 | 0.6691 |
| GENDER×NAV | 2 | 0.017 | 0.23 | 0.7907 |
| GENDER×TRAFFIC | 3 | 0.012 | 0.17 | 0.9157 |
| AGE×NAV | 2 | 0.047 | 0.65 | 0.5201 |
| AGE×TRAFFIC | 3 | 0.061 | 0.85 | 0.4688 |
| NAV×TRAFFIC | 1 | 0.006 | 0.09 | 0.7683 |
| SIGN×GENDER×AGE | 3 | 0.024 | 0.34 | 0.7977 |
| EXPOSURE×GENDER×AGE | 29 | 0.033 | 0.46 | 0.9935 |
| GENDER×AGE×NAV | 2 | 0.025 | 0.34 | 0.7115 |
| GENDER×AGE×TRAFFIC | 3 | 0.033 | 0.45 | 0.7149 |

# APPENDIX L - MEAN GLANCE DURATION TO IVD AFTER INITIAL EXPOSURE PERIOD ANOVA TABLE

| Source | DF | Sum of Squares | Mean Square | F | p |
|---|---|---|---|---|---|
| **Model** | 307 | 27.13 | 0.088 | 1.61 | <.0001 |
| **Error** | 817 | 44.912 | 0.055 | | |
| **Corrected Total** | 1,124 | 72.042 | | | |

| Source | DF | Mean Square | F Value | p |
|---|---|---|---|---|
| SIGN | 3 | 0.008 | 0.15 | 0.9312 |
| EXPOSURE | 23 | 0.097 | 1.77 | 0.0147 |
| GENDER | 1 | 0.172 | 3.13 | 0.0772 |
| AGE | 1 | 0.716 | 13.02 | 0.0003 |
| NAV | 2 | 0.154 | 2.81 | 0.0611 |
| TRAFFIC | 3 | 0.091 | 1.66 | 0.1740 |
| SIGN×EXPOSURE | 62 | 0.045 | 0.82 | 0.8435 |
| SIGN×GENDER | 3 | 0.034 | 0.62 | 0.6035 |
| SIGN×AGE | 3 | 0.032 | 0.58 | 0.6281 |
| SIGN×TRAFFIC | 1 | 0.018 | 0.32 | 0.5726 |
| EXPOSURE×GENDER | 23 | 0.040 | 0.72 | 0.8257 |
| EXPOSURE×AGE | 23 | 0.049 | 0.89 | 0.6138 |
| EXPOSURE×NAV | 46 | 0.057 | 1.03 | 0.4155 |
| EXPOSURE×TRAFFIC | 65 | 0.059 | 1.08 | 0.3217 |
| GENDER×AGE | 1 | 0.020 | 0.37 | 0.5436 |
| GENDER×NAV | 2 | 0.017 | 0.31 | 0.7352 |
| GENDER×TRAFFIC | 3 | 0.012 | 0.22 | 0.8793 |
| AGE×NAV | 2 | 0.047 | 0.86 | 0.4249 |
| AGE×TRAFFIC | 3 | 0.061 | 1.11 | 0.3448 |
| NAV×TRAFFIC | 1 | 0.006 | 0.11 | 0.7360 |
| SIGN×GENDER×AGE | 3 | 0.024 | 0.44 | 0.7222 |
| EXPOSURE×GENDER×AGE | 23 | 0.033 | 0.61 | 0.9272 |
| GENDER×AGE×NAV | 2 | 0.025 | 0.45 | 0.6402 |
| GENDER×AGE×TRAFFIC | 3 | 0.033 | 0.59 | 0.6190 |

# APPENDIX M - MAXIMUM GLANCE DURATION TO DISPLAY – ALL EXPOSURES ANOVA TABLE

| Source | DF | Sum of Squares | Mean Square | F | p |
|---|---|---|---|---|---|
| **Model** | 92 | 69.384 | 0.754 | 3.87 | <.0001 |
| **Error** | 1316 | 256.218 | 0.195 | | |
| **Corrected Total** | 1408 | 325.603 | | | |

| Source | DF | Mean Square | F Value | p |
|---|---|---|---|---|
| SIGN | 3 | 1.562 | 8.02 | <.0001 |
| EXPOSURE | 29 | 0.903 | 4.64 | <.0001 |
| GENDER | 1 | 0.552 | 2.83 | 0.0926 |
| AGE | 1 | 4.487 | 23.05 | <.0001 |
| NAV | 2 | 0.071 | 0.37 | 0.6941 |
| TRAFFIC | 3 | 0.022 | 0.11 | 0.9517 |
| SIGN×GENDER | 4 | 0.516 | 2.65 | 0.0319 |
| SIGN×AGE | 3 | 0.923 | 4.74 | 0.0027 |
| EXPOSURE×AGE | 29 | 0.133 | 0.68 | 0.8976 |
| AGE×TRAFFIC | 3 | 0.154 | 0.79 | 0.4983 |
| AGE×NAV | 2 | 0.129 | 0.66 | 0.5147 |
| GENDER×TRAFFIC | 3 | 0.135 | 0.69 | 0.5554 |
| GENDER×NAV | 2 | 0.361 | 1.86 | 0.1568 |
| SIGN×GENDER×AGE | 5 | 0.763 | 3.92 | 0.0016 |

# APPENDIX N - MAXIMUM GLANCE DURATION TO DISPLAY AFTER INITIAL EXPOSURE PERIOD

## ANOVA TABLE

| Source | DF | Sum of Squares | Mean Square | F | p |
|---|---|---|---|---|---|
| Model | 80 | 32.940 | 0.412 | 3.71 | <.0001 |
| Error | 1045 | 116.120 | 0.111 | | |
| Corrected Total | 1125 | 149.060 | | | |

| Source | DF | Mean Square | F | p |
|---|---|---|---|---|
| SIGN | 3 | 1.602 | 14.41 | <.0001 |
| EXPOSURE | 23 | 0.125 | 1.12 | 0.3098 |
| GENDER | 1 | 0.647 | 5.83 | 0.016 |
| AGE | 1 | 3.522 | 31.69 | <.0001 |
| NAV | 2 | 0.039 | 0.35 | 0.7047 |
| TRAFFIC | 3 | 0.121 | 1.09 | 0.3529 |
| SIGN×GENDER | 4 | 0.385 | 3.46 | 0.0081 |
| SIGN×AGE | 3 | 1.012 | 9.1 | <.0001 |
| EXPOSURE×AGE | 23 | 0.112 | 1.01 | 0.4464 |
| AGE×TRAFFIC | 3 | 0.099 | 0.89 | 0.4457 |
| AGE×NAV | 2 | 0.046 | 0.41 | 0.6633 |
| GENDER×TRAFFIC | 3 | 0.155 | 1.39 | 0.2431 |
| GENDER×NAV | 2 | 0.076 | 0.68 | 0.5046 |
| SIGN×GENDER×AGE | 5 | 0.581 | 5.23 | <.0001 |

# APPENDIX O - MAXIMUM GLANCE DURATION AFTER INITIAL EXPOSURES ANOVA INTERACTIONS

**Sign × Gender**

| Level of SIGN | Level of GENDER | N | DURATION Mean | DURATION Stud Dev |
|---|---|---|---|---|
| BLACKOUT | FEMALE | 13 | 0.544 | 0.237 |
| | MALE | 16 | 0.421 | 0.187 |
| PWC | FEMALE | 408 | 0.520 | 0.254 |
| | MALE | 402 | 0.507 | 0.210 |
| SURPRISE | FEMALE | 24 | 0.623 | 0.184 |
| | MALE | 24 | 0.576 | 0.191 |
| SWITCH | FEMALE | 49 | 0.861 | 1.010 |
| | MALE | 47 | 0.615 | 0.468 |
| STOP | FEMALE | 73 | 0.680 | 0.570 |
| | MALE | 70 | 0.583 | 0.418 |

**Sign × Age**

| Level of SIGN | Level of Age | N | DURATION Mean | DURATION Stud Dev |
|---|---|---|---|---|
| BLACKOUT | 25 and Under | 16 | 0.425 | 0.187 |
| | 55 Plus | 13 | 0.539 | 0.240 |
| PWC | 25 and Under | 410 | 0.444 | 0.182 |
| | 55 Plus | 400 | 0.585 | 0.257 |
| SURPRISE | 25 and Under | 25 | 0.539 | 0.160 |
| | 55 Plus | 23 | 0.664 | 0.196 |
| SWITCH | 25 and Under | 49 | 0.515 | 0.268 |
| | 55 Plus | 47 | 0.975 | 1.063 |
| STOP | 25 and Under | 73 | 0.447 | 0.209 |
| | 55 Plus | 70 | 0.826 | 0.632 |

**Sign × Gender × Age**

| Level of SIGN | Level of GENDER | Level of AGE | N | DURATION Mean | DURATION Stud Dev |
|---|---|---|---|---|---|
| **BLACKOUT** | **FEMALE** | **25 and Under** | **6** | 0.545 | 0.213 |
| | | **55 Plus** | **7** | 0.543 | 0.274 |
| | **MALE** | **25 and Under** | **10** | 0.354 | 0.134 |
| | | **55 Plus** | **6** | 0.534 | 0.220 |
| **PWC** | **FEMALE** | **25 and Under** | **207** | 0.442 | 0.170 |
| | | **55 Plus** | **201** | 0.601 | 0.299 |
| | **MALE** | **25 and Under** | **203** | 0.447 | 0.194 |
| | | **55 Plus** | **199** | 0.569 | 0.207 |
| **SURPRISE** | **FEMALE** | **25 and Under** | **13** | 0.549 | 0.142 |
| | | **55 Plus** | **11** | 0.710 | 0.196 |
| | **MALE** | **25 and Under** | **12** | 0.529 | 0.183 |
| | | **55 Plus** | **12** | 0.623 | 0.194 |
| **SWITCH** | **FEMALE** | **25 and Under** | **26** | 0.495 | 0.160 |
| | | **55 Plus** | **23** | 1.274 | 1.363 |
| | **MALE** | **25 and Under** | **23** | 0.537 | 0.356 |
| | | **55 Plus** | **24** | 0.690 | 0.553 |
| **STOP** | **FEMALE** | **25 and Under** | **37** | 0.437 | 0.191 |
| | | **55 Plus** | **36** | 0.931 | 0.710 |
| | **MALE** | **25 and Under** | **36** | 0.458 | 0.227 |
| | | **55 Plus** | **34** | 0.716 | 0.525 |

# APPENDIX P - SCANNING BEHAVIOR ALL EXPOSURES ANOVA TABLES

### Mean number of Glances

| Source | DF | Mean Square | F Value | p |
|---|---|---|---|---|
| **Model** | 125.00 | 15.70 | 12.11 | <.0001 |
| **Error** | 4,317.00 | 1.30 | | |
| **Corrected Total** | 4,442.00 | | | |

| Source | DF | Mean Square | F Value | p |
|---|---|---|---|---|
| SIGN | 4 | 61.94 | 47.77 | <.0001 |
| LOCATION | 2 | 57.82 | 44.59 | <.0001 |
| EXPOSURE | 30 | 4.41 | 3.4 | <.0001 |
| NAV | 2 | 33.18 | 25.59 | <.0001 |
| TRAFFIC | 3 | 21.70 | 16.74 | <.0001 |
| GENDER | 1 | 22.11 | 17.05 | <.0001 |
| AGE | 1 | 0.21 | 0.16 | 0.69 |
| LOCATION×SIGN | 8 | 10.72 | 8.27 | <.0001 |
| LOCATION×EXPOSURE | 60 | 5.02 | 3.87 | <.0001 |
| LOCATION×NAV | 4 | 66.69 | 51.43 | <.0001 |
| LOCATION×TRAFFIC | 6 | 17.74 | 13.68 | <.0001 |
| LOCATION×AGE | 2 | 7.49 | 5.78 | 0.0031 |
| LOCATION×GENDER | 2 | 14.47 | 11.16 | <.0001 |

## Mean Glance Duration

| Source | DF | Mean Square | F Value | p |
|---|---|---|---|---|
| **Model** | 125.00 | 6.48 | 10.67 | <.0001 |
| **Error** | 4,317.00 | 0.61 | | |
| **Corrected Total** | 4,442.00 | | | |

| Source | DF | Mean Square | F | p |
|---|---|---|---|---|
| SIGN | 4 | 18.02 | 29.68 | <.0001 |
| LOCATION | 2 | 17.39 | 28.64 | <.0001 |
| EXPOSURE | 30 | 1.83 | 3.01 | <.0001 |
| NAV | 2 | 10.55 | 17.37 | <.0001 |
| TRAFFIC | 3 | 0.34 | 0.56 | 0.6444 |
| GENDER | 1 | 8.67 | 14.28 | 0.0002 |
| AGE | 1 | 4.19 | 6.91 | 0.0086 |
| LOCATION×SIGN | 8 | 4.11 | 6.77 | <.0001 |
| LOCATION×EXPOSURE | 60 | 2.41 | 3.97 | <.0001 |
| LOCATION×NAV | 4 | 28.99 | 47.75 | <.0001 |
| LOCATION×TRAFFIC | 6 | 5.45 | 8.97 | <.0001 |
| LOCATION×AGE | 2 | 14.91 | 24.56 | <.0001 |
| LOCATION×GENDER | 2 | 1.66 | 2.73 | 0.0654 |

# APPENDIX Q - SCANNING BEHAVIOR AFTER INITIAL EXPOSURE PERIOD ANOVA TABLES

**Mean number of Glances**

| Source | DF | Mean Square | F Value | p |
|---|---|---|---|---|
| **Model** | 104.00 | 4.71 | 10.34 | <.0001 |
| **Error** | 3,363.00 | 0.46 | | |
| **Corrected Total** | 3,467.00 | | | |

| Source | DF | Mean Square | F Value | p |
|---|---|---|---|---|
| SIGN | 4 | 62.09 | 53.25 | <.0001 |
| LOCATION | 2 | 32.41 | 27.79 | <.0001 |
| EXPOSURE | 23 | 1.88 | 1.62 | 0.0319 |
| NAV | 2 | 32.87 | 28.19 | <.0001 |
| TRAFFIC | 3 | 21.47 | 18.41 | <.0001 |
| GENDER | 1 | 9.90 | 8.49 | 0.0036 |
| AGE | 1 | 1.04 | 0.9 | 0.3441 |
| LOCATION×SIGN | 8 | 10.08 | 8.65 | <.0001 |
| LOCATION×EXPOSURE | 46 | 1.41 | 1.21 | 0.1545 |
| LOCATION×NAV | 4 | 66.49 | 57.02 | <.0001 |
| LOCATION×TRAFFIC | 6 | 17.65 | 15.14 | <.0001 |
| LOCATION×AGE | 2 | 7.75 | 6.65 | 0.0013 |
| LOCATION×GENDER | 2 | 9.22 | 7.91 | 0.0004 |

## Mean Glance Duration

| Source | DF | Mean Square | F Value | p |
|---|---|---|---|---|
| **Model** | 104 | 4.71 | 10.34 | <.0001 |
| **Error** | 3,363 | 0.46 | | |
| **Corrected Total** | 3,467 | | | |

| Source | DF | Mean Square | F | p |
|---|---|---|---|---|
| SIGN | 4 | 18.02 | 39.53 | <.0001 |
| LOCATION | 2 | 9.44 | 20.71 | <.0001 |
| EXPOSURE | 23 | 0.81 | 1.79 | 0.0119 |
| NAV | 2 | 10.46 | 22.95 | <.0001 |
| TRAFFIC | 3 | 0.32 | 0.7 | 0.5541 |
| GENDER | 1 | 2.68 | 5.89 | 0.0153 |
| AGE | 1 | 0.35 | 0.76 | 0.382 |
| LOCATION×SIGN | 8 | 3.75 | 8.23 | <.0001 |
| LOCATION×EXPOSURE | 46 | 0.58 | 1.27 | 0.1075 |
| LOCATION×NAV | 4 | 28.86 | 63.3 | <.0001 |
| LOCATION×TRAFFIC | 6 | 5.40 | 11.85 | <.0001 |
| LOCATION×AGE | 2 | 14.22 | 31.2 | <.0001 |
| LOCATION×GENDER | 2 | 1.17 | 2.56 | 0.0777 |

# APPENDIX R - POST HOC TEST FOR APPENDIX Q

**Table 37. Glance Duration**
**Tukey-Kramer Comparison LS Means: LOCATION×TRAFFIC**

| GROUP [a] | | | LSMEAN MEAN_DURATION | LOCATION | TRAFFIC |
|---|---|---|---|---|---|
| | A | | 1.44 | **Left** | **3** |
| | A | | 1.43 | **Left** | **2** |
| B | A | | 1.28 | **Display** | **0** |
| B | A | C | 1.21 | **Left** | **0** |
| B | | C | 1.13 | **Left** | **1** |
| | D | C | 0.76 | **Display** | **1** |
| | D | C | 0.73 | **Display** | **3** |
| | D | C | 0.69 | **Display** | **2** |
| | D | | 0.49 | **Right** | **1** |
| E | D | | 0.38 | **Right** | **2** |
| E | D | | 0.37 | **Right** | **3** |
| E | | | -0.05 | **Right** | **0** |

[a]: LS Means with the same letter are not significantly different

**Table 38. Number of Glances**
**Tukey-Kramer Comparison LS Means: LOCATION×TRAFFIC**

| GROUP [a] | | | LS MEAN NUM_GLANCES | LOCATION | TRAFFIC |
|---|---|---|---|---|---|
| | A | | 3.57 | **Left** | **3** |
| | B | | 3.07 | **Left** | **2** |
| C | B | | 2.44 | **Left** | **0** |
| C | | | 2.36 | **Left** | **1** |
| C | D | | 1.95 | **Display** | **0** |
| C | D | | 1.53 | **Right** | **3** |
| C | D | E | 1.50 | **Display** | **3** |
| C | D | E | 1.48 | **Display** | **1** |
| | D | E | 1.38 | **Display** | **2** |
| | D | E | 1.11 | **Right** | **1** |
| | D | E | 1.02 | **Right** | **2** |
| | | E | 0.49 | **Right** | **0** |

[a]: LS Means with the same letter are not statistically different

# APPENDIX S - SIGN STUDY

An Assessment of Sign Characteristics for In-Vehicle Adaptive Stop Displays

Alexandria M. Noble

**ABSTRACT**

Traffic signs are an important communication tool used to communicate regulatory, warning, and guidance information to road users. Signs that are inappropriately designed or misused can have unintended consequences for the operators of motor vehicles such as confusion and missed messages. Given the emerging practice of connected vehicle technology, there are no standards on the shape and colorings of in-vehicle regulatory signs, in lieu of focusing on a particular standard, the focus was instead turned to optimizing in-vehicle display's ability to convey the appropriate message. Ninety-four participants participated in the online survey; participants were randomly given one of three versions of the survey, asking the same questions about different displays Results indicated that the wording on the display matters much more to users than the shape or colors used in the display.

# Introduction

Traffic signs are an important communication tool used to communicate regulatory, warning, and guidance information to road users. Signs that are inappropriately designed or misused can have unintended consequences for the operators of motor vehicles such as confusion and missed messages. In the development and evaluation of new signs intended to convey important regulatory type messages, it is essential that the opinion of the driver be taken into account in evaluating new symbol usage particularly in the application of in-vehicle displays and warnings.

## Problem Statement

Given the emerging practice of connected vehicle technology, there are no standards on the shape and colorings of in-vehicle regulatory signs. On public roads, the governing standard of sign shape, color, and conspicuity is the Manual on Uniform Traffic Control Devices (MUTCD), in consumer products, the American National Standards Institute (ANSI) is the primary authority, and when it comes to workplace hazards, the International Standards Organization (ISO). The road and the vehicles that occupy them do not fit neatly under one category as it pertains to a connected vehicles environment. The automobile is of course a consumer product; however, the roadway itself can be considered at times a consumer product and a work place. The selection of any one standard to follow in the design of an in-vehicle display can be challenging.

According to the MUTCD, traffic control devices "notify road users of regulations and provide warning and guidance needed for the safe, uniform, and efficient operation of all elements of the traffic stream." [2] The MUTCD also states that for a traffic control device to be effective it should, fulfill a need, command attention, and convey a clear, simple meaning.

There are several basic provisions for regulating, warning, and guiding traffic:

1. Fulfill a need
2. Command attention
3. Convey a clear, simple meaning
4. Command respect of road users
5. Give adequate time for proper response

## Support

State or local laws written in accordance with the "Uniform Vehicle Code" (see Section 1A.11) establish the right-of-way rule at intersections having no regulatory traffic control signs such that the driver of a vehicle approaching an intersection must yield the right-of-way to any vehicle or pedestrian already in the intersection. When two vehicles approach an intersection from different streets or highways at approximately the same time, the right-of-way rule requires the driver of the vehicle on the left to yield the right-of-way to the vehicle on the right. The right-of-way can be modified at through streets or highways by placing YIELD (R1-2) signs (see Sections 2B.08 and 2B.09) or STOP (R1-1) signs (see Sections 2B.05 through 2B.07) on one or more approaches.

## Objective

In lieu of focusing on a particular standard, the focus was instead turned to optimizing in-vehicle display's ability to convey the appropriate message. The MUTCD was followed closely as a reference for development of these displays primarily due to the context of when the alert is intended to be given (at/approaching an intersection)

1. Determine what alternative display type would be most appropriate for our application?
2. Which matters most shape/color or wording?
3. Are there any demographic variations in user comprehension?

Display Design Goals

1. The display meaning should be easily understood by drivers.
2. The display should not provide road users with a false sense of security
3. The display should be easily identified both in and out of context (vehicle)

## Display Designs

Multiple displays were designed to be tested in a comprehension survey in order to allow for a range of color, shape, and word pairings across participants. The following criterion were considered in designing the displays.

### Symbology (Shape/Color)

*Section 1A.12 Color Code*

Support:

*The following color code establishes general meanings for 11 colors of a total of 13 colors that have been identified as being appropriate for use in conveying traffic control information tolerance limits for each color are contained in 23 CFR Part 655, Appendix to Subpart F and are available at the Federal Highway Administration's MUTCD website at http://mutcd.fhwa.dot*

*02 The two colors for which general meanings have not yet been assigned are being reserved for future applications that will be determined only by FHWA after consultation with the States, the engineering community, and the public. The meanings described in this Section are of a general nature.*

**Standard**: Meaning for select colors used in this study as specified by the MUTCD.

A. Black—regulation
G. Green—indicated movements permitted, direction guidance
K. Red—stop or prohibition
L. White—regulation
M. Yellow—warning

The symbology used for the in-vehicle display types analyzed in this study was inspired by two signs from the MUTCD, the Yield Sign, and the Cross Road Symbol. According to the MUTCD, a Yield sign depicted in Figure 27, may be used on the approaches to a through street or highway where conditions are such that a full stop is not always required. The Cross Road Symbol shown in Figure 28 may be used in advance of an intersection to indicate the presence of an intersection and the possibility of turning or entering traffic.


**Figure 27: Yield Sign MUTCD R1-2**

**Figure 28: Cross Road Symbol MUTCD W2-1**

Base displays shown in Figure 29 were selected/designed due to subtitle variations that could potentially have an impact on a road user's comprehension of the in-vehicle display. The shape of Displays 1 and 3 were designed with the intention of looking similar to a yield sign; however, the apex of the triangle was inverted so as not to cause confusion to drivers. Additionally, the colored portions of the triangle were modified to create further distinction between these displays and a yield sign. The color used for Display 1 is the same as the background color of W2-1; the color used for Display 3 is green, and a similar shade to that used on a freeway/expressway guide sign according to the MUTCD.

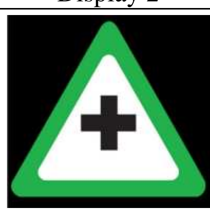
Display 2 is MUTCD W2-1; it was selected as a potential candidate because it is already in use on public roads so participants would likely already be familiar with its meaning. All displays tested in this study share the Cross Road symbol from MUTCD W2-1.

Display 1

Display 2

Display 3

**Figure 29: Base displays**

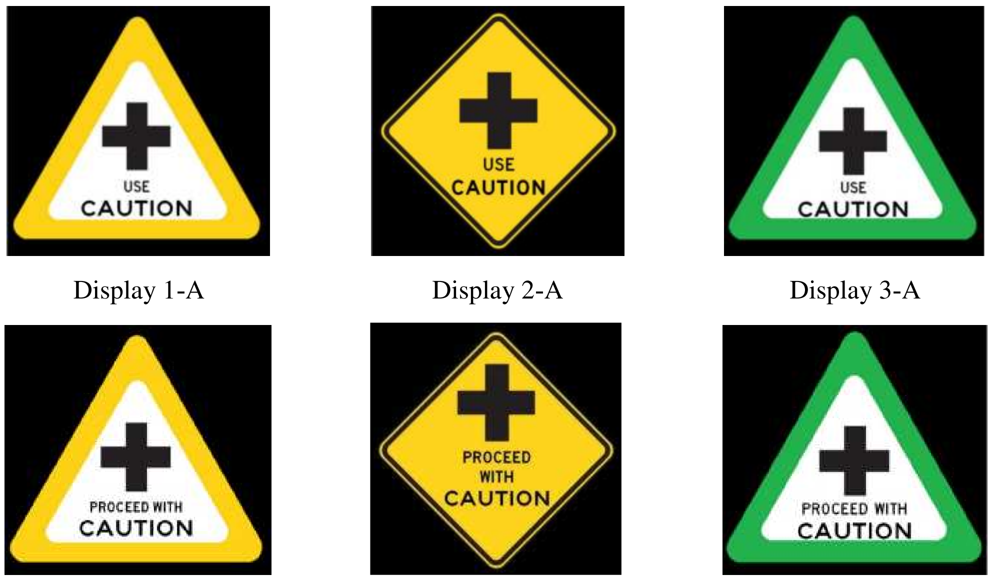
| Table 39: Comparison of MUTCD Signs and Base Experimental Displays | | | | |
|---|---|---|---|---|
| | **Shape** | **Border** | **Background** | **Legend** |
|   R1-2: Yield Sign | Inverted equilateral triangle | Red | White | Red |
|  W2-1: Cross Road | Diamond | Black | Yellow | Black |
|  Display 1 | Equilateral triangle | Yellow | White | Black |
|  Display 2 | Diamond | Black | Yellow | Black |
|  Display 3 | Equilateral triangle | Green | White | Black |

## Message Selection

The intended purpose of the display is to advise drivers that there is an intersection ahead and while they are legally permitted to proceed through, they should remain alert for drivers who may violate their expectations.

The Standard Alphabets for Traffic Control Devices were prepared by the Federal Highway Administration (FHWA) to create uniform signing of all by-ways open to public travel. FHWA series fonts are of the Sans-serif category and consist only of upper case letters (with the exception of E (M)).

To improve conspicuity of the in-vehicle display, FHWA Series E was the chosen font type for written messages.




Display 1-A, Display 2-A, Display 3-A

Display 1-B, Display 2-B, Display 3-B

**Figure 30: Alternative displays to base displays**

## Methodology

Ninety-four participants participated in the online survey; participants were randomly given one of three versions of the survey, asking the same questions about different displays. Thirty-three people completed version A; 36 completed Version B; 24 completed Version C. The screening criteria for participation in this study was participants must be 18 years of age or older and they must hold a valid United States driver's license.

Participant ages are shown in Table 40. Forty-seven percent of the participants who participated in the survey were male. Fifty-two percent of survey respondents worked in the transportation industry, this was expanded to mean transportation and materials moving occupations, transportation policy and safety research. The large portion of participants working in the transportation industry has been accounted for in the statistical analysis of the reported data in order to decrease the impact of those who might have a higher level of knowledge of traffic signs than the general public.

**Table 40. Participant Ages**

| Age Ranges | Distribution |
|---|---|
| 18 - 24 years old | 22% |
| 25 - 34 years old | 24% |
| 35 - 44 years old | 19% |
| 45 - 54 years old | 20% |
| 55 - 64 years old | 14% |
| 65 years or older | 1% |

**Table 41. Participant Years of Driving Experience**

| Driving Experience | Percent |
|---|---|
| Less than 1 year | 1% |
| 1 - 5 years | 7% |
| 6 - 10 years | 27% |
| 11 - 15 years | 8% |
| 16 - 20 years | 7% |
| Over 20 years | 49% |

## Recruiting and Informed Consent

Participants completed an online survey. The survey was estimated to last approximately 10 to 15 minutes. Participants were recruited via email listervs and social media outlets, in using this strategy, the research team hoped to obtain responses from a wide range of drivers, including those who work in the field and those naïve to connected vehicles and signage.

Participants were informed of the purpose of the survey as a connected vehicles in-vehicle display development tool prior to beginning questions pertaining to display development.

> *"Adaptable traffic signs have been proposed by some transportation professionals to improve travel time, reduce air pollution, and increase fuel economy. These signs have the capability to adjust to different traffic conditions, weather, or emergency vehicles. With the advent of Connected Vehicle (CV) technology, we now have the ability to have these signs change based on vehicle-to-infrastructure (V2I) communications. This technology would also allow traditional physical traffic signs to be replaced with electronic in-vehicle displays. This survey will help to select an in-vehicle display that will convey the appropriate message to drivers about what course of action they should take when approaching the intersection."*

Consent was implied upon the return of the completed survey.

## Experimental Design

The participants were randomly assigned either Version A, B, or C. All versions of the survey have identical sets of questions showing different base displays. Participants were shown question in increments so not influence to their responses to later questions.

- Open responses – "What does this display mean to you?"
- Multiple Choice of best representation – "Of the following options, which best fits with the shown display"
- Words rating – ranking the same display background with different words printed
- Shapes rating – ranking the same words printed on different display backgrounds
- Rank order – rank all displays shown over the course of the study

- Participant suggestions for improvement about their most preferred display

109 people responded to the survey, 8 participants were removed from the dataset due to incomplete surveys or ineligibility based on age.

# Results

## Open Response Questions

Participants were asked two open response questions after they provided some demographic information. The open response questions were the first display related questions presented so not to influence the participant's perception of the meaning of the display.

### Display Meaning

Participants were shown a base display, which varied depending on the version of the survey they received. The participants were asked, *"What does this display mean to you?"* the responses were grouped as "Correct", "Nearly Correct", and "Incorrect" based on the participant response in relation to the desired meaning of the display, which is, "there is an intersection ahead."

| | | |
|---|---|---|
|  |  |  |
| Version A<br>Base Display | Version B<br>Base Display | Version C<br>Base Display |

**Table 42. Meaning - Percent Open Ended Response**

| **Response Group** |  **Version A** |  **Version B** |  **Version C** |
|---|---|---|---|
| Incorrect | 25% | 0% | 62% |
| Generally correct | 18% | 3% | 27% |
| Correct | 57% | 97% | 12% |

### Display Action

The participants were then asked about their original base display, "*What action, if any, is required when you see this display?"* the responses were grouped as "Correct", "Nearly Correct", and

"Incorrect" based on the participant response in relation to the desired meaning of the display, which is, "proceed through the intersection with caution."

| Table 43. Action - Percent Open Ended Response | | | |
|---|---|---|---|
| **Response Group** |  **Version A** |  **Version B** |  **Version C** |
| Incorrect | 21% | 3% | 42% |
| Generally correct | 14% | 9% | 27% |
| Correct | 64% | 88% | 23% |

## Multiple-Choice Questions

The purpose of having multiple choice questions available was to give the participant limited options of the meaning of the display and to allow them to interpret the meaning of the display as they saw fit given the options available. This simulated a "within context" scenario.

### Multiple-Choice; Display Meaning

The participants were then asked, *"Select the choice that best represents the meaning of this display or is true about this display."* as it pertains to their base display.

| Table 44. Multiple Choice - Frequency | | | |
|---|---|---|---|
| **Response Group** |  **Version A** |  **Version B** |  **Version C** |
| There is an intersection ahead | 0% | 14% | 19% |
| There is an intersection ahead and you should use caution | 93% | 83% | 31% |
| There is a hospital ahead | 7% | 0% | 15% |
| There is an intersection ahead and you should proceed through | 0% | 3% | 35% |
| There is a church ahead | 0% | 0% | 0% |

- There is a church ahead
- There is an intersection ahead
- There is an intersection ahead and you should use caution
- There is a hospital ahead
- There is an intersection ahead and you should proceed through

## Preference

### Wording

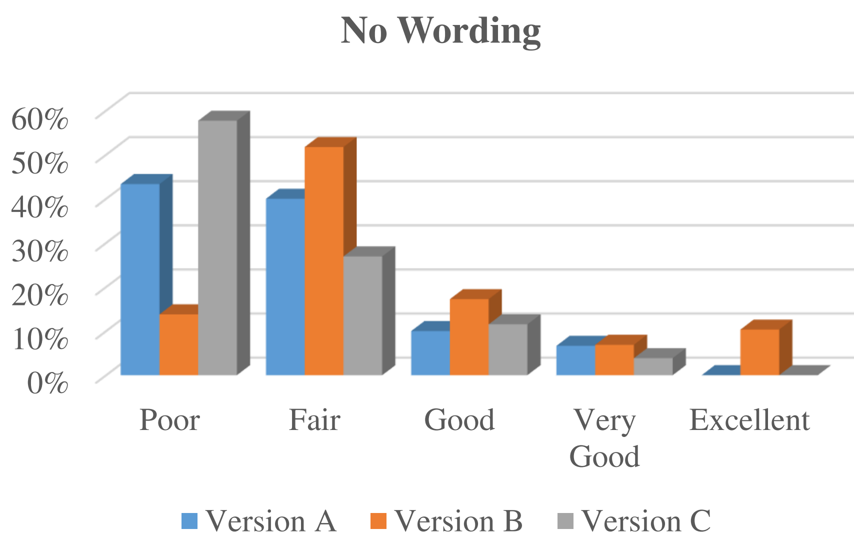
Survey participants were told, “The intended meaning of the display is to alert the driver that they should vigilantly driver through the oncoming intersection. For our purposes, consider vigilantly to mean in a watchful manner. Using that definition, for each presented display, selected the number that corresponds with how well you think the display describes its intended meaning.

**Table 45. No wording**

Version A

Version B

Version C




The responses to the displays from Version A, B, and C from the Likert Scale ranking question (Table 45) indicate that an absence of wording does not adequately convey the intended message. The responses to the “Use Caution” wording on different display types show that this particular wording offers some improvement in user understanding of the message, but perhaps is still not the best terminology for the display.

**Table 46. Use Caution**


Version A


Version B


Version C

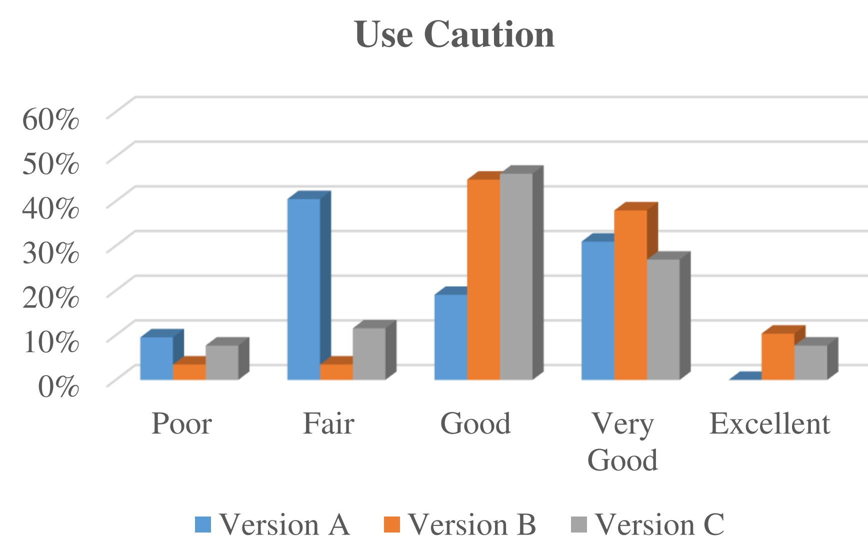
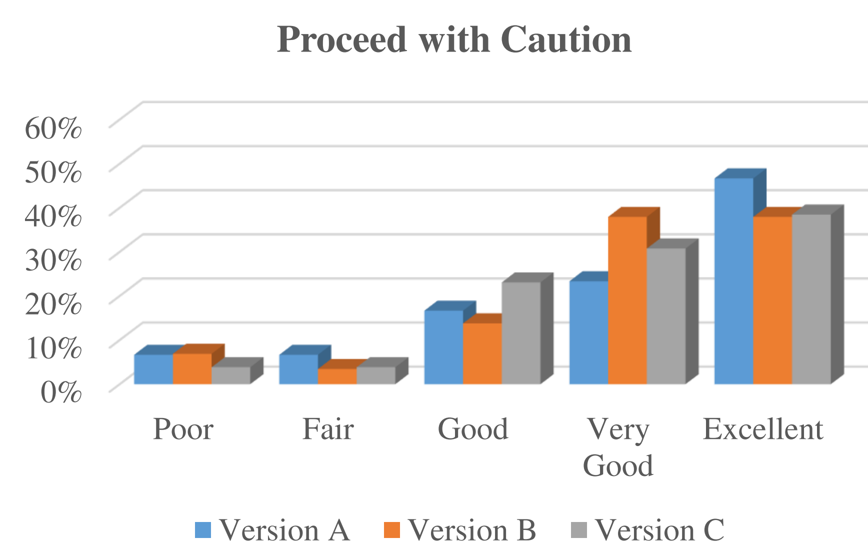



**Table 47. Proceed with Caution**


Version A


Version B


Version C



The results for the “Proceed with Caution” displays in Table  indicate that users found that this wording best conveyed the intended message. Users were partial to the yellow and lack triangular sign with “Proceed with Caution” written on the sign face.

### Shape

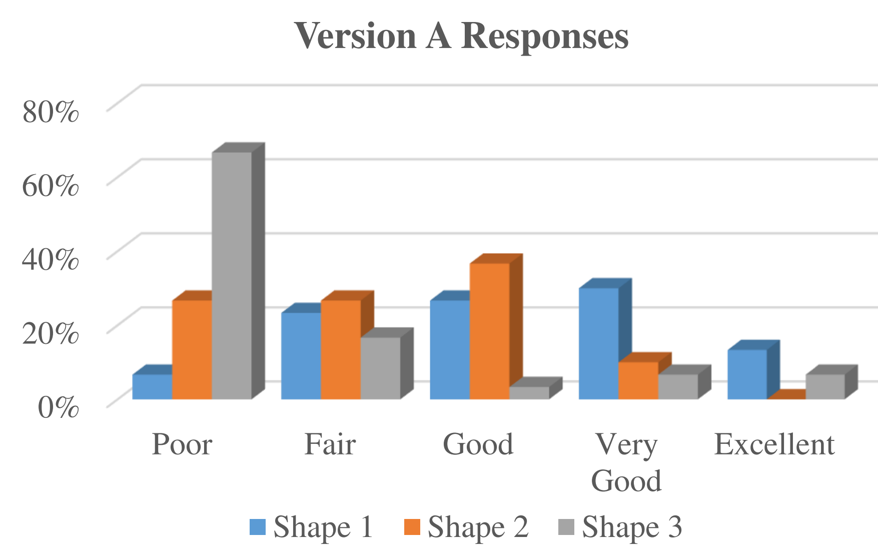
Participants seem to favor the Shape 1 when regardless of the wording, or lack thereof on the sign face. This is likely because the sign is in use on public roads, and they are familiar with it. However Table 48 - Table 50 show that participant preference of the sign changes much more dependent on which selection of wording is present on the sign. Table

**Table 48. Version A Responses**

Shape 1

Shape 2

Shape 3




As mentioned in the previous section, regardless of the sign’s shape or color, No Wording is generally perceived as less helpful, where “Proceed with Caution” is perceived as most helpful. The wording “Use Caution” does not appear to be descriptive enough for users to properly ascertain what the appropriate response is to the situation.

**Table 49. Version B Responses**

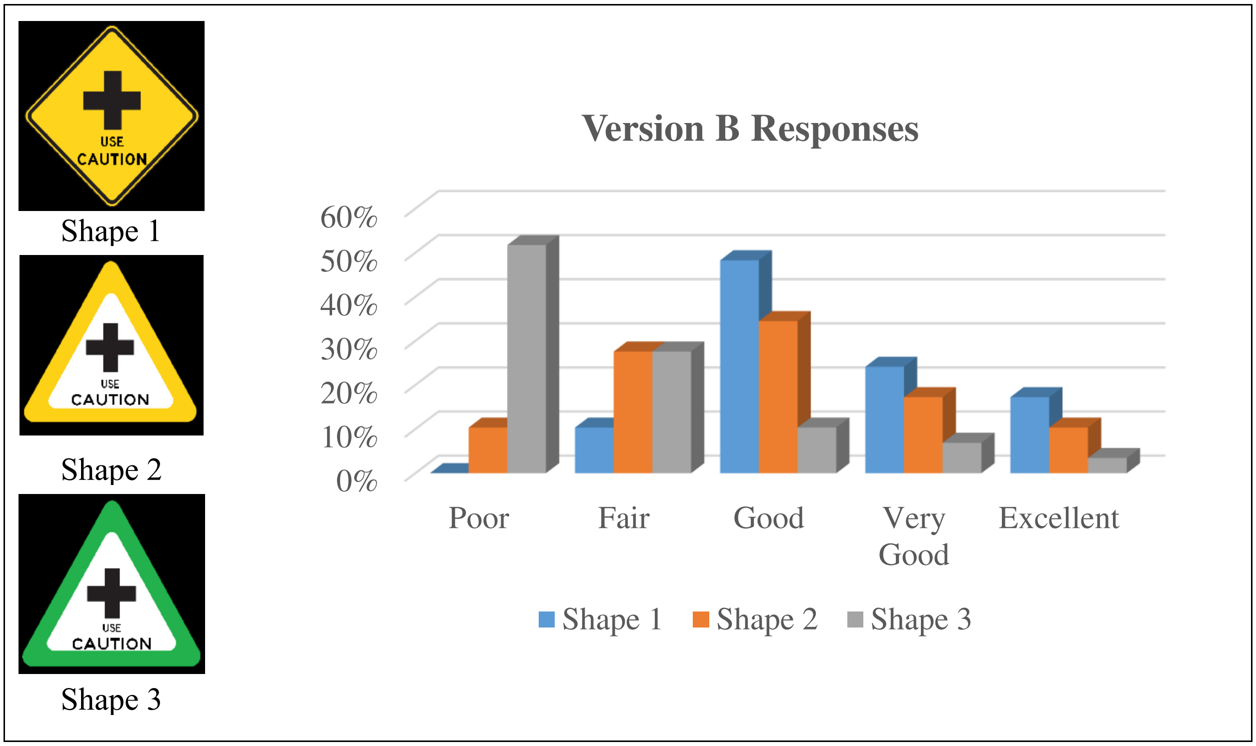
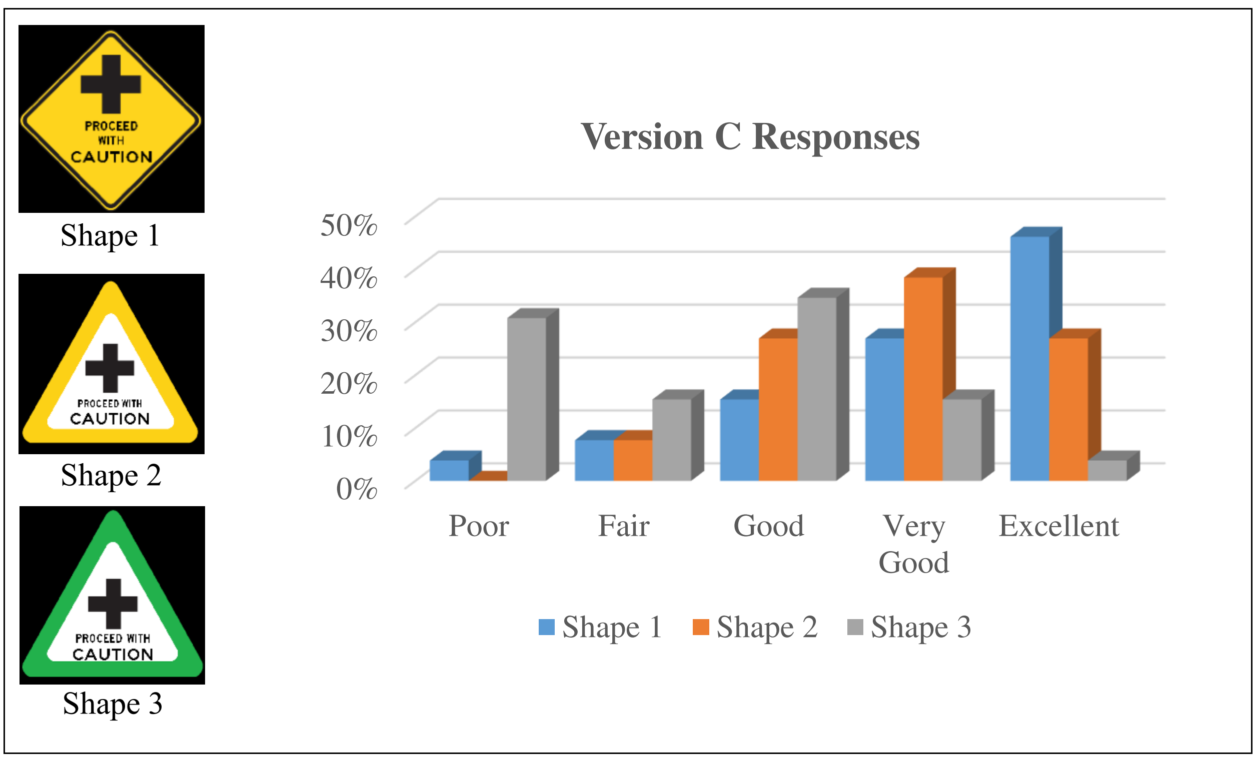



**Table 50. Version C Responses**



## Conclusions

The results from the survey indicate that the user's preference was more heavily biased based on the wording on the sign than any other factor. Participant's preferred the sign that they were most familiar with in all cases, however for the purpose of the display, it was deemed that it would not be appropriate to alter an existing roadway sign and risk negative safety implications. It was decided that the display shown in Figure 31 would be most appropriate for our purposes because of the color schemes used and the user preference of this wording "Proceed with Caution".


**Figure 31. Proceed with Caution Display**

The final in-vehicle display as used in the on road portion of the Adaptive Stop Display Study is shown below in Figure 32 and Figure 33.

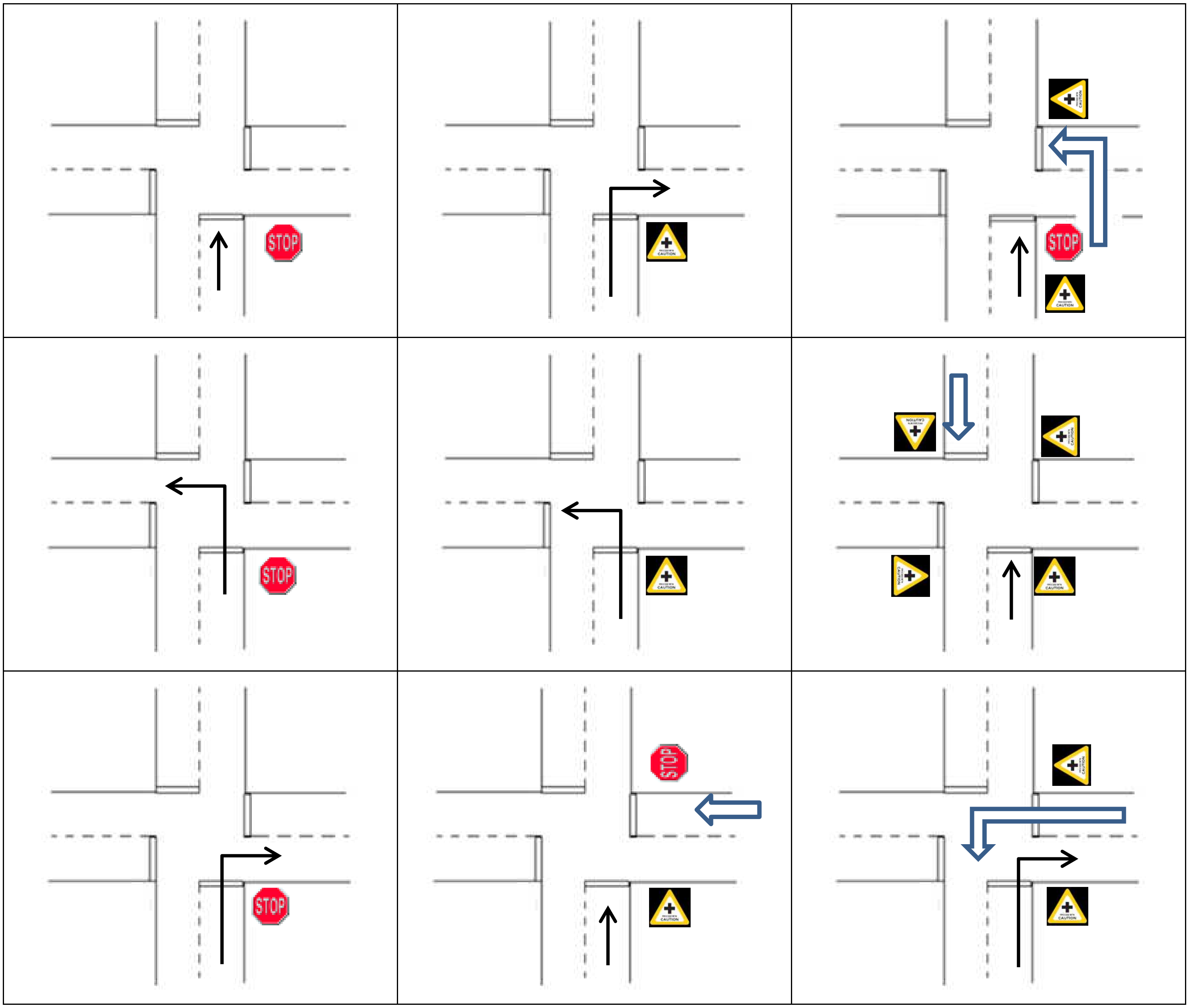
**Figure 32. Proceed with Caution on in-vehicle display**

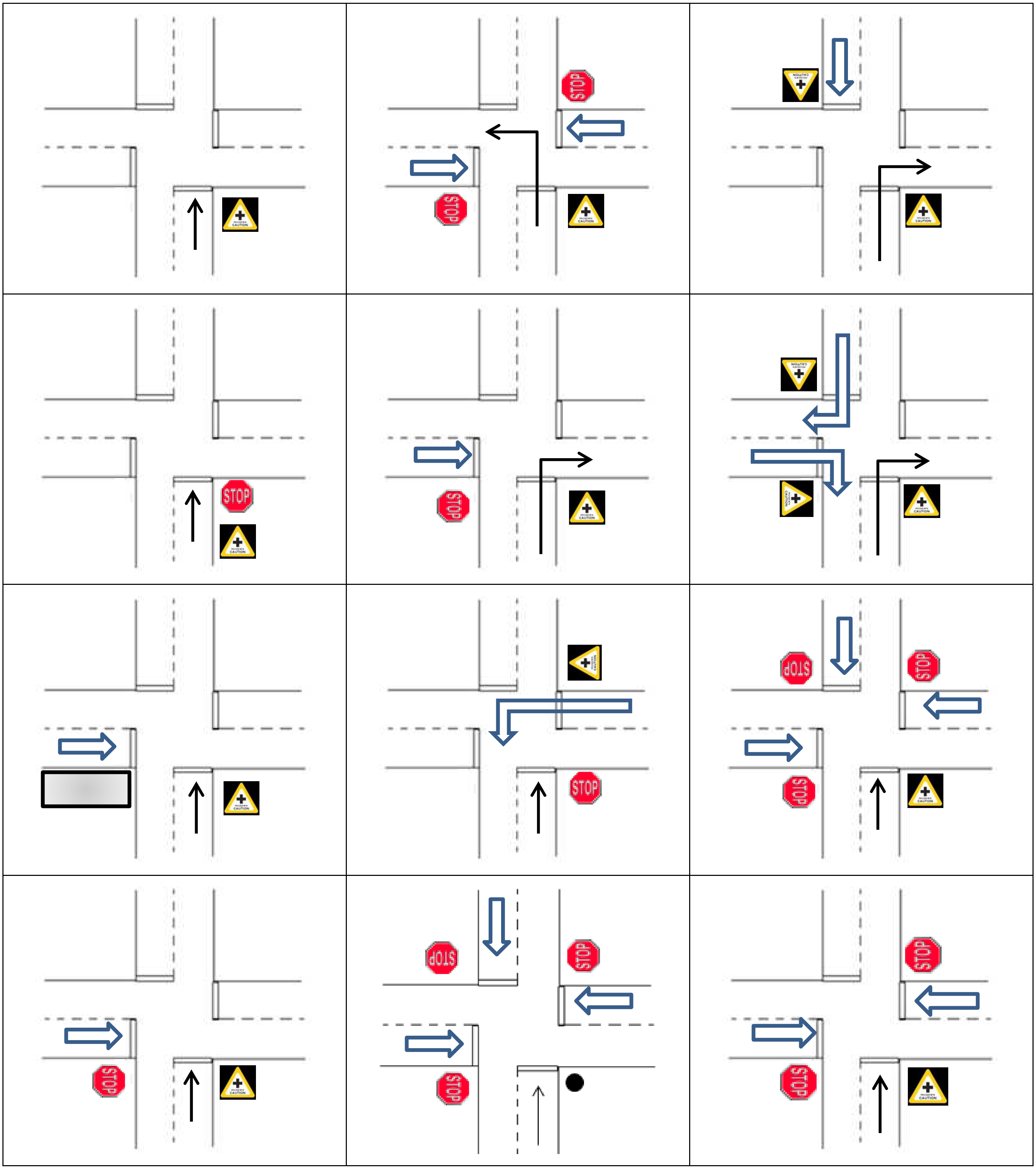

**Figure 33. Close up of Proceed with Caution on in-vehicle display**

## References

MUTCD, *Manual on Uniform Traffic Control Devices for Streets and Highways*. 2009, Federal Highway Administration: Washington, DC.

# APPENDIX T - STUDY SCENARIOS




STOP

# APPENDIX U - NUMBER AND COST OF STOP SIGNS CALCULATIONS

| Virginia Stop Sign Usage Estimates based on VDOT Study Data [34] | | |
|---|---|---|
| **Functional Class** | **# Stop Signs** | **Percentage** |
| Interstate | 1,320 | 0.7% |
| Primary | 2,338 | 1.2% |
| Secondary | 195,917 | 98.2% |
| *TOTAL:* | *199,575* | |

$$Proportion\ of\ VA\ Stop\ Signs\ by\ Functional\ Class = \frac{\#\ Stop\ Signs\ by\ Class}{Road\ Miles\ by\ Class}$$

| Virginia Highway System [35] | | | |
|---|---|---|---|
| **Functional Class** | **Road Length [mi.]** | **# Stop Signs** | **Per Mile** |
| Interstate | 1,118 | 1,320 | 1.2 |
| Primary | 8,111 | 2,339 | 0.3 |
| Secondary | 48,305 | 195,917 | 4.1 |

$$U.S.\ Stop\ Sign\ Estimate = US\ Road\ Length\ by\ Class \times Proportion\ of\ VA\ Stop\ Signs\ by\ Class$$

| United States Estimate of Stop Sign Usage [36] | | |
|---|---|---|
| **Functional Class** | **Road Length [mi.]** | **# Stop Signs** |
| Interstate | 47,432.2 | 56,003 |
| Primary | 415,903.1 | 119,936 |
| Secondary | 3,629,394.4 | 14,720,217 |
| | ***TOTAL:*** | ***14,896,156*** |