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In-Vehicle Decision Support to Reduce Crashes at Rural Thru-Stop Intersections

Final Report

Prepared by:

Caroline Hayes
Daniel Drew

Department of Mechanical Engineering
University of Minnesota

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16. Abstract (Limit: 250 words)

Purpose: Within the context of thru-stop intersections, investigate the feasibility and future promise of warning systems inside the vehicle, where interfaces are best placed, and what modalities are most effective (visual versus haptic). **Methods**: A driving simulator study was conducted to compare three decision support systems (DSSs): a dynamic traffic sign, a set of displays on the vehicle side mirrors, and a vibrating seat. Dependent variables included measurements of safe driving behavior, and a usability questionnaire. A follow-up focus group study was conducted to gain further feedback on the in-vehicle systems and on ideas for how to improve the systems. **Results**: The vibrating seat yielded significantly higher results than the dynamic traffic sign on two safety variables. No system clearly outperformed the others in terms of promoting safer driving behavior, nor did any improve driving performance compared to the control condition. The questionnaire and usability data showed that the dynamic traffic sign was most preferred, while the in-vehicle displays were most comprehended. Comments during the simulator studies suggested that participants wanted stronger advisory messages from the systems, and the Focus Group Study confirms this. **Conclusions**: In-vehicle DSSs appear to be feasible for the purposes of assisting drivers with navigating rural thru-stop intersections. No results of this study indicate that in-vehicle systems are an inherently poor means of presenting traffic gap information to the driver. Results indicate that a visual display would be easier to comprehend than a vibrotactile display when no training or explanation is provided.

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University of Minnesota
200 Transportation and Safety Building
511 Washington Ave. S.E.
Minneapolis, Minnesota 55455

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The authors would like to thank the University of Minnesota HumanFIRST program for use of its driving environment simulator, training in how to use it, and for setting up the software for the decision support systems tested in the studies. In particular, Michael Manser provided guidance designing the experiment and put HumanFIRST's resources at our disposal. Michael Rakauskas and Janet Creaser provided advice on statistical and experimental methods. Peter Easterlund programmed the decision support systems used in the studies and helped numerous times with issues related to learning to use the simulator. Last but not least, the work by HumanFIRST and the University of Minnesota Intelligent Vehicles Lab on the Cooperative Intersection Collision Avoidance Systems-Stop Sign Assist (CICAS-SAA) program provided the foundation for our study of in-vehicle decision support.

Daniel McGeehee, of the University of Iowa, reviewed the work plan and this report, and the authors thank him for his feedback.

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Nomenclature

CSAH 9—County State Aid Highway 9, also sometimes called County 9. CSAH 9 is a road in rural Minnesota. The intersection of CSAH 9 and Highway 52 is a rural thru-stop intersection.
DSS—Decision Support System
DSSs—Plural of DSS
Rural thru-stop intersection—An intersection where a minor road crosses a major highway, often a divided highway. Traffic on the highway is not controlled by any traffic signs or signals and thus does not stop. Traffic on the minor road is controlled by stop signs, and—if the highway is divided—by yield signs in the median.

Executive Summary

In 2002 there were 590 fatal traffic accidents in Minnesota, and an estimated 17 percent of these occurred at rural thru-stop intersections. A thru-stop intersection presents a challenge to a driver attempting to cross or enter the highway because he/she must stop at the stop sign and wait for a gap in highway traffic. If a driver misjudges whether a gap is large enough, a high-speed collision with highway traffic may result.

Previous studies have developed a prototype decision support sign (often referred to as the Icon Sign) that is aware of highway traffic and warns drivers when it is not safe to cross. The driving simulator studies described in this report tested two in-vehicle decision support systems (DSSs) and compared them to the Icon Sign. The first in-vehicle system, called the Side Mirror Displays, consisted of two visual displays located on the vehicle's side mirrors. The second system, called the Vibrotactile Seat, was a driver's seat with left and right vibrational pads.

No system clearly outperformed the others in terms of promoting safer driving behavior, nor did any improve driving performance compared to the control condition (in which no DSS was present). The questionnaire and usability data showed that the Icon Sign was most preferred, with 50 percent of participants rating it as their top choice. The Icon Sign may have been preferred because drivers are more accustomed to gaining information from traffic signs and signals than from other systems. The Side Mirror Displays and Vibrotactile Seat were preferred nearly equally, with each rated as top choice by 25 percent of participants. The Side Mirror Displays were comprehended by 83.3 percent of participants, the Icon Sign by 62.5 percent, and the Vibrotactile Seat by 58.3 percent. The high comprehension rate for the Side Mirror Displays may have been due to the display continuously changing, giving the driver more opportunities to interpret the displays and deduce what information the displays were providing.

In-vehicle DSSs appear to be feasible for the purposes of assisting drivers with navigating rural thru-stop intersections. No results of this study indicate that in-vehicle systems are an inherently poor means of presenting traffic gap information to the driver. The in-vehicle aspects of the Side Mirror Displays and Vibrotactile Seat are confounded with their individual designs, thus we cannot draw any strong, generalized conclusions about in-vehicle systems. However, because the Mirror Display and Vibrotactile Seat were not significantly different from the control condition, and because they were outperformed by the Icon Sign only in terms of preference, there do not appear to be any caveats for in-vehicle DSSs that make them an inherently poor choice. Results indicate that a visual display would be easier to comprehend than a vibrotactile display when no training or explanation is provided.

Also included in this report is the Focus Group Study, which was conducted to gain feedback on:

1. The DSSs tested in the previous simulator study (the Side Mirror Displays and the Vibrotactile Seat).
2. Ideas for improvements to the DSSs tested in the previous simulator study.
3. Ideas not tested in the previous simulator study due to time and resource limitations.

The Focus Group Study used participant small group discussions and paper prototypes of the DSSs to quickly get feedback in a setting where the participants could discuss their opinions and ideas could emerge from the group. Using paper prototypes of the DSSs instead of building the DSSs into a driving simulator had the downside that participants would not be able to see the DSS displays change in real time in response to changing traffic conditions. While seeing the

DSSs only on paper limited the participants' ability to evaluate them, it allowed more DSSs to be evaluated without expending the resources needed to create a driving simulation. The results from the driving simulator studies combined with results from the Focus Group Study suggest possible future revisions for the in-vehicle DSSs evaluated in these studies.

Comments during the simulator studies suggested that participants wanted stronger advisory messages for systems such as the Side Mirror Displays, and the Focus Group Study confirms this. This desire for clear advisory messages was a common theme throughout the participants' responses during the Focus Group Study. The Focus Group Study evaluated three potential modifications to the side mirror displays:

1. Extend the bar gauge to provide information about traffic as far as 11 s away.
2. Change the color of the display when traffic is within 7.5 s.
3. Change the icon on the display to a prohibitive symbol when traffic is within 7.5 s.

Participant comments on these were generally positive, they didn't seem to like the prohibitive symbols chosen by the researchers. They suggested using a red X, a circle with a slash, or a hand symbol (the same as is used at crosswalks).

Results from the simulator studies suggested that when using the Vibrotactile Seat, some participants had trouble distinguishing the left and right vibrational pads. In future work, the pads will need to be spaced far enough apart that almost all drivers can distinguish the two vibrations. Comments from the Focus Group Study suggested several other issues that should be addressed. Participants commented that the driver's posture might affect whether the driver could feel the pads vibrating. Future work should insure that the vibrational pads are of optimal size and location to be felt by the driver regardless of the driver's physical size or posture. Participants also commented that the Vibrotactile Seat could be drowned out by other vibrations, such as from a cell phone, form the vehicle's speakers, or from the vehicle's normal vibrations. Further work should investigate if a particular frequency and amplitude of pad vibration would be clearly discernable when these other sources of vibration are present.

Future studies should consider examining driver behavior both before and after an explanation of the DSSs is provided. This study and previous studies in the Cooperative Intersection Collision Avoidance Systems-Stop Sign Assist (CICAS-SSA) program have focused on designing intuitive systems that need no explanation. However, with the proper design and implementation of training programs, non-intuitive DSSs could be helpful as well. Such non-intuitive DSSs would have to be very helpful indeed for their added benefits to offset the added cost of training programs, but perhaps it is worth investigating nonetheless.

Chapter 1 discusses the motivation for the studies included in this report, the historical background of the work, and the scope of the studies. *Chapter 2 Pilot Study* and *Chapter 3 Larger Scale Study* describe simulator studies testing the three decision support systems (DSSs). Chapter 4 discusses the follow-up Focus Group Study, which examined possible improvements to the DSSs. Chapter 5 discusses the combined conclusions of all three studies.

Chapter 1. Introduction

Rural thru-stop intersections present a major challenge to drivers. At thru-stop intersections, a high-volume highway crosses a low-volume minor road; traffic on the highway never stops, while traffic on the minor road is controlled by a stop sign (see Figure 1-1 for an example sketch, or Figure 2-2 for an aerial photo). Drivers on the minor road must stop at the stop sign and wait for a gap in mainline (highway) traffic large enough to allow them time to cross or turn, and then accelerate from a stop to perform the maneuver. If a driver misjudges a gap to be safe when it is not, a collision may result. This misjudgment could arise from many causes ranging from difficulties in perceiving speed and distance of oncoming vehicles (Davis & Swenson, 2004), distractions from cell phones (Cooper and Zheng, 2002), or driver impatience (Tarek, Brown, & Navin, 1994).

To assist drivers to better recognize when gaps are unsafe, researchers in the CICAS-SSA program have developed and tested a dynamic road sign (which we will refer to as the Icon Sign) that provided information about approaching traffic, including warnings of unsafe traffic gaps (Creaser et al, 2008; Rakauskas, et al. 2009). In the work presented in this report, we explore whether the efficacy of such warnings can be improved by moving the warning system inside the vehicle, allowing different and possibly more convenient positioning of the a visual display so that drivers can see it more easily while also watching traffic, and making other warning modalities possible such as haptic and auditory warnings. Haptic warnings (delivered through vibrating devices) are of particular interest in our studies because they allow drivers to keep their eyes on the road while attending to warnings, and the literature suggests that they can result in faster reaction times than visual or auditory warnings in front-end collision avoidance (Ho, et al. 2004; 2005; 2006; Scott and Gray, 2007; 2008; Brown 2005.

We report on a series of studies aimed at addressing the research question: can a haptic warning system inside the vehicle provide more safety benefits at a rural thru-stop intersection than can a visual sign placed in the intersection? We asked this question so that we could determine whether it was worth while spending investing more time and energy in haptic warning interfaces; thus these studies are primarily formative in their goals. We explored the question by comparing the performance of drivers when using the CICAS-SSA Icon Sign (located in the intersection), with their performance when using a visual display mounted on the vehicle (the Side Mirror Display), and a haptic warning that conveys warning through vibrating pads in the driver's seat (the Vibrotactile seat). The studies included 1) a pilot study and 2) a larger-scale to compare the effectiveness of the three interfaces, and 3) a focus group study to explore possible ways to improve each of the top performing interfaces (the Vibrotactile Seat, followed by the Side Mirror Display).

The results show that the Vibrotactile seat resulted in significantly better safety margins (e.g. space between the vehicle entering the intersection and oncoming traffic) than the Icon Sign. However, none of the interfaces produced significantly better results than the control (no DSS), although the Vibrotactile seat came close. The focus group studies provided feedback as to how the interfaces might be improved; additional studies are underway to gain more insights into why the Vibrotactile seat produced superior performance than the other interfaces. Through these efforts, these we hope to provide DSSs that can increase driving safety and save lives.

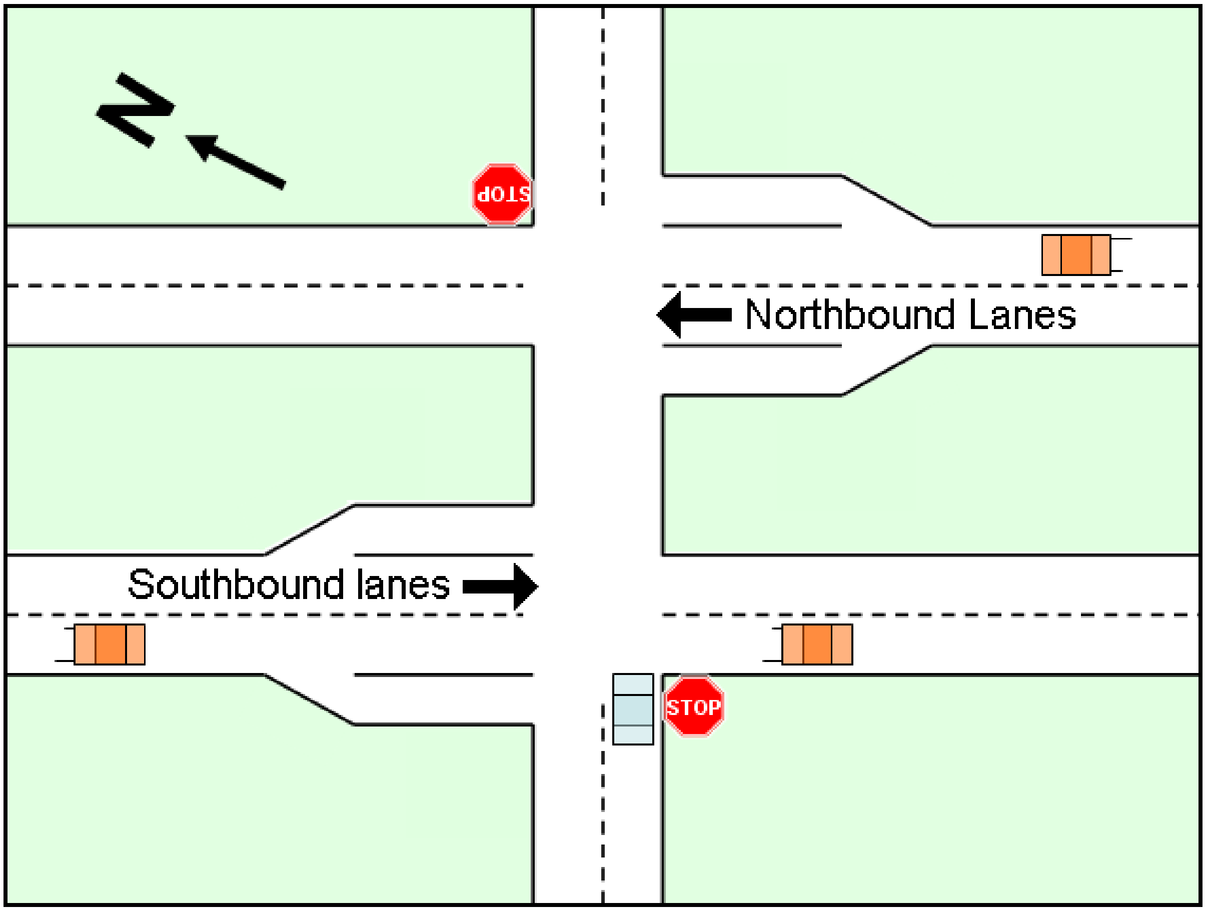


Figure 1-1: Sketch of the rural thru-stop intersection in Goodhue County, Minnesota. Adapted by permission of HumanFIRST program.

1.1 Crash Statistics

Intersection crashes account for over 45% of reported crashes, and result in approximately 21% of roadway fatalities each year in the United States (Federal Highway Administration [FHWA], 2004). Intersection crashes lead to approximately 1.5 million injuries/year, accounting for approximately 50% of all traffic injuries (Gorjestani, Menon, Cheng, and Shankwitz, 2008). Although rural intersection crashes are fewer in number than urban intersection crashes, they more often result in serious injuries or fatalities because of the high speeds involved on rural highways and expressways (FHWA, 2004). During 2002, over 22,000 fatal crashes occurred in rural areas in the United States, with most crashes involving speeds greater than 55 mph (88 kph) (National Highway Transportation Safety Administration [NHTSA], 2003). These fatal rural crashes accounted for 59% of the total number of fatal accidents for that year. Sixteen percent of fatal rural accidents occur at intersections (American Association of State Highway and Transportation Officials [AASHTO], 1997).

At the state level, there were 34,175 reported crashes on Minnesota rural two-lane roads between 2000 and 2002 (Preston & Storm, 2003). Over 32% (11,069) of these Minnesota crashes were intersection related. In 2002, there were 590 fatal crashes in Minnesota, with 425 fatal crashes occurring in rural areas. An estimated 98 of these fatal crashes occurred at rural thru-stop intersections, while an estimated 12 fatal crashes occurred at rural signalized intersections.

Figure 1-2 below presents a breakdown of fatal crashes in Minnesota for 2002 (Preston, Storm, Donath, & Shankwitz, 2004, p. 25).

It is this high rate of crashes and fatalities that has prompted research and development of decision support systems (DSSs) for thru-stop intersections.

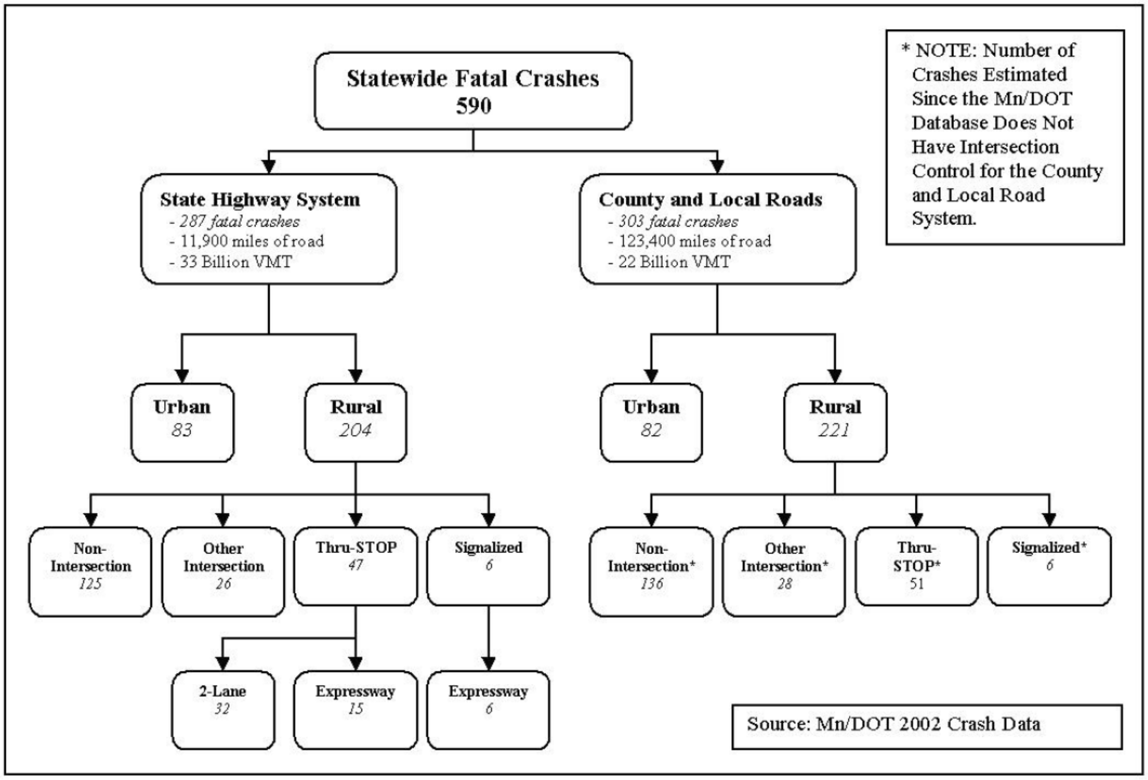


Figure 1-2: Breakdown of fatal crashes in Minnesota in year 2002 (Preston et al. 2004, p. 25, sponsored by MnDOT)

1.2 Test Intersection

The intersection used as a case study for previous work is Highway 52 and County State Aid Highway (CSAH) 9 in Goodhue County, Minnesota (a few miles south of Cannon Falls). This intersection was selected because it exhibited a higher than normal crash severity rate (Preston et al. 2004, p. 17). Research and development on decision support systems for rural intersections has used this intersection for on-road studies, modeled this intersection in driving simulator studies, and fitted this intersection with sensors to monitor traffic. The GPS coordinates are approximately 44 ° 23 ’ 57.980 4 ”, -92 ° 50 ’ 38.882 4 ” (44.399 439 ° N, -92.844 134 ° W). Figure 1-1 above shows a sketch of this intersection.

Visibility is limited for drivers approaching from the west (from the bottom of Figure 1-1). Due to the topography of the intersection, drivers stopped at the west stop sign are unable to see much of northbound traffic until they cross to the median (Laberge, Ward, & Rakauskas, 2003, p.26).

The intersection does not form an exact 90 degree angle; the angle is approximately 100 degrees. Drivers approaching on the minor road from either direction will be facing slightly away from traffic while at the stop sign and slightly towards traffic while in the median.

It is technologically feasible to install sensors at rural thru-stop intersections to detect approaching traffic, and the University of Minnesota Intelligent Vehicles Lab has done so at intersections in Minnesota, Wisconsin, and North Carolina (Gorjestani et al., 2008). Of the three, only the Minnesota intersection has been used for experiments, though all three have been used to collect information on traffic patterns and driver behavior. The interface design challenge is to determine how to present the sensor information to drivers in a useful form which results in the minor road drivers driving more safely. The drivers could potentially benefit from a decision support system (DSS) that can provide information for choosing safer gaps in traffic, thus reducing crashes, injuries, and fatalities. Previous work to develop such a DSS has been named the Cooperative Intersection Collision Avoidance Systems-Stop Sign Assist program, or CICAS-SSA.

The previous work of the CICAS-SSA program is discussed further in section *1.5 Previous Work of the CICAS-SSA Program* below. The following section discusses literature reviewed other than the CICAS-SSA program.

1.3 Literature Review on Age Factors and Unsafe Driving Behaviors

The literature on age has mixed findings. Some literature suggests that old and young drivers are at higher risk at rural thru-stop intersections. Bao and Boyle (2008) examined the performance of younger (18-25), middle-aged (35-55), and older (65-80) drivers at two-way stop-controlled intersections (both high- and low-crash intersections). Compared to middle-aged drivers, younger and older drivers were more likely to run stop signs and less likely to yield at medians. When approaching the high-crash intersection, middle-aged drivers also had significantly less brake differential time. Bao and Boyle (2009a) studied age-related differences in visual scanning at median-divided highway intersections. The three age groups were the same as in Bao and Boyle (2008). Younger and older drivers did not make use of their full visual scanning range compared to middle-aged drivers. In particular, older drivers sampled to the left and right less frequently. Older and younger drivers also checked the rearview mirror less frquently. Bao and Boyle (2009b) studied whether driver safety programs (DSPs) targeted towards older drivers had a positive influence on their driving behavior at rural expressway intersections. Drivers who had attended a DSP stopped earlier when approaching an intersection and were more likely to come to a complete stop. These drivers also made more head movements to check for traffic.

However, the results from Gorjestani et al. (2008) indicate that at rural thru-stop intersections, driver age (and gender) had no substantial effect on the time needed to cross mainline traffic. This may indicate behaviors found in younger and older drivers at stop-controlled intersections do not carry over to thru-stop intersections, or that the behaviors described above do not result in substantially reduced safety.

1.4 Literature Review on Decision Support Systems

This section discusses supporting literature for the DSSs used in the experiments described in this paper (not including the literature of the CICAS-SSA program). General literature is discussed first, and the remaining literature is split up by modality.

Adding a DSS has the potential to add to the driver's mental workload. If so, the added workload cost must be compared to the added benefit of the DSS. This issue increases in importance as more in-vehicle technologies are invented, increasing the potential for clutter or information overload in the driver's cockpit. Horrey and Wickens (2004) noted that "In-vehicle technologies (IVTs) create additional tasks for the driver. To the extent that these devices degrade driving performance, there will be safety concerns." They conducted a study on how a phone number side task affected driving performance, manipulating whether the side task was overlaid on the horizon, overlaid just below the horizon, near the midconsole, or presented auditorily. There was a driving performance decrement for the midconsole and auditory displays. Although this study dealt with a side task intended to distract instead of with DSSs intended to assist, it shows that adding a display that the driver must monitor can potentially impair driving performance.

As an example of the effects of distraction from devices (including devices meant to help drivers) Lee, Lee, and Boyle (2009) found that the added distractions slowed drivers' responses to cues intended to orient the driver's attention. They studied how a cognitively loading driver with non-driving tasks affected drivers' ability to respond to attentional cues, both endogenous and exogenous. In this simulator study, endogenous cues took the form of pedestrian crossing signs that predicted the location of pedestrians. The cognitive load was imposed using an auditory in-vehicle task meant to replicate newer in-vehicle technologies. The added cognitive load reduced the distracting effect of irrelevant exogenous cues (scene clutter in this case) but also delayed response to endogenous cues meant to orient the driver's attention. Thus, the added distraction slowed down the driver's response to cues meant to orient the driver's attention.

The issue of whether added DSSs will reduce performance or cause distraction applies to the aviation domain as well, and the driving domain can benefit from lessons learned there. Wickens, Helleberg, and Xu (2002) compared a visual traffic information display to auditorily receiving air traffic control instructions (the traditional method), and found that although the visual display pulled visual attention away from the outside world, it did not leave pilots vulnerable to missing traffic that was not shown on the display. A visual display warning at thru-stop intersections may have a similar effect or pulling the driver's attention away from the road. A modality other then visual may be more appropriate since they need to focus their visual resources on the road for safety. In the work presented in this report we compare the effectiveness of visual and non-visual displays for drivers.

Literature pertaining to in-vehicle DSSs in general will be discussed in this section.

The in-vehicle DSSs (the Side Mirror Displays and Vibrotactile Seat) were designed with the principle that they should provide prompt, continuous information that can be easily accessed while the driver is watching traffic. Support for this principle is described below.

Abe and Richardson (2004) conducted a simulator study in which participants followed a lead vehicle. A buzzer alarm sounded when the lead vehicle braked suddenly, and the alarm timing varied between early, middle, and late. Earlier alarms led to more timely responses to imminent collisions, and later alarms were trusted less than earlier alarms. In particular, trust was impaired if the alarm occurred after the driver had already started to brake. Abe and Richardson (2005) found that trust in more prompt alarms was higher than for less prompt alarms, regardless of whether the lead vehicle's deceleration was abrupt or gradual. In situations where the lead vehicle decelerated suddenly, the prompt alarms resulted in more timely and consistent braking responses than the less prompt alarms. In situations where the deceleration was gradual, more prompt alarms did not improve performance. Abe and Richardson (2006) found that participants perceived alarms to be late if the alarm occurred after the participant had already started braking. They concluded that trust in the system is decreased when alarms occur after braking.

The above studies suggest that DSSs should provide prompt information that gives drivers sufficient time to act We chose to design all of our DSS displays to provide warning information as soon as it arose (at least 7.5 seconds or more prior to possible collision).

1.4.1 Tactile Displays Literature

The studies described below support the notion that haptic warnings can be intuitively associated with direction and result in faster reaction times, especially for braking. Although the supporting studies typically involved reacting to sudden events rather than deciding when to act (drivers crossing an intersection would be deciding when to act), it is nonetheless preferable for drivers to be able to react quickly to the information provided by the DSS (e.g. braking quickly if the driver was about to enter unsafe traffic) and to act promptly before an availible gap passes.

De Vries, Van Erp, and Kiefer (2009) used a tactile chair to code eight different directions and demonstrated that directional information can be communicated tactilely. They also note that touch-based displays have shown favorable effects on navigation performance, situational awareness, and workload reduction for pilots (Van Erp et al., 2007; Van Erp, Groen, Bos, & Van Veen, 2006), astronauts (Van Erp & Van Veen, 2006), and speed boat drivers (Van Erp & Van Veen, 2005). Although drivers at rural thru-stop intersections have less complicated navigation tasks than, for example do pilots, driving does require situational awareness in a complex environment, thus reducing the driver's workload may make free up more cognitive resources to focus on watching for hazards and executing safe maneuvers.

Van Erp and Van Veen (2004) compared a vibrotactile navigation display (eight tactors mounted in a seat), a visual navigation display, and a multimodal navigation display in both normal and high workload conditions. The tactile display reduced the driver's workload more than the visual display, especially in the high workload condition. The multimodal display had the fastest reaction time. It was concluded that "a localized vibration or tap is an intuitive way to present direction information, and that employing the tactile channel may release other heavily loaded sensory channels, therefore potentially providing a major safety enhancement."

Fitch, Kiefer, Hankey, and Kleiner (2007) also used a haptic seat with eight-directional capability and tested both haptic and auditory alerts (and combinations of them) to indicate the direction of a crash threat. With the haptic systems (whether haptic-only or combined), drivers had better response times and more often localized the correct direction than for the purely auditory systems. Diederich and Colonius (2007) found that saccadic reaction time to the presentation of a visual target improved with the addition of a redundant tactile stimulus (redundant with the visual stimulus of the target). These studies suggest that a directional haptic system can direct the driver's attention towards dangerously close vehicles, and improve reaction time. (In this case the reaction is to not do something: restrain one's foot from the gas).

A series of experiments tested various warnings in front-to-rear-end collision situations, in which a lead vehicle decelerated suddenly or a following vehicle accelerated suddenly. Ho, Spence, and Tan (2005) compared auditory, visual, and vibrotactile warnings for this situation, and found drivers reacted significantly more rapidly and somewhat more accurately (direction-wise) to the vibrotactile cues. Ho, Tan, and Spence (2005) also suggested that the tactile sense is intuitively associated with direction. Participants responded more quickly when vibrotactile cues came from the same rather than the opposite direction as the critical driving events. Results from

Ho, Tan, and Spence (2006) actually contradicted those from Ho, Tan, and Spence (2005), showing that vibrotactile signals were not helpful in attentional cuing, but that vibrotactile signals may still help to prime the appropriate response. Results from Ho, Reed, and Spence (2006) showed faster braking responses and larger safety margins when the vibrotactile warning was present than when it was absent (the task was to brake to avoid a collision with a lead vehicle with disabled brake lights).

Lee, Hoffman, and Hayes (2004) compared auditory and haptic warnings in a lead vehicle braking situation. Though the modality had little effect on performance, drivers preferred the haptic warnings on several dimensions including trust, benefit to driving, and annoyance.

Lee, Stoner, and Marshall (2004) investigated how techniques from Ecological Interface Design could identify how to best convey driving-relating information through haptic interfaces, and their preliminary analysis suggested that "haptic interfaces are best suited to support skill and rule-based levels of control, which is precisely what is needed to support drivers."

In a driving study involving critical incidents relating to lateral and longitudinal control on rural roads, Martens and Van Winsum (2001) found that speech warnings were better suited to law enforcement issues, whereas tactile warnings were better suited to driver safety issues. The task of gap selection at thru-stop intersections would seem to be safety-critical enough to fall into the "safety issues" category.

Scott and Gray (2007) compared reaction times for auditory, visual, and tactile rear-end collision warnings, and found the tactile warning significantly outperformed the visual warning. Results from Scott and Gray (2008) were similar, with the tactile warnings having the shortest mean reaction time, which was significantly shorter than having no warning or having visual warnings.

Brown (2005) created a scenario in which a moving driver needed to brake suddenly at a stop light while being followed by another vehicle and found that "Participants receiving haptic warnings stopped at the intersection more often than those receiving auditory warnings". Although the CICAS-SSA program and the current study assume the biggest problem is gap selection rather than failure to stop at the intersection, these results suggest that haptic warnings can direct a driver's attention or prompt a braking response.

The above studies suggest that haptic warnings can be intuitively associated with direction and result in faster reaction times than either visual or auditory warnings in many situations.

1.4.2 Visual Displays Literature

Literature on visual displays indicated that the display should be positioned where the driver can easily monitor both the display and the approaching traffic.

In an evaluation of different locations for an in-vehicle visual display, Burnett's (2004) results imply that if a visual display is positioned closer to the driving scene, the driver will glance at the display for shorter periods of time, and thus look away from the road for shorter periods of time. This suggests that if the display is positioned closer to the driving scene, the driver can do a better job of monitoring the road because s/he will look away for only small amounts of time and thus stay better updated and more situational aware. This is also consistant with the principles of Minimizing Information Access Cost and the Proximity Compatibility principle (Wickens, Lee, Liu, & Becker, 2004, p. 189). Information access cost, in terms of time, is minimized when the DSS is placed in close proximity to the direction of gaze required by the task.

The above studies suggest that a visual display should be positioned where the driver can easily monitor both the display and the approaching traffic.

1.4.3 Auditory Displays Literature

The literature below on DSSs and auditory warnings modality was not tested during the current study for several reasons.

1. For timely completion of the experiment, the scope was limited to four conditions: control, Icon sign, and two in-vehicle DSSs.
2. Given available equipment it would have been more difficult to design the alert sound and integrate it into the simulator.
3. We assumed that outside of a laboratory, sounds inside the car such as radio, cell phones, passenger conversations, MP3 players, and from ambient noise may substantially interfere with auditory warnings.
4. The auditory DSS would need an intuitive prohibitive sound for communicating the system state (the state being "warning" or "caution"), and the process of designing an auditory icon (Belz, Winters, Robinson, & Casali, 1997, 1998) was beyond the scope of the study. It was hypothesized that a verbal alert repeated over and over again to describe the system state would be annoying (e.g. "warning, warning, warning…"). Gaver (1997) describes how it is possible to create unique and complex sounds, and refers to a methodology for designing informative alarms for civil aircraft (Patterson, 1982). However, it appears that such complex sounds would be more appropriate for expert users, not drivers who may have little practice with the DSS, and it is one of our goals to produce a DSS that could be used by the general public with little training.
5. The literature on in-vehicle DSSs and alarms did not indicate a clear advantage of the auditory modality over the visual and tactile modalities. This literature is described below.

Ho and Spence (2005) used a car horn sound or a verbal warning to indicate the sudden deceleration of a lead car or the sudden approach of a following car. Gray (2011) studied increasing intensity (looming) auditory warnings in rear-end collision situations, comparing looming warnings to nonlooming warnings. He concluded that "Looming auditory warnings produce the best combination of response speed and accuracy". Although these alerts were useful for discrete events, they would not necessarily be useful for a continuous alert that shows the system state. Drivers may have to wait a while (e.g. one minute) for a gap in traffic, so a continuous alarm buzzer or a continuously repeated verbal message could become aggravating. In the case of looming warnings, such warnings would be absolute measures of time-to-arrival, and for this study relative measures were favored for reasons explained in *3.2.2.3.2.1.Reasoning Behind Side Mirror Displays* below.

In Fitch et al, (2007), haptic systems were better than auditory systems for alerting drivers to direction of a crash threat, and resulted in better response times. In Lee, Hoffman, and Hayes (2004), the drivers preferred haptic warnings over auditory warnings, though the modality itself had little effect on performance. Martens and Van Winsum (2001) found that speech warnings were better suited to law enforcement issues, whereas tactile warnings were better suited to driver safety issues.

Deatherage (1972) (cited in Sanders and McCormick, 1993) indicated that auditory alarms are ideal for messages that are simple, short, will not be referred to later, deal with events in time, and call for immediate action, while visual systems are appropriate for messages that deal with locations in space. Although the intersection navigation DSSs possess all of these traits, their primary function is to describe the locations of approaching vehicles, thus a visual DSS appears more appropriate.

The above studies do not show a clear advantage of auditory systems over visual and tactile systems.

1.5 Previous Work of the CICAS-SSA Program

The CICAS-SSA program followed several principles, which are described in Gorjestani et al. (2008).

1. First Principle: The system assists drivers to recognize and properly respond to unsafe gap conditions. Previous research has shown that in 57% of crashes at rural thru-stop intersections in Minnesota, the driver stopped before entering the intersection. Thus, the problem is not failure to recognize the intersection but failure to perceive gaps and judge the safety of gaps (Preston & Storm, 2003). Furthermore, gap acceptance problems contribute significantly to crashes at such intersections, regardless of sight distance limitations (Chovan, Tijerina, Pierowicz, & Hendricks, 1994; Najm, Koopmann, & Smith, 2001; Preston et al., 2004). Efforts to increase visibility, such as larger stop signs, flashers, and improved pavement markings, did not improve crash rates at such intersections.
2. Second Principle: To lessen liability issues, the system does not indicate to a driver when to go; it only indicates when it is unsafe to proceed.
3. Third Principle: The system does not stop traffic on the main road. Due to high traffic volumes on the main road and the need to maintain throughput and avoid congestion, the system should not interfere with mainline traffic. The addition of traffic signals at such intersections has resulted in fewer right-angle crashes but more rear-end crashes (Gorjestani et al., 2008, p. 1-2).

Gorjestani et al. (2008) summarize how the alert algorithm for the DSS was designed. The DSSs enter a caution state when a gap in traffic is in the 7.5 s to 11 s time-to-collision range and a warning state when a gap is 7.5 s or less. Sensors at the intersections in Minnesota, Wisconsin, and North Carolina have gathered data on the sizes of the gaps in traffic that drivers have rejected. A value of 6.5 s represents the average weighted 80th percentile gap rejection threshold for the test intersections in Minnesota and Wisconsin. The 80th percentile gap rejection for the North Carolina test intersection is 6.34 s (thresholds explained in Gorjestani et al., 2008). Assuming it takes 1 s to recognize and comprehend the DSSs, the threshold rises to 7.5 s. Kittelson and Vandehey (1991) showed that all gaps larger than 12 s are accepted, and results from Gorjestani et al. (2008) confirmed this. This was reduced by 1 s to bring the caution threshold into the range in which drivers sometimes reject a gap. To summarize, the warning threshold was 7.5 s and the caution threshold was 11 s.

Originally, it was a goal of the researchers to make CICAS-SSA “cooperative,” meaning the system would adapt its alerts based on information about vehicle size and driver characteristics (Gorjestani et al., 2008; Laberge, Creaser, Rakauskas, & Ward, 2006). However, the results from Gorjestani et al. (2008) indicated no differences in gap rejection based on vehicle size, and that driver age and gender had no substantial effect on the time needed to cross mainline traffic. Thus, creating a cooperative system is no longer a goal for the program.

Laberge et al. (2006) describe several types of gap acceptance problems that lead to crashes include:

1. Failure to detect approaching vehicles that make up a gap.
2. Failure to accurately perceive or estimate the size of the gap.
3. Failure to accurately judge a gap as safe enough to enter.

Thus, the information considered important for presentation to the driver includes:

1. Showing the presence of gaps (or perhaps the presence of major road vehicles).
2. Indicating the size of available gaps.
3. Judging the safety of available gaps.

Previous work has also experimented with indicating the speed, distance, or arrival time of major road vehicles (Creaser, Rakauskas, Ward, Laberge, & Donath, 2007).

The DSSs used in the experiments describe in this report focus primarily on providing information to assist in 3) judging the safety of available gaps. The DSSs do so by providing warnings when the current gap is unsafe. We did not focus on showing gaps or indicating the size of gaps which might be interpreted by drivers as recommending particular gaps as safe which may violate the Second Principle above: the system should not indicate when to go because of liability.

1.6 Icon Sign Description

The Icon Sign is the name for the roadside sign that has been developed in previous work in the CICAS-SSA program. The Icon Sign has been tested both in simulator studies (Creaser, Manser, & Rakauskas, 2008) and on-road studies (Rakauskas, Manser, & Graving, 2009). Though the Icon Sign conveys alert and warning messages, it is not intended to modify traffic laws, thus acting against the Icon Sign is not illegal in and of itself. Describing the Icon Sign requires describing both its display features and the locations where it is placed. Since the locations affect the display features, first the locations will be explained, and then the various display features.

Figure 1-3 below shows how four Icon Signs would be placed at an intersection. A driver approaching from the bottom of Figure 1-3 and stopped at the stop sign will see two Icon Signs facing him/her: one to the driver's left in the median (Sign 1) and one to the driver's right on the far shoulder of the intersection (Sign 2). While at the stop sign, the driver would watch Sign 1 to the left. Once in the median, the driver would watch Sign 2 on the far shoulder. Sign 3 on the near shoulder and Sign 4 to the right in the median would be facing away from the driver and could only be used if approaching from the opposite direction (i.e. from the top of Figure 1-3).

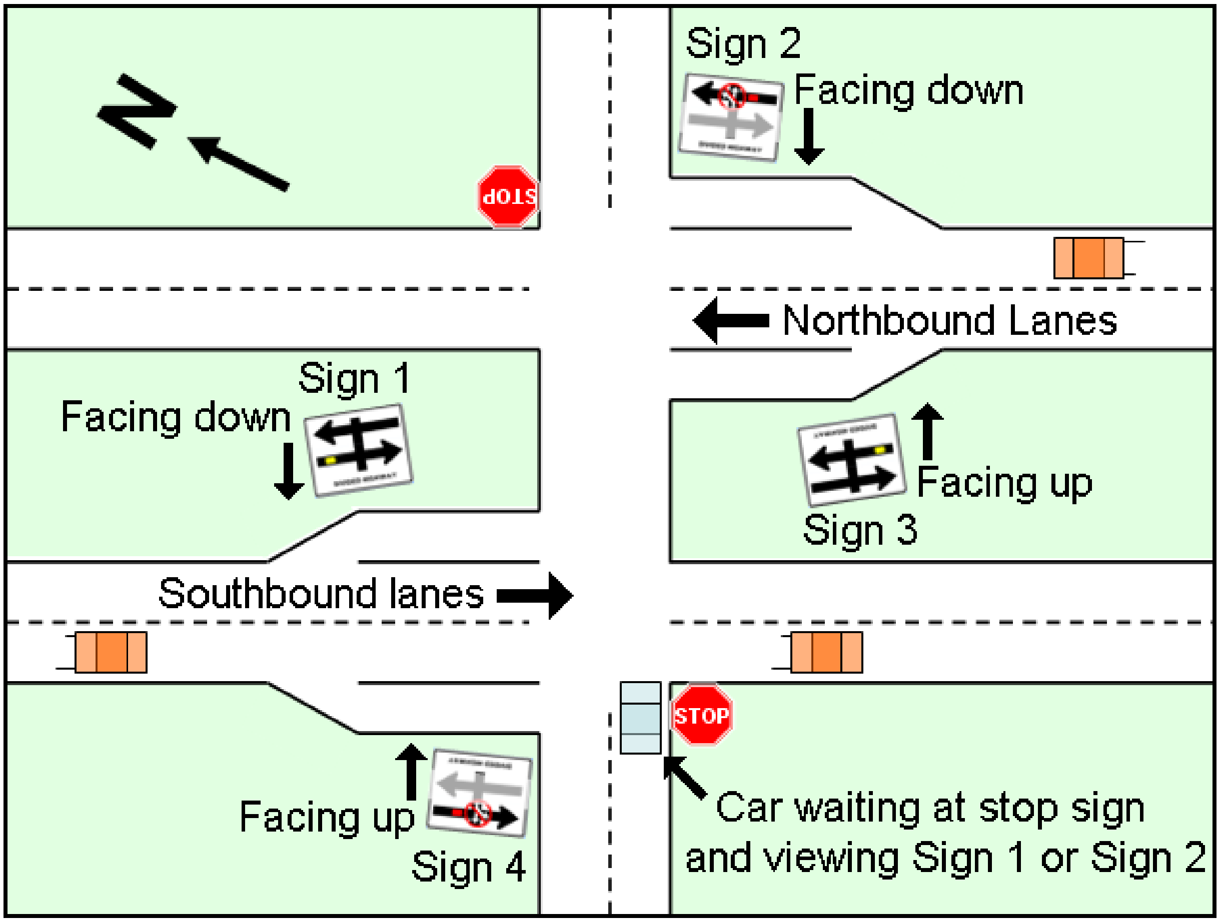


Figure 1-3: Sketch of the Minnesota test intersection with icon signs present. Adapted by permission of HumanFIRST program.

Figure 1-4 below shows a photograph of an instrumented vehicle (from the on-road study in Rakauskas et al., 2009) driving through Highway 52 and CSAH 9 with the Icon Signs present. The vehicle is at the stop sign and only the Icon Sign to the left in the median is visible in the photograph.

Figure 1-4: Photograph of the icon sign during an on-road study (specifically, during the study described in Rakauskas et al. 2009). Reproduced by permission of HumanFIRST program.

All four Icon Signs at an intersection have the same display features. The Icon Sign resembles a large Divided Highway sign with additional symbols. Red or yellow rectangles show when traffic falls into the warning or caution thresholds (7.5 s and 11 s, respectively), and a circle with a slash advises the driver to wait if traffic is too close. The bottom half of the sign represents the two lanes of traffic nearer to the stop sign, and the top half represents the two lanes farther from the stop sign. Figure 1-5 below illustrates the features of the Icon Sign, and Table 1-1 below shows several possible states of the Icon sign. Not all display states are shown in Table 1-1. The top and bottom portions of the sign operate independently, and each portion can display a warning, a caution, or no alert. However, the signs in the median (Sign 1 and Sign 3) never show a caution state for the farther lanes (i.e. the top halves of the signs) and in place of this caution state is a warning state with the far rectangle filled in red instead of yellow. This is to account for the time the driver would need to cross to the median, and an example is shown in Figure 1-6 below.

As shown in Figure 1-3, the lower halves of the Icon Signs located on the shoulders (Sign 2 and Sign 4) are slightly faded. This is because it is assumed the driver will typically use these signs only after crossing to the median, at which point the bottom halves of the signs will refer to traffic in lanes the driver has already crossed. By using the same design for both the median sign (Sign 1) and the far shoulder sign (Sign 2), the driver does not have to learn to use two different displays. Fading out the lower portion of the far shoulder sign (Sign2) allows the driver to focus on the appropriate portion of the sign while still providing context (Creaser et al., 2007, p. 214).

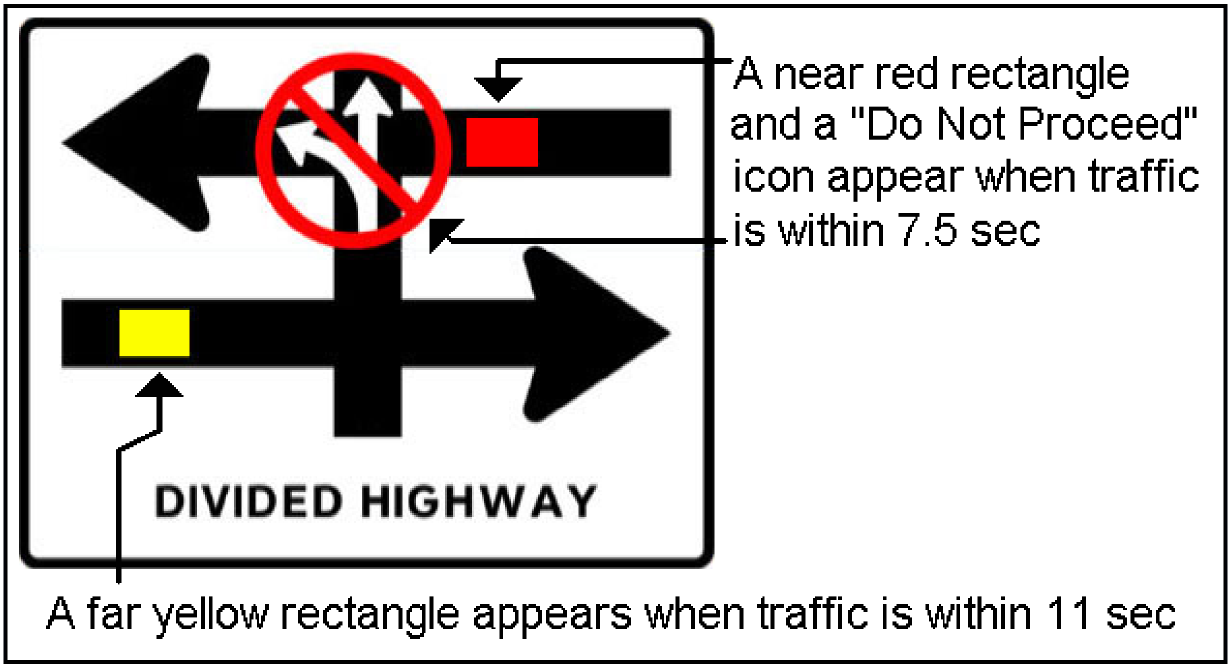
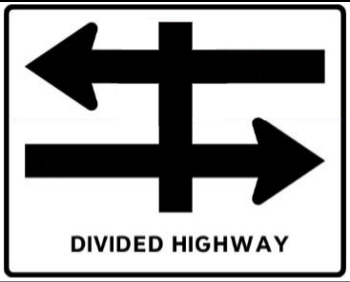
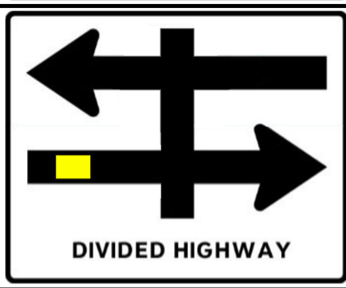


Figure 1-5: Features of the icon sign explained. Adapted by permission of HumanFIRST program.

Table 1-1: Example states of the icon sign. Adapted by permission of HumanFIRST program.

Example display states	What Each State Means
	If at the stop sign or median, you may be able to cross or turn; vehicles are farther than 11 s away in both the near lanes (approaching from left) and far lanes (approaching from right).
	If at the stop sign, you may be able to proceed to the median or make a right turn, but use caution; vehicles are between 7.5 s and 11 s away in the near lanes (approaching from the left). If in the median, you may be able to cross or turn left; vehicles are more than 11 s away in the far lanes (approaching from the right).
	If at the stop sign, do not enter the intersection; vehicles are less than 7.5 s away in the near lanes (approaching from the left). If in the median, you may be able to cross or turn left; vehicles are more than 11 s away in the far lanes (approaching from the right).
	If at the stop sign, you may be able to turn right or cross to the median; vehicles are more than 11 s away in the near lanes (approaching from the left). If in the median, do not proceed; vehicles are closer than 7.5 s in the far lanes (approaching from the right).
	If at the stop sign or median, do not proceed; vehicles are closer than 7.5 s in both the near lanes (approaching from left) and far lanes (approaching from right).

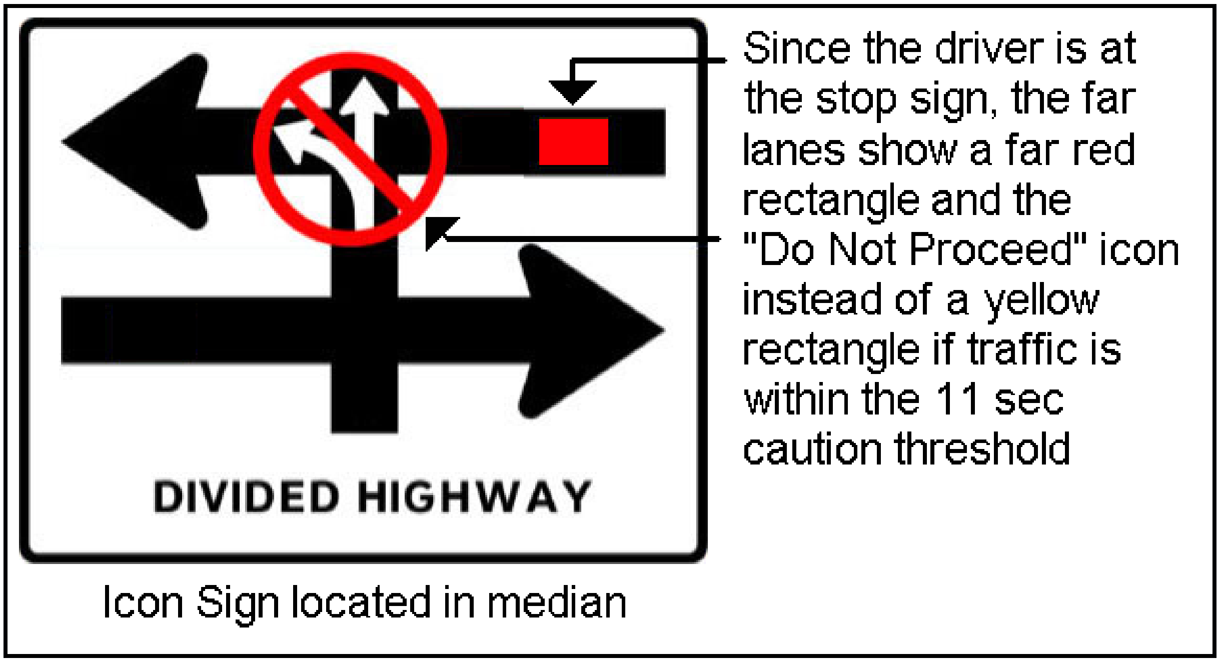


Figure 1-6: A median icon sign will not show a caution state for the far lanes. Adapted by permission of HumanFIRST program.

1.7 In-Vehicle Decision Support: The Focus of This Report

Prior to the current study, the HumanFIRST Program conducted driving simulator and on-road studies to test various DSS designs for CICAS-SSA, all of which have been some form of a roadside sign that changes appearance based on traffic conditions (Creaser et al., 2008; Creaser et al., 2007; Gorjestani et al. 2008; Rakauskas et al., 2009). However, it is possible to transmit the intersection sensor data to a system inside the driver's vehicle instead of (or perhaps in addition) to a roadside sign. In the CICAS-SSA program, there has been little testing of in-vehicle DSSs prior to the current study.

An in-vehicle DSS would have the disadvantage of not necessarily being available to every driver, while a roadside sign DSS would be available to everyone. The cost of installing a DSS in the vehicle of every driver who might cross a rural intersection could be greater than the cost of installing Icon Signs at every rural intersection. Whether an in-vehicle DSS would be worth the cost depends partially on the effectiveness of the system. In-vehicle DSSs could potentially utilize more sensory modalities than roadside sign DSSs. Compared to a roadside sign, a visual display located inside the vehicle has more options for where it can be located within the driver's field of view, while the roadside sign is restricted to being placed in the median or by the side of the road.

Research questions:

1. What sorts of information are useful to a driver navigating a rural thru-stop intersection?
2. Is there potential for in-vehicle decision support systems to be helpful for navigating rural thru-stop intersections? If so, what sort of in-vehicle decision support system would be best? How does it compare to the Icon Sign in terms of performance and understandability?

The goals of the studies described in this report are to:

1. Examine the utility of in-vehicle DSSs with respect to driver comprehension and safe driving behaviors using various display modalities.
2. Compare the in-vehicle DSSs to the Icon Sign.

Chapter 2. Pilot Study

The purpose of the pilot study was to identify any problems or issues in the basic experimental design that might need to be corrected before running many subjects in a larger study. The pilot study was a simplified version of the planned larger study which used only 3 conditions: control (no DSS), Icon Sign and Vibrotactile Seat. It also provided an opportunity to get feedback from a small number of participants on the usability of the Vibrotactile Seat in a the simulator context. Wickens et al. (2004, p. 409) state that usability studies tend to see diminishing returns after five or six participants, so we planned for a maximum of six participants.

Hypotheses:

1. Use of a DSS will help drivers to reject unsafe gaps in traffic when entering the highway, and increase safe driving behaviors, which we measured by: accepted gap size (bigger gaps are safer), safety margin (i.e. space between the driver and approaching highway traffic when entering the highway), and number of (simulated) crashes.
2. Use of a DSS may change driver workload. We used the NASA TLX inventory to measure workload including the user's perceptions of mental demand, physical demand, time performance, effort, and frustration (which the user reports on a Likert scale as part of a questionnaire administered after each trial). Sometimes a DSS reduces the drivers workload by sharing the burden for some of the user's tasks (for example by monitoring traffic for safe gaps), but it may also increase workload by adding the task of monitoring the DSS on top of the users' existing tasks. However, a DSS may increase workload even as it assists the driver, and whether that is good or bad ultimately depends on the overall balance of costs and benefits associated with the DSS.
3. Use of the haptic DSS (vibrotactile seat) will result in larger safety margins than use of the visual DSS (Icon Sign).

2.1 Design Considerations for the Vibrotactile Seat

We have already described the ICON sign, which was designed and tested by other researchers, and use as a baseline for comparison in our studies. In this section we describe the design parameters for the Vibrotactile seat, the options we considered, and the criteria and rationale behind our choices.

2.1.1 Design Parameters

Design parameters for the haptic DSS interface which included:

- Location of the device within the vehicle,
- Directionality: should it orient the user towards the hazard?
- Activation criteria, when should the device start providing warnings?

Since the literature indicates that warning devices can direct drivers' attention towards hazards faster and improve reaction time, we decided that the haptic DSS interface should indicate the direction of the oncoming traffic (Hankey, and Kleiner, 2007; Diederich and Colonius, 2007).

Since warnings concerned traffic coming from both the left and right, we wanted to select a device that could somehow indicate two directions: left and right.

2.1.2 Options Considered

A number of options were considered for the location of the haptic DSS interface, including vibrating pads in the:

- Driver's seat bottom,
- Driver's seat back,
- The steering wheel,
- Floor mat on the driver's side,
- Velcro wrist bands worn on the left and right wrists,
- Brake pedal,
- Gas pedal.

2.1.3 Selection Criteria and Rationale

The device must:

- Be in contact with the user when the decision to enter the intersection is made,
- Supply directionality information, orienting the user towards the hazard,

Additionally, given multiple choices that were otherwise equal, we considered:

- Ease implementation,
- The potential to annoy the driver (motivating them to turn-off or otherwise refuse to use the device).

These criteria eliminated most of the options above. The seat back was eliminated because the driver may lean forward when stopped at an intersection to see traffic better, and no longer be in contact with the seat back. A vibrating gas or brake pedal would not be able to provide directionality information, furthermore, we later found during pilot testing that they are necessarily be in contact with either when they make the decision to proceed. Similarly, it may be hard to indicate direction of the hazard with a floor mat because the driver's right foot may be on the brake rather than the floor. Two pads in the seat belt might be possible, but the left pad would be high on the shoulder, and the right pad low on the hip, which might be confusing. Furthermore, if the driver leans forward, then the pads would shift position as the seat belt lengthens and might no longer be positioned on the driver's left and right. This left the seat belt, seat bottom and wrist bands. We felt that drivers would probably not be willing to put on and wear wrist bands. Pads on the steering wheel were a possibility if each covered half the steering wheel (rather than just a small area). However not all drivers position both hands on the left and right of wheel. Some place a single hand on the top, or bottom, particularly when stopped. This left the seat bottom as the only viable option; drivers are always in contact with it and direction can be indicated by having a left pad and a right pad.

We decided that all DSS in our studies (visual or haptic) would be activated when the driver was within 110ft (33 m) of the intersection. Additionally, we decided that the haptic DSS should not be activated until the driver had taken his or her foot from the brake. Thus, the seat would vibrate if the driver was close to the intersection *and* had started to move his or her foot towards the gas *and* oncoming traffic in either lane was dangerously close. We did this because of a concern that if traffic were heavy with few gaps, the continuous vibration produced as the driver waits at the intersection might become annoying. (The pilot tests proved, however, this last design decision to be misguided because to caused warnings to be delivered too late – after drivers had already made the decision to proceed, but we will discuss this further in the results).

2.2 Experimental Methods

The goals of the Pilot Study were to:

1. Obtain feedback on the Vibrotactile Seat.
2. Compare a visual DSS (the Icon Sign) with a tactile DSS (the Vibrotactile Seat).
3. Compare the two DDSs to a control condition (e.g. no DSS).

2.2.1 Participants

A total of four subjects participated, all of whom were male graduate students (approximately ages 24-28) at the University of Minnesota, Twin Cities. Participants were recruited by email. Participants at higher risk for simulator-induced discomfort were screened out using HumanFIRST's simulator sickness screening questionnaire (see Appendix I Simulator Sickness Screening Questionnaire, see also Creaser et al., 2007, p. 214 for more details on the construction of this questionnaire). Participants were not compensated for their time. Use of human subjects was approved by the University of Minnesota Institutional Research Board.

2.2.2 HumanFIRST Driving Environment Simulator

The DSSs described below were built into the HumanFIRST Program's driving environment simulator (Oktal; AutoSim) within the ITS Institute at the University of Minnesota. The driving environment simulator consisted of a full-sized Saturn vehicle with realistic operational controls and instrumentation and a high-resolution visual scene (1.96 arc minutes per pixel) projected to a 5-channel 210-degree forward field-of-view screen. The rear visual scene was projected onto a screen behind the driver and was visible in the vehicle's rear-view mirror. The side mirror views were provided by LCD panels placed on the side mirrors. Auditory and haptic feedback were provided by a 3D surround audio system, subwoofer, car body vibration, and a three-axis (roll, pitch, z-axis) electric motion system (description taken from Creaser et al., 2008). Auditory feedback included ambient traffic noise. Figure 2-1 below shows a photograph of the simulator.

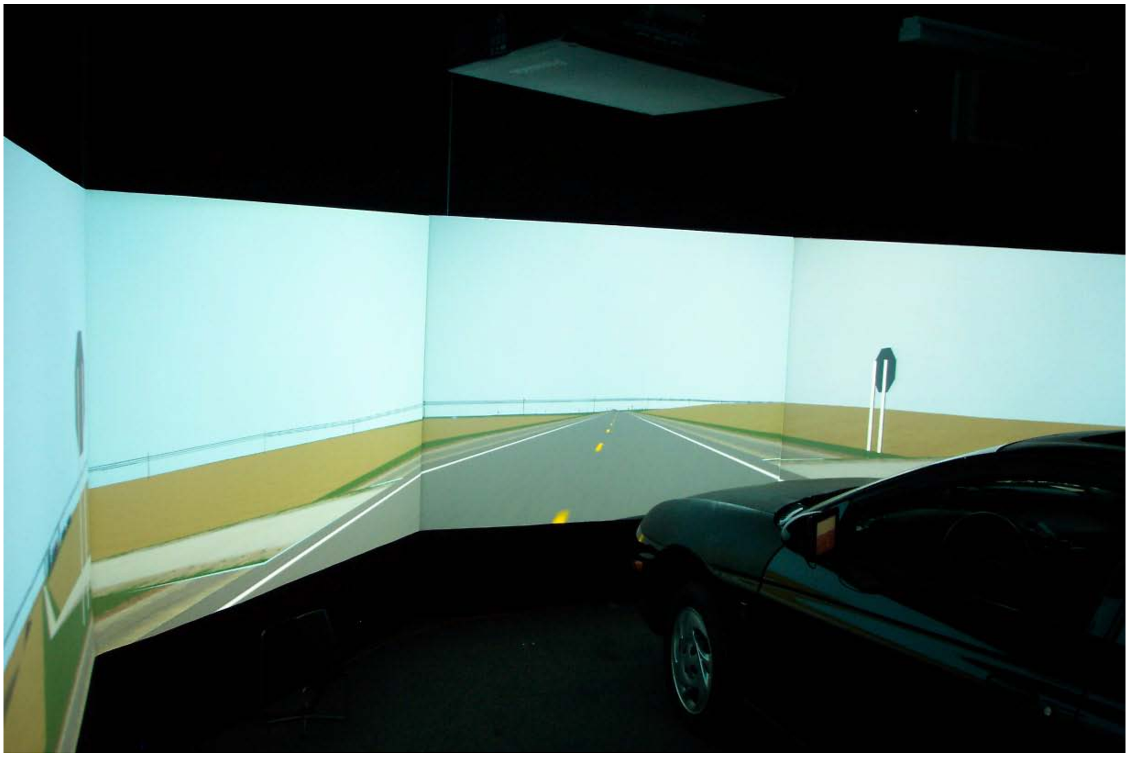
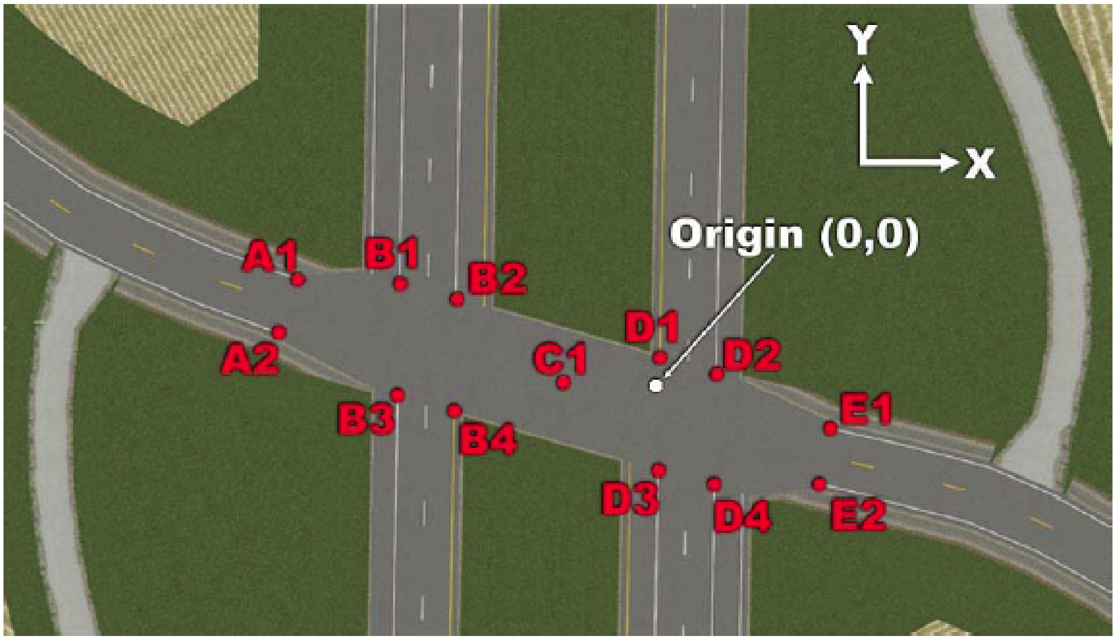


Figure 2-1: HumanFIRST driving environment simulator.

In the driving simulator's coordinate system, Highway 52 runs parallel to the y-axis and the origin is in the median. CSAH 9 lies diagonally, thus the west side of CSAH 9 is in quadrant II (x negative, y positive), and the east side is in quadrant IV (x positive, y negative). Figure 2-2 below shows the simulated intersection along with the coordinates of several locations. Participants in the simulator study approached from the left and drove across to the right.



	X	Y	Z
A1	-46.83	12.82	6.8
A2	-49.21	5.96	6.8
B1	-33.59	12.77	7.03
B2	-26.24	10.80	7.06
B3	-33.59	-1.73	7.20
B4	-26.24	-3.69	7.28
C1	-12.36	0.18	6.85
D1	0.29	3.69	6.61
D2	7.59	1.74	6.62
D3	0.29	-10.81	6.69
D4	7.59	-12.76	6.70
E1	22.86	-5.18	6.56
E2	21.35	-12.35	6.58

Figure 2-2: Simulated intersection and coordinates. Based on Highway 52 and CSAH 9 in Goodhue County, Minnesota. Units are in meters. The highway is parallel to the y-axis. Adapted by permission of HumanFIRST program.

2.2.3 Design

The study was conducted in the HumanFIRST driving simulator (described in *2.2.2 HumanFIRST Driving Environment* Simulator above), which reproduced the intersection described in *1.2 Test Intersection* above.

2.2.3.1 Lighting

Daytime lighting was simulated since the simulator was not configured for nighttime at the time.

2.2.3.2 *Independent Variables*

The independent variable was the DSS condition presented to the driver: the control condition (i.e. No DSS), the Icon Sign condition (outside the vehicle), and the Vibrotactile Seat condition.

2.2.3.3 *Counterbalance*

To counterbalance for order effects, each participant completed the three conditions in a different order. The four participants completed the conditions in the orders listed in Table 2-1 below. With four participants, the study was not fully counterbalanced. Had there been two more participants, the counterbalance would have been completed. However, we stopped the study after 4 participants because several major usability issues with the Vibrotactile seat became fairly evident, as will be described below. We did not feel that two additional subjects would tell us much more.

Table 2-1: Pilot study order counterbalance. The counterbalance was incomplete. Two additional participants would have allowed the counterbalance to be completed.

Participant	First condition	Second condition	Third condition
1	No DSS	Icon Sign	Vibrotactile Seat
2	No DSS	Vibrotactile Seat	Icon Sign
3	Icon Sign	No DSS	Vibrotactile Seat
4	Icon Sign	Vibrotactile Seat	No DSS

2.2.3.4 *DSS Descriptions*

The DSSs used in the Pilot Study are described below. Before the experiment, the participants were only told the forms of the DSSs (traffic sign or vibrating seat) and that the DSSs were meant to provide information about traffic. The purpose of the study was to see how first-time users would respond to the DSSs, thus the details of the DSSs were purposely not explained beforehand. At the same time, it was not desirable for users to ignore the DSSs. Thus, they were told what forms the DSSs would take, so that they would know what to expect.

2.2.3.4.1 Icon Sign

At the time, the design of the Icon Signs placed them both to the right of the participant (see Figure 2-3 below), with one next to the stop sign and one in the median (Creaser et al., 2008 explains the reasons for design revisions since this version). Besides this difference, the Icon Sign functioned as described in *1.6 Icon Sign Description* above.

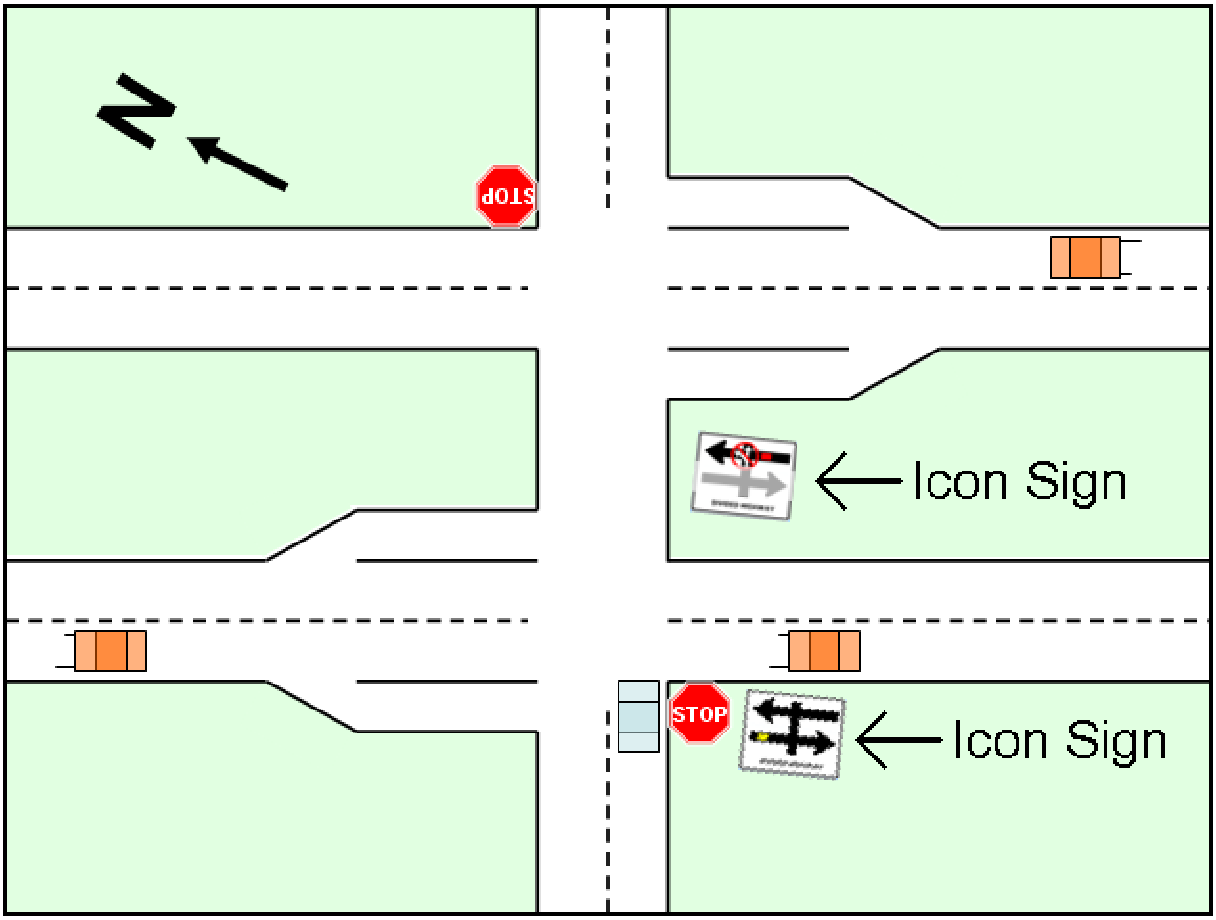


Figure 2-3: Icon sign locations during the pilot study. Adapted by permission of HumanFIRST program.

2.2.3.4.2 <u>Vibrotactile Seat</u>

The purpose of the Vibrotactile Seat was to direct attention to the left or right in the event of a warning (traffic within 7.5 s), and to prompt a braking response to such an event. We chose to use a haptic rather than an auditory warning, as an alternative to the visual interfaces because we assumed that the noise from the road, motor, radio, passenger conversations and cell phones might interfere significantly with an auditory warning. We assumed that the driver's haptic channel would be less used than the visual or auditory channels and thus might be a more effective means of delivering a warning. The visual channel may already be full performing the driving task, and the auditory channel could be full from listening to music, talking to passengers, or from ambient noise.

This haptic DSS used two vibrational pads in the driver's seat (see Figure 2-4 below) to warn the driver of traffic from the left and right. The pads were inactive until the vehicle's front bumper was approximately 72 ft (22 m) from the edge of the nearest highway lane (vehicle's rear axle at x = -60 m in simulator coordinates). There is nothing significant about this exact distance, but it was chosen because it was close to the intersection. Presumably the driver will not want the warnings until he or she is very close to the intersection, possibly waiting at the stop sign or rolling up to it. When the simulation started, the vehicle was 1700 ft (520 m) from the intersection. Although it would have been possible for the Vibrotactile Seat to become active as soon as the simulation started, this might confuse the participant as to the meaning of the vibrations; if the seat were to start vibrating before the participant could even see the traffic, the participant might not understand that the vibration was referring to the traffic.

Figure 2-4: Vibrotactile seat. The vibrational pads are marked in yellow.

Once active, the left pad vibrated if traffic from the left was within the warning threshold (7.5 s, same as the Icon Sign) and the right pad vibrated if traffic from the right was within the warning threshold. The amplitude cycled between zero and the maximum at a frequency of approximately 5 Hz. However, neither pad would vibrate if the driver was pressing the brake pedal, at least in the initial version of the design. The reasoning was that a continuous vibration might become annoying if the driver had to wait a relatively long time for an acceptable gap. Therefore, idea was that seat should only vibrate when its feedback is necessary (i.e. when the driver is about to proceed). The purpose of this design was to direct the driver's attention towards the hazard (approaching traffic), and to warn the driver that he or she might want to reconsider the decision to proceed. Since the vibrational pads only had two possible states, on or off, the caution threshold (11 s) used in the Icon Sign was not incorporated into the Vibrotactile Seat (section *1.5 Previous Work of the CICAS-SSA Program* elaborates on how the thresholds were determined). The left pad became inactive once the driver entered the median, and the right pad also became inactive once the driver completely crossed the intersection.

2.2.3.5 Procedure

Each participant completed two trials in each of the three conditions. In each trial, the participant was instructed to drive across the intersection when he or she felt it was safe to do so, with the option of using feedback from a DSS if one was present. At the start of each trial, the participant's vehicle was approximately 1700 ft (520 m) from the intersection, measured from the vehicle's front bumper to the edge of the nearest highway lane. The duration of each trial depended on when the participant decided to cross the intersection, thus each trial could last approximately 1-5 minutes. Two trials were included in each condition in case some data was lost due to a simulator error or in case the participant waited for all highway traffic to pass before proceeding. If a participant waited for all traffic to pass, we lost two variables that could only be calculated if the participant accepted a gap, though we do know that the participant was willing to accept a larger gap than was present in the traffic stream. Performing two trials in each condition increased the odds of having at least one full set of data for each condition. For cases where there were useful data for both trials, the trials were averaged. By performing two trials and then averaging them, we gain a more reliable estimate of driver performance than we would by performing one trial.

The duration of the study was approximately one hour. The following tasks were performed:

1. The participants were given an introduction to the study which summarized what they were expected to do. They then completed the consent form (see Appendix A Pilot Study consent form and Appendix B Pilot Study participant instructions).
2. The participants completed a practice drive in which they crossed the intersection starting from the side opposite of the starting point for subsequent trials. By including practice drives, we can be more certain that driving behavior during the rest of the study is affected mainly by the experimental conditions and not by the process of learning to drive the simulator.
3. The participants crossed the intersection (two lanes of traffic, then the median, then two more lanes of traffic) twice in each of three conditions:
   i. No DSS (control condition)
   ii. Icon Sign
   iii. Vibrotactile Seat
4. The participants completed the NASA TLX questionnaire (Hart & Staveland, 1988; as cited in Creaser et al. 2007) on a computer after each time they crossed the intersection (see Appendix C NASA TLX questionnaire). The NASA TLX measures workload, which may be affected by the use of a DSS.
5. The participants completed a post-condition questionnaire on a computer after the Icon Sign and Vibrotactile Seat conditions (see Appendix D Pilot Study post-condition questionnaire). This questionnaire measured the usability of each DSS.
6. After all the conditions and questionnaires were completed the experimenter debriefed the participants, explained the meanings of the DSSs, and conducted an interview and discussion about the DSSs. This interview was done verbally with the experimenter and participant sitting at a table while the experimenter took notes (see Appendix E Interview questions and Appendix F Visual aids for explanation of decision support systems). These interviews allowed for a deeper understanding of the participants' experiences with the DSSs than would have been possible had only questionnaires been used. The interviews allowed the experimenter to learn more about how the participants interpreted the DSSs, whether they found the DSSs to be useful, which aspects of the DSSs were useful or not useful.

2.2.3.6 Simulated Traffic Stream

The Pilot Study and the Larger Scale Study used different traffic streams. The simulated traffic stream for the Pilot Study was the same as described in Creaser et al. (2007, pp. 216-217). The traffic pattern was deliberately high-volume and was identical across trials. This was done to determine the minimum gap sizes drivers would accept. In the near lanes, traffic started out spaced 3 s apart so that only the most risky drivers would proceed and so that drivers who waited would have an opportunity to observe the signs. At the same time, traffic in the far lanes was spaced 10 s apart to tempt risky drivers to cross the near lanes. After 120 s of this pattern, the near lane traffic was gradually spaced farther apart while the far lanes traffic was changed to be spaced 3 s apart. The gradual spacing out of near lane traffic allowed data collection on the minimum gap size drivers would accept. After another 87 s, near lane traffic ended and far lane traffic was switched to 10 s gaps and then gradually spaced farther apart. After another 105 s, the far lane traffic ended as well.

Both southbound (near lanes) and northbound (far lanes) traffic always drove in the right-hand lane. Unlike in Creaser et al. (2007), there was only one traffic stream instead of two identical streams that used different types of vehicles. Thus, drivers may have been able to learn when a gap would appear based on the pattern of car and truck types. Based on comments from participants, at least some of them did notice the pattern. However, it was not clear whether this affected driver behavior.

2.2.3.7 Dependent Variables

The primary performance measures in the experiment were:

1. Accepted Gap (measured in seconds)—The accepted gap is the size of the gap in traffic when the driver crosses the intersection. Gap size is defined as the amount of time between vehicles in the stream of highway traffic. A gap of 7.5 s is considered appropriate for crossing two lanes (AASHTO, 2001; Alexander, Barham, & Black, 2002; FHWA, 2001; Harwood et al., 1999; Lerner et al., 1995; as cited in Creaser et al., 2007, p. 215).
2. Safety Margin (measured in seconds)—The safety margin is the amount of the gap remaining when the driver's car is at the midpoint of the two lanes being crossed. It is important to know this in addition to the accepted gap size because a driver may choose a large gap but proceed slowly and thus have a small safety margin.
3. Number of Collisions—The number of times the driver collided with oncoming (simulated) traffic. In the simulator, collisions are not hazardous to the study participants. The simulated vehicles do not collide as they do in the real world, but instead pass right through each other.

These were the most important measures because the goal of these DSSs are to help drivers to accept more appropriate gaps and navigate the intersection. These performance variables measured how safe the driver behaved when crossing the intersection and are the means to evaluate the hypothesis that using a DSS will increase safe driving behavior.. User preference and acceptance only need to be considered for DSSs that contribute to more ideal driving.

The secondary performance measures in the experiment were:

1. Interview feedback—The participants were interviewed at the end of the experiment. The participants' feedback gives insight into the participants' thinking when they first

encountered the DSSs. We would hope that the DSSs are easy to interpret, and the interview can tell us whether this is the case. Collecting this feedback allowed the experiment to double as a usability study (see Appendix E Interview questions).

2. Questionnaires—The experiment participants completed the NASA TLX (Hart & Staveland, 1988; as cited in Creaser et al. 2007) to measure workload, and a post-condition questionnaire relating to the usefulness of the DSSs (see Appendix C NASA TLX questionnaire and Appendix D Pilot Study post-condition questionnaire).
3. Wait Time, and Movement Time—The amount of time the participant's (simulated) vehicle was stopped, and the amount of time the participant's vehicle was moving. These were measured between the point when the participant's vehicle was approximately 220 ft (67 m) from the intersection (rear axle at x = -81 m in simulator coordinates) and the point when the vehicle's front bumper exited the Northbound lanes (x = 7.59 m in simulator coordinates). For the traffic pattern present in this Pilot Study, we would expect the accepted gap size and wait time to be positively correlated since the gap sizes increase over time (full details on the gap sizes are in section *2.2.3.6 Simulated Traffic Stream* above). Ideally, a DSS that promotes safer driving behavior would also minimize the driver's wait time, but it can only reduce wait time so far since its purpose is to make the driver wait until a large enough gap is available. Shorter movement time is preferable since it indicates the driver crossed the intersection more quickly and was thus exposed to danger for a shorter amount of time.

2.2.3.8 Statistical Procedures

The accepted gap, safety margin, wait time, movement time, and questionnaire items were analyzed using paired-comparison t-tests ($\alpha = 0.05$). For each variable, three t-tests were used to compare each of the three conditions to the other two conditions. Since using multiple t-tests for each variable increased the chance of having at least one Type I error, a Bonferroni correction (Howell, 2007, pp. 356-357) was applied to the alpha value to control for this increase in chance of a Type I error. Thus, alpha was divided by the number of tests (three), and $\alpha = 0.05 / 3 = 0.016\ 6$ was considered significant.

2.3 Results

Due to the resulting unbalanced design and small sample size, meaningful statistical analyses were not possible for any of the quantitative measures. However, we did the statistical analysis anyway, and found that Vibrotactile seat was significantly poorer than the Icon Sign in terms of accepted gap ($p < 0.001$), perceived physical demand ($p = 0.038$) and perceived performance ($p = 0.026$), most likely due to the fact that its warnings were delivered to late to be useful (see Appendix G). Additionally, it was still useful to have collected the data as we confirmed that the setup and methods we were using would allow us to reliably collect this data in the larger scale experiment. The interview feedback suggested the need for revising the DSS designs, thus the experiment was ended after four participants, before the counterbalance could be completed.

Appendix H contains the interview feedback. The meanings of the DSSs were explained during the interviews. Highlights are summarized below.

1. All participants commented that when watching the nearer traffic (approaching from the left), they could not simultaneously watch the nearer Icon Sign since it was positioned to their right. They disliked this aspect of the Icon Sign.
2. Three of the four participants reported using the Icon Sign to confirm their decisions to enter the intersection. The other participant reported following the Icon Sign's suggestion not to proceed, even when they felt that they saw gaps in traffic that were safe in their own judgment.
3. All participants preferred the Icon Sign to the Vibrotactile Seat.
4. All four participants understood the Icon Sign while only one understood the Vibrotactile Seat. One participant thought the Vibrotactile Seat was telling him to proceed when it vibrated (the opposite of the intended message), or at least to edge up further.
5. Three participants commented on how the Vibrotactile Seat only vibrated after the driver took his/her foot off of the brake pedal. All three indicated that this was not desirable, and two of them suggested that the vibration should run whenever it was unsafe to proceed, regardless of whether the brake pedal was depressed or not. One commented that this would allow him to use the Vibrotactile Seat during the decision process. When the driver makes the decision to enter the intersection, he or she may be pressing the brake to slow down or stop, pressing the accelerator to begin proceeding, or not pressing either pedal (to inch forward).

2.4 Discussion and Conclusions from Pilot Study

From the participant feedback, we can see that participants would have preferred that the nearer Icon Sign be located to the left so that they could more easily watch both the traffic and the sign. At the time the Pilot Study was conducted, the Icon Sign's developers already had plans to move the nearer Icon Sign to the left. In the 12 months following the Pilot Study, they performed further testing which resulted in the current locations of the signs as described in *1.6 Icon Sign Description* above (Creaser et al., 2008).

The participants were frequently confused by the Vibrotactile Seat; more specifically, their feedback indicated that they disliked the ambiguous message, not the vibration itself. They indicated they would have preferred to be able to use it while watching traffic and their foot was still on the brake, instead after they started to proceed (i.e. after the driver took his/her foot off of the brake pedal). Thus, they felt the feedback from the DSS came too late; they needed the feedback during the decision process, *before* they made the decision to proceed. Decision making occurred before removing their foot from the brake an putting it on the gas. Abe and Richardson's work (2004; 2005; 2006) suggests that lateness of the warning will reduce drivers' trust in the DSS since it cannot be relied upon to give a timely and therefore usable warning.

In conclusion, the lessons learned from the Pilot Study were that:

1. The design of both DSSs needed modification before they could be properly assessed in a larger experiment in the following ways:
   a. The position of the Icon Sign needed to be moved to where drivers could see it and still watch traffic at the same time.
   b. The vibrotactile seat needed to be "active" when the driver was making the decision to proceed, e.g. *before* pressing the gas pedal. In the revised design, the

vibrotactile seat could give warnings regardless of whether the driver's foot was on the pedals or not.

2. The design of the experimental procedure also needed some modification. Specifically, drivers needed more training to properly interpret the current design of the Vibrotactile Seat. Perhaps it would be easier to interpret if it functioned the entire time, instead of only when the driver took his/her foot off of the brake.

These changes were made prior to the Larger Scale Study.

Chapter 3. Larger Scale Study

This study was conducted to further investigate in-vehicle decision support systems for rural thru-stop intersections. The Larger Scale Study used feedback from the Pilot Study to revise the design of the Vibrotactile Seat. The Larger Scale Study compared a control condition (no DSS), the Icon Sign, the Vibrotactile Seat, and additionally a pair of in-vehicle visual displays called the Side Mirror Displays. We added the side mirror displays to allow comparison of a visual display and a haptic display, both on the car. All conditions were evaluated in terms of safety, workload, comprehension, preference, and usability.

3.1 Design Considerations for the Side Mirror Displays

3.1.1 Design Parameters

The design parameters for the Side Mirror Displays were:

- The display location,
- Amount and type of information,
- Screen layout.

3.1.2 Options Considered

The display locations considered were:

- Center of the dash,
- Rear-view mirror,
- Side pillars, and
- Side mirror.

Symbols considered for inclusion on the Mirror Display were a:

- yellow triangle with exclamation point in the center,
- hand icon (as pedestrians would see at crosswalks)
- the words "dangerous traffic" (which would have an issue of legibility if fit onto a screen the size of the side mirrors),
- A circle with a slash,
- A red (indicating “warning”) car icon,

The car icon was chosen over these to indicate that the display was giving information about traffic.

3.1.3 Selection Criteria and Rationale

The main criteria for choosing one location for the display over another were, that it:

- Should not block view of road, and
- Should be located near direction of gaze when looking for traffic on the main highway,

  Additional considerations included:
- Ease of implementation in the current simulator, if the options are otherwise equal.

Neither the rear view mirror, nor the center of the dash, was appropriate places for displays because to look at them, the driver had to turn his/her head away from the traffic being watched for openings. Both the side pillars and side view mirrors were closer to the direction of the driver's gaze. However, we chose to use the side view mirrors because the simulator already had convenient programmable LCD displays mounted there. In an actual implementation, the display might be mounted on or near the side pillars, instead of on the side view mirrors.

To facilitate comparison between interfaces we chose to base the symbols in the Side Mirror Display at least loosely on the Icon Sign display. However, we could not use the identical display because the amount of information on the Side Mirror Displays had to be reduced to make the symbols legible on significantly smaller display area available on the mirrors. In the "reduced" version of the display, we eliminated the road, the yellow warning car, and the "don't go" icon (circle with slash). We also showed only one lane on each display, so only information on vehicles coming from the left was shown on the left-hand mirror, and only information on traffic approaching from the right was shown on the right-hand mirror. Only the red 7.5 sec. warning car was kept. Speed lines were added to show the direction of travel of the vehicle which was no longer obvious without the road layout. Finally, a "fill gauge" was added to show the relative distance of the vehicle.

The fill gauge was added based on the suggestion found in Creaser et al. (2005). Creaser et al. (2005, 2007, 2008) tested a sign with a numeric countdown (an absolute measure) of the time-to-arrival of the next vehicle. For this numeric Countdown Sign, participants reported using the numbers based on what they felt themselves to be capable of, for example a participant might say that s/he thought s/he had enough time to pull into the intersection if the countdown was at 5 sec or more. This desire to "beat the clock" was seen in Creaser et al. (2008) and Creaser et al. (2005, 2007). However, to satisfy participants desire for time-to-arrival information, Creaser et al. (2005) proposed a bar gauge that would provide instead arrival time information, with no specific numbers. These issues are further discussed in section 3.1.2.3.2.1 Reasoning behind Side Mirror Displays.

3.2 Experimental Methods

Hypotheses:

1. Use of a DSS will increase safe driving behavior. If a DSS is effective at presenting information on traffic conditions, we would expect it to increase safe driving behavior (i.e. crossing the intersection with a larger space cushion between the driver and approaching highway traffic).
2. Use of a DSS may increase or decrease driver workload. Ideally, using a DSS would reduce the workload required to cross the intersection safely. However, a DSS may increase workload even as it assists the driver, so it is important to determine whether workload is affected.

3.2.1 Participants

Twenty-four participants (12 males, 12 females) age 19-69 completed this study. An additional three males withdrew due to simulator sickness (an experience somewhat similar to motion sickness) and were not included in data analysis since they did not complete the study. Participants were recruited via a local recruitment agency (Masterson Personnel) and by posting flyers around the University of Minnesota, Twin Cities campus. Participants were required to have had a valid driver's license for at least one year. Participants were required to have vision equal to or better than 20/40 with or without corrective lenses, and no visual or physical anomalies that might influence normal driving. Participants at higher risk for simulator-induced discomfort were screened out using HumanFIRST's simulator sickness screening questionnaire (Appendix I, see also Creaser et al., 2007, p. 214 for more details on the construction of this questionnaire). Participants were paid $50. Use of human subjects was approved by the University of Minnesota Institutional Research Board.

Previous studies had already documented that there were no significant age or gender differences at the type of thru-stop intersection being studied (Creaser et al., 2008; Gorjestani et al., 2008; Rakauskas et al. 2009), so we did not feel the need to specifically recruit participants of a particular gender or age group. Age and gender balance was not specifically sought or avoided. Table 3-1 below shows the number of participants for each gender and age group.

Table 3-1: Participant age and gender demographics.

	Age 19-30	Age 30-60	Age 60+
Male	7	3	2
Female	6	4	2

3.2.2 Design

The study was conducted in the HumanFIRST driving simulator (described in *2.2.2 HumanFIRST Driving Environment* Simulator above), which reproduced the intersection described in *1.2 Test Intersection* above.

3.2.2.1 Lighting

As with the pilot study, daytime lighting was simulated. Nighttime lighting would have been preferred because it was hypothesized that less optimal lighting (and thus poorer traffic visibility) would encourage the participants to use the DSSs instead of ignoring them. If the participants used the DSSs more often, then the results would be more likely to show any differences between the DSSs. Due to technical issues it was not possible to set up nighttime lighting.

3.2.2.2 Independent Variable / Conditions

To counterbalance for order effects, each participant completed the four conditions in a different order (see Appendix J Counterbalance). Twenty-four participants were sufficient to complete the counterbalance exactly once.

The four conditions for this experiment were the control condition (i.e. no DSS), the Icon Sign condition, the Vibrotactile Seat condition, and the Side Mirror Displays condition (shown in Table 3-2 below).

Age and gender differences are already well-documented by previous studies (Creaser et al., 2008; Gorjestani et al., 2008; Rakauskas et al. 2009), so age and gender were not used as variables in this study.

Table 3-2: Larger scale study experiment conditions.

EXPERIMENT CONDITIONS
Control (no decision support system)
Icon Sign (roadside sign; external to the vehicle)
Vibrotactile Seat (in-vehicle)
Side Mirror Displays (in-vehicle)

3.2.2.3 DSS Descriptions

The DSSs used in the Larger Scale Study are described below. Before the experiment, the participants were only told the forms of the DSSs (traffic sign, mirror displays, or vibrating seat) and that the DSSs were meant to provide information about traffic. The purpose of the study was to see how first-time users would respond to the DSSs, thus the details of the DSSs were not explained beforehand. At the same time, it was not desirable for users to ignore the DSSs or to fail to notice the DSSs. Thus, they were told what forms the DSSs would take, so that they would know what to expect.

All of the participants were first-time users of the DSSs; none of them had participated in other studies involving these DSSs. Some participants had participated in other studies in the HumanFIRST driving simulator.

3.2.2.3.1 <u>Icon Sign</u>

The Icon Sign functioned as described in *1.6 Icon Sign Description* above.

3.2.2.3.2 <u>Side Mirror Displays</u>

The reasoning behind the design of the Side Mirror Displays will be explained first, followed by the full description of the Side Mirror Displays

3.2.2.3.2.1 Reasoning Behind Side Mirror Displays

Feedback from participants from the Pilot Study (described in *Chapter 2 Pilot* Study above) implied that for navigating rural thru-stop intersections they would prefer a DSS that could be used during the decision process. During the Pilot Study, both Icon Signs were located to the driver's right, positioned on the roadside next to the stop sign and next to the yield sign in the median. Some participants stated they would prefer the nearer sign to be to the left to be able to watch traffic and the Icon Sign at the same time. This suggests that a visual display should be close to traffic in the driver's field of view, which follows the principle of Minimizing Information Access Cost and the Proximity Compatibility principle (Wickens et al., 2004, p. 189), described in *1.4.2 Visual Displays Literature* above. These principals were applied in the Side Mirror Displays.

An early idea for the Side Mirror Displays was to reproduce the Icon Sign, displaying the left Icon Sign on the left mirror and the right Icon Sign on the right mirror. This idea was rejected in favor of the current design for two reasons:

1. If the Side Mirror Displays reproduced the Icon Sign, the only difference between the two DSSs would be the location of the information. Thus, we would only learn which of these two particular locations was preferable. If the only objective was to find the optimal location for an in-vehicle display, it would be more efficient to start with a usability study that tested several locations for each design.
2. This study was designed to follow the procedures of previous CICAS-SSA studies as much as possible. In previous CICAS-SSA studies, the meaning of each DSS was explained after the participant used that DSS but before the participant used the next DSS. The reason for this was to test how intuitive the DSSs were. Were these DSSs to be implemented in the real world, users might have little or no training, thus the DSSs should be as intuitive as possible. If the Side Mirror Displays reproduced the Icon Sign, then the participant would already understand the meaning of whichever of the two DSSs was encountered second in the experiment. To follow the procedures of previous studies, each DSS needed a different display, so that each DSS would be novel to the participant.

The design of the Side Mirror Displays includes a fill bar showing the time-to-arrival of approaching traffic. This idea came from Creaser et al. (2008, 2007) and Creaser, Rakauskas, Ward, and Laberge (2005), which describe the Countdown Sign, a roadside sign design that was tested in CICAS-SSA simulator studies. The Countdown Sign displayed a warning message and the number of seconds until the nearest highway vehicle reached the intersection (i.e. the time-to-arrival of the highway vehicle). There were two Countdown Signs (positioned on the roadside), one for traffic from the left and one for traffic from the right. Drivers tended to calibrate the Countdown Sign to their own behavior, frequently ignoring the warning messages. They would pick a time-to-arrival value that they thought was best, whether or not the Countdown Sign warned them it was unsafe to proceed. Creaser et al. (2008, 2007) hypothesized that this calibration could be due to the presentation of an absolute value for time-to-arrival (i.e. an absolute value as opposed to a relative value). Creaser et al. (2005, pp. 59, 174) suggested that the Countdown Sign could have a fill bar instead of a timer, since drivers may not be able to interpret absolute values for time-to-arrival. Creaser et al. (2005, p. 174) noted that time-to-arrival information was preferred by drivers and that alternate ways of presenting time-to-arrival were worth investigating in future work to see if it was possible to prevent the driver from calibrating the system to his/her current behavior. For these reasons we chose to use a bar gauge to show time to arrival qualitatively (a relative measure) but not quantitatively (an absolute measure) for this study.

3.2.2.3.2.2 Description of Side Mirror Displays

The visual DSS was displayed on the simulator's two LCD panels that are usually used as side mirrors (see Figure 3-1 below). The initial idea was to install two LCD panels on the vehicle's A-pillars, which are the portion of the chassis that frames the left and right edges of the windshield. To test the basic concept, the side mirrors were used instead since they were in nearly the same location, and because it was much easier in the context of the HumanFIRST simulator to use the current simulator hardware to implement the display. The side mirrors were not needed during the simulated intersection crossing task, thus it is reasonable to assume the absence of the side mirrors did not affect driver behavior during the experiment. Were this DSS to be implemented commercially, the display should be placed in a location that does not obstruct the side mirrors or other sources of information that are important for the driver. Alternatively, future work may investigate:

1. Whether the mirror or the A-pillar is the better position for the display.
2. The safety impact, if any, of the temporary loss of the side mirrors while crossing the intersection.

Figure 3-1: The left side mirror display as it appears in the simulator.

These Side Mirror Displays consisted of a car icon with speed lines (horizontal lines indicating movement and after-image) and a fill bar showing the time-to-arrival of the nearest vehicle, with the left mirror corresponding to vehicles approaching from the left and the right mirror corresponding to vehicles approaching from the right. Figure 3-2 below illustrates the features of the Side Mirror Displays, and Table 3-3 below shows several possible display states. The fill bar had no numbers or labels, thus it could be interpreted as either the time-to-arrival of the nearest vehicle or the distance to the nearest vehicle. All simulated traffic moved at a constant speed, thus the ratio between distance and time-to-arrival was constant. The fill bar was “full” (all orange) at an arrival time of 7.5 s. As arrival time decreased, the fill bar gradually decreased until it was “empty” (all black) when the approaching vehicle had arrived. If the next vehicle was farther away than 7.5 s, the bar remained empty until the vehicle was within 7.5 s, at which time it immediately became full.

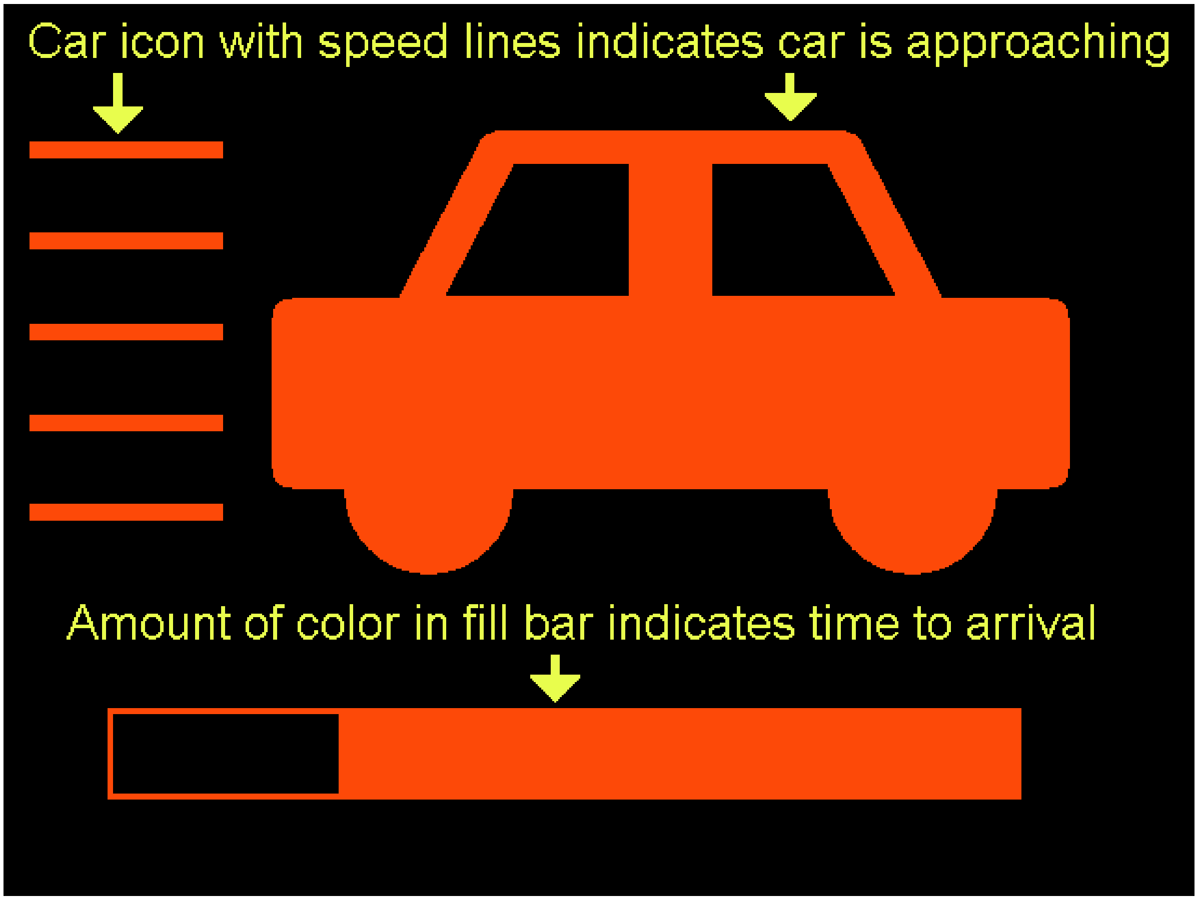


Figure 3-2: Features of the side mirror displays (in this case the left display).

Table 3-3: Example states of the side mirror displays.

Mirror Display example states	What each image means
	This image would appear on the left mirror. The car icon indicates traffic is approaching from the left. The bar indicates how close traffic is to the intersection. The bar is over half full, and would be decreasing to the right.
	This image would appear on the left mirror. The car icon indicates traffic is approaching from the left. The bar indicates how close traffic is to the intersection. The bar is less than half full, and would be decreasing to the right.
	This image would appear on the right mirror. The car icon indicates traffic is approaching from the right. The bar indicates how close traffic is to the intersection. The bar is over half full, and would be decreasing to the left.
	This image would appear on the right mirror. The car icon indicates traffic is approaching from the right The bar indicates how close traffic is to the intersection. The bar is less than half full, and would be decreasing to the left.

The color orange was selected to be deliberately neutral and carry no message on its own. Red might have implied “stop until you see green”, and yellow might have implied “proceed with caution”, neither of which was the correct message for this DSS. “Traffic approaching” was the intended message of this DSS as a whole. The Side Mirror Displays are meant to direct attention to approaching vehicles and provide continuous feedback on the locations of the nearest vehicles. Since the fill bar only spans 7.5 s, it incorporates the warning threshold of 7.5 s but not the caution threshold of 11 s (section *1.5 Previous Work of the CICAS-SSA Program* elaborates on how the thresholds were determined). Therefore, compared to the Icon Sign, the Side Mirror

Displays do not provide as much information about gaps above 7.5 s. However, the fill bar provides more information about gaps below 7.5 s since it shows the size of the gap, where the Icon Sign only shows a warning state. The reasoning for this design is that drivers frequently accept gaps below 7.5 s (which is not ideal), and that more information may help a driver to accept a larger gap, even if that accepted gap is below the recommended threshold of 7.5 s. For example, although accepting a gap less than 7.5 s is not ideal, accepting a 6 s gap is better than accepting a 4 s gap. Although it would have been possible to have warning and caution states (as with the Icon Sign) and a fill bar that spanned 11 s, a simpler display was selected for the current study to better understand which aspects were useful.

3.2.2.3.3 Vibrotactile Seat

For the Larger Scale Study, a few changes were made to the Vibrotactile Seat as described in *2.2.3.4.2 Vibrotactile Seat* above.

1. The brake pedal did not affect whether the seat vibrated. The pads vibrated if traffic was within the warning threshold (7.5 s), regardless of whether the driver's foot was on the brake. In the Pilot Study, participant feedback indicated they would like to use the DSS during the decision process instead of the DSS only providing feedback after they had decided to proceed and taken their foot off of the brake.
2. The Vibrotactile Seat activated once the vehicle's front bumper was approximately 110ft (33 m) from the edge of the nearest highway lane (vehicle's rear axle at x = -70 m in simulator coordinates). In the Pilot Study the distance was 72ft (22 m) instead of 110 ft (33 m). This was changed because some participants stop somewhat far away from the stop sign and then begin inching forward. From observing participants in previous simulator studies in the CICAS-SSA program, it appeared that 110 ft (33 m) was about as far away as anyone stopped. Since the participants were looking at traffic while this far back, they may have been thinking about gap acceptance decisions while this far back, thus it was necessary for the Vibrotactile Seat to be active at that location, so that the participants could begin learning to interpret the DSS.

3.2.2.4 Procedure

Each participant completed two trials in each of the four conditions (eight trials total). In each trial, the participants were instructed to drive across the intersection when they felt it was safe to do so, with the option of using feedback from a DSS if one was present. At the start of each trial, the participant's vehicle was approximately 482 ft (147 m) from the intersection, measured from the vehicle's front bumper to the edge of the nearest highway lane. The duration of each trial depended on when the participant decided to cross, thus each trial could last approximately 1-5 minutes. Two trials were included in each condition to give the participant multiple chances to interpret the DSS, and in case a trial's data was lost due to an error. After checking for learning effects, the two trials were averaged. By performing two trials per condition and then averaging them, we gain a more reliable estimate of driver performance than we would by performing one trial.

The duration of the study was approximately two hours. The following tasks were performed:

1. Participants were given an introduction to the study and completed the informed consent process (see Appendix L Consent form).
2. Participants completed the Driving History Questionnaire (Appendix N Driving history and driver demographic questionnaire). This was to record driver demographic information so that this information could be used in analyses if it was later deemed necessary.
3. Participants were given a description of the intersection and the driving task so that they would understand what sort of driving situation the study involved and what was expected of them (Appendix O Study summary).
4. Participants completed two practice drives. Participants completed a third practice drive if they wished or if the experimenter thought they needed more practice. By including practice drives, we can be more certain that driving behavior during the rest of the study is affected mainly by the experimental conditions and not by the process of learning to drive the simulator.
5. In each of the four conditions, participants completed two trials. In each trial, they crossed the simulated intersection once, first crossing the southbound (near) lanes, then the median, and then the northbound (far) lanes. The four conditions were:
    a. Control (no DSS)
    b. Icon Sign
    c. Side Mirror Displays
    d. Vibrotactile Seat
6. After each trial, participants completed a questionnaire to measure workload (Appendix P Post-driving maneuver questionnaire). Workload may be affected by the use of a DSS.
7. After each condition, participants completed a questionnaire about that DSS before moving on to the next condition (see Appendix Q through Appendix T for copies relating to each condition).
8. At the end of the study, participants completed a questionnaire in which they ranked their preference for the DSSs (Appendix U Ranking questionnaire). This was to understand which DSSs the participants preferred and why they preferred them.
9. Participants were debriefed and paid (see Appendix M Participant reimbursement form).

3.2.2.5 Questionnaires

After each trial, participants answered a questionnaire about their mental workload during the trial (see Appendix P). At the end of each condition, they also answered questionnaires about how they used the decision support system in deciding when to cross the intersection, their comprehension of the decision support system, and their judgment of the usability of the decision support system (see Appendix Q through Appendix T). At the end of the study, they completed a questionnaire in which they ranked their preferences for the decision support systems (see Appendix U).

3.2.2.6 Simulated Traffic Stream

The Pilot Study and the Larger Scale Study used different traffic streams. Between the Pilot Study and the Larger Scale Study, CICAS-SSA experiments had switched to using a traffic stream that appeared more natural than the long, crowded pattern described in *2.2.3.6 Simulated Traffic Stream* above. The reasoning was that for participants to behave as they would in the real world, it was necessary to have traffic conditions that more closely approximated the real world. The traffic pattern used in the Larger Scale Study was the same as used in Creaser et al. (2008, p. 66), which employed gap patterns based on actual traffic observed at Highway 52 and CSAH 9. Table 3-4 below shows the sizes of the simulated gaps and the frequency of each size. For each trial, these gaps were presented in random order. A random traffic stream was used instead of a controlled traffic stream in order to avoid learning effects. Traffic approached the intersection at 105 kph (65 mph).

Table 3-4: Gap size and frequency.

Gap size (seconds)	Number of gaps, Southbound traffic	Number of gaps, Northbound traffic
3	18	18
4	5	5
5	5	5
6	4	4
7	4	4
8	3	3
9	3	3
10	3	3
11	2	2
12	2	2
13	2	2

Although based on actual traffic distributions, the gaps in simulated traffic were always approximately whole numbers. However, there was a discrepancy somewhere between the simulator's traffic generation algorithm and the simulator's data collection software. As a result of this discrepancy, the simulator data files reported each southbound gap as approximately 0.1 s less than the gap's whole number value. Each northbound gap was reported as approximately 0.3 s greater than the gap's whole number value. Because this was consistent across conditions, it was not addressed in analysis.

Simulated northbound and southbound traffic almost always drove in the right-hand lane. Rarely, one vehicle in the traffic stream would use the left-hand lane to pass another vehicle as they drove past the intersection. This occurred when the traffic generation algorithm happened to place a slow-accelerating vehicle in front of a fast-accelerating vehicle.

When the participant's vehicle entered the intersection, the simulated traffic made some attempt to avoid the participant's vehicle by braking hard at the last moment if the participant's vehicle was in the way. It is not clear whether this affected experiment results.

3.2.2.7 Dependent Variables

This section discusses the dependent variables used to measure performance and usability. The performance dependent variables measured various aspects of the driver's behavior and safety. The usability dependent variables were all questionnaire-based.

3.2.2.7.1 <u>Dependent Variables for Performance</u>

The performance variables describe how the driver crossed the intersection and the relation between the driver's vehicle and the highway traffic. Nine performance variables were used in this study. Figure 3-3 below shows a visual definition of the concepts of *gap*, *lag*, and *lead gap*. These concepts are used in defining some of the performance dependent variables.

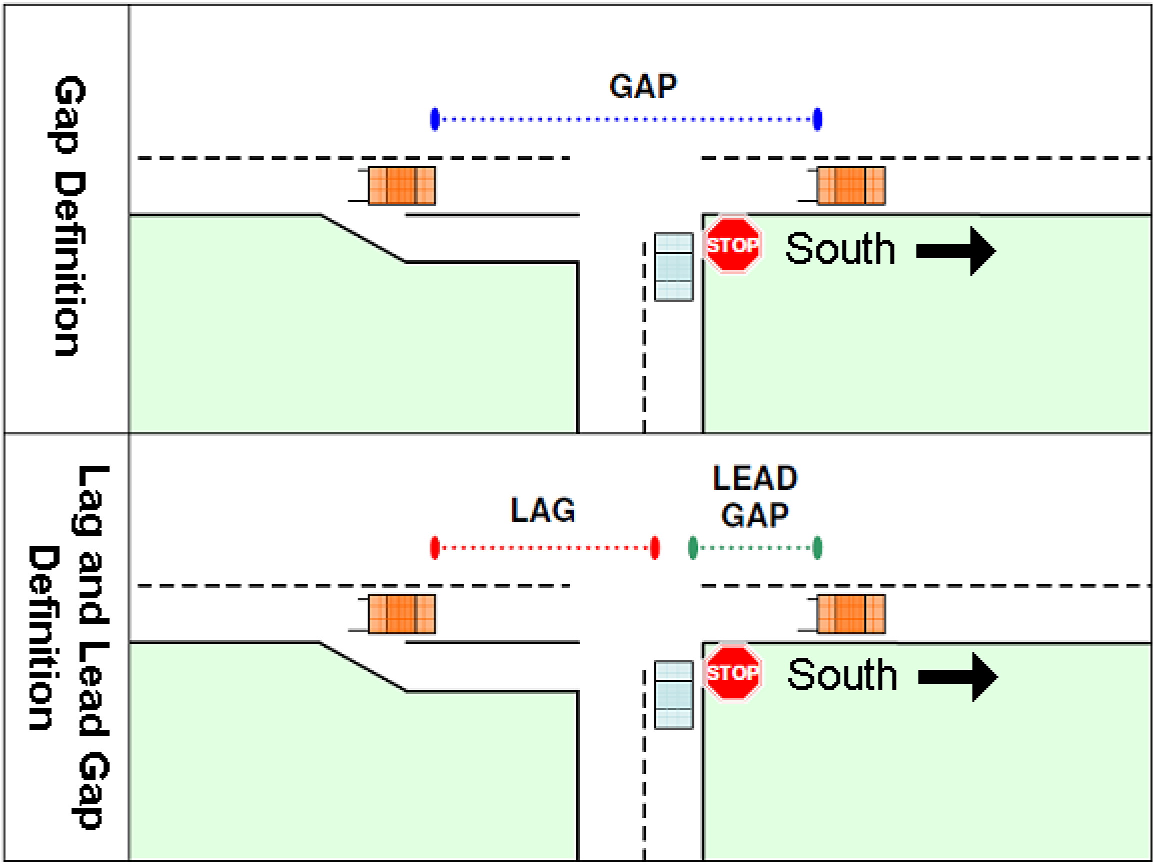


Figure 3-3: Depiction of gap, lag, and lead gap. Adapted by permission of HumanFIRST program.

A *gap* occurs between a lead vehicle and a following vehicle, and is measured by the number of seconds apart they are driving. In other words, the *gap* is the number of seconds between the time when the lead vehicle passes the intersection and the following vehicle passes the same point. When the *gap* straddles the intersection, the *gap* can be split into the *lag* and the *lead gap*. The *lag* is the time it will take the following vehicle to reach the intersection, and the *lead gap* is the time since the lead vehicle passed through the intersection, as shown in Figure 3-3 above. Lag could be also be thought of as the amount of the gap remaining. These concepts are used in describing the dependent variables below (Rakauskas et al., 2009).

The dependent variables for performance are defined below. For each trial, almost every performance dependent variable had two values: one for the southbound lanes (i.e., the near lanes, which were crossed first), and one for the northbound lanes (i.e. the far lanes, which were crosses second). For the southbound lanes, traffic was approaching from the participant's left.

For the northbound lanes, traffic was approaching from the participant's right. Traffic directions are illustrated in Figure 3-4 below.

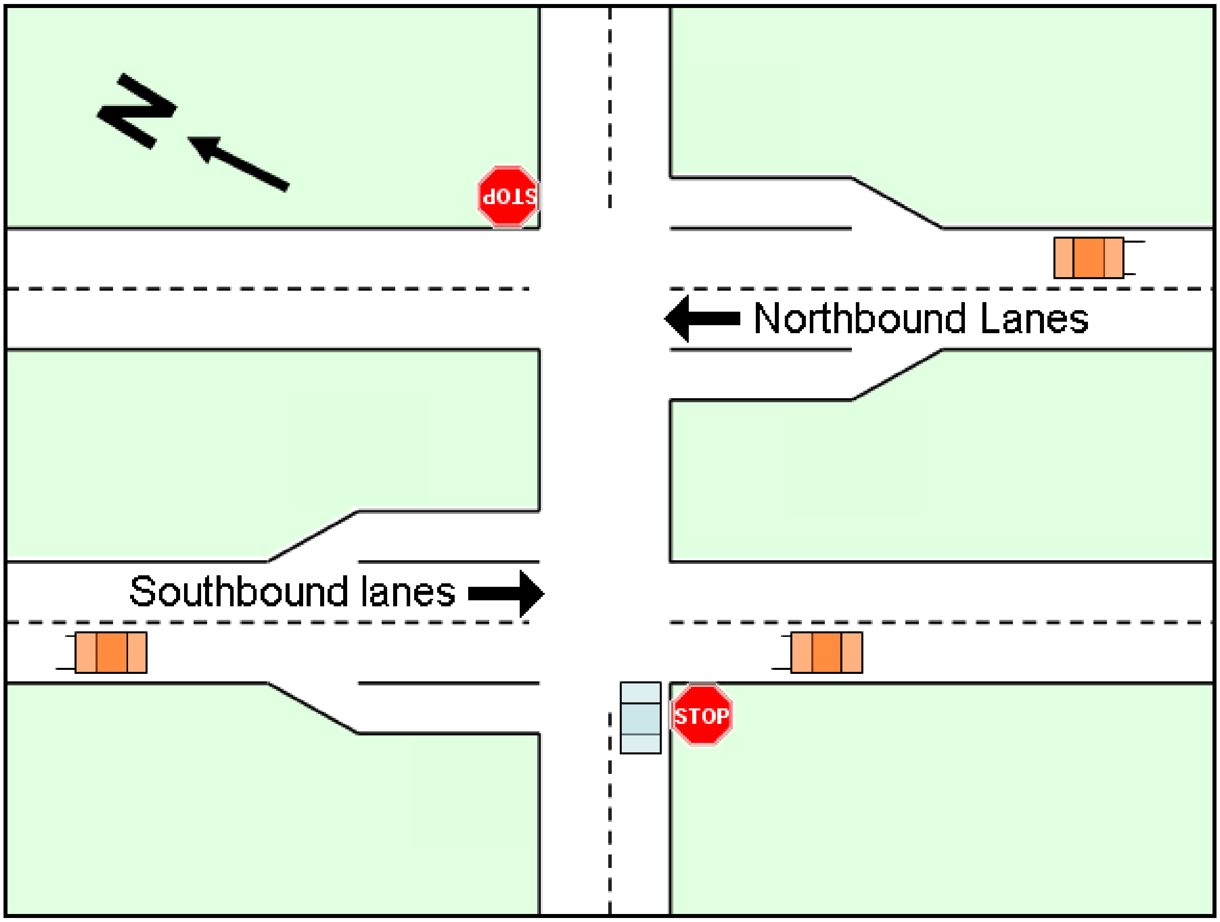


Figure 3-4: Sketch of the rural thru-stop intersection at Highway 52 and CSAH 9 in Goodhue County, Minnesota. Adapted by permission of HumanFIRST program.

With the exception of the number of conflicts, these variables are the same as those used in previous CICAS-SSA studies. In some cases, a single variable was evaluated multiple ways to explore the best way to evaluate the variable.

Accepted Gap (seconds)—size of the gap at the time the participant crossed the northbound / southbound lanes. This is useful to know but does not give a complete picture of driver behavior because a driver could wait for part of the gap to pass before proceeding.

Rejected Gaps (seconds)—sizes of the gaps that occurred before the participant accepted a gap. There are four dependent variables (described below) that relate to rejected gaps. Rejecting unsafe gaps does not necessarily lead to accepting safer gaps, but we would expect that safer drivers would generally do both. The assumption is that drivers reject gaps because they are waiting for even larger, safer gaps to accept. Therefore, having a higher mean rejected gap is assumed to indicate the driver was accepting larger gaps. Gorjestani et al. (2008) note that drivers are very consistent in their gap rejection behavior, and suggests that examination of gap rejection is a good supplement to examination of gap acceptance.

The rejected gap data is an unusual variable because the number of data points per trial varies depending on the participant's behavior. A participant may choose to reject as many or as few gaps as s/he wishes. For example, if the participant accepted the first gap s/he encountered when crossing the southbound lanes, then there are no rejected gaps for the southbound lanes for that trial. During a different trial, the participant might reject a dozen or more gaps before crossing the southbound lanes.

Only rejected gaps encountered by the participant were included. We would not want to include gaps that occurred before the participant even reached the intersection. We would also not want to include northbound gaps if the participant had not yet crossed the southbound lanes. The following inclusion criteria were used. For the southbound lanes, only rejected gaps occurring after the participant's vehicle was approximately 72 ft (22 m) (x = -60m in simulator coordinates) from the intersection were included. For the northbound lanes, only rejected gaps occurring after the rear bumper of the participant's vehicle exited the southbound lanes were included (at which point the participant's vehicle was approximately 72 ft (22 m) from the northbound lanes).

Because there may be from zero to several rejected gaps per trial, analyzing the rejected gap variable is not as straightforward as other variables. Several measures were used to better understand driver rejected gap behavior. For the percentage of rejected gaps less than 7.5 s, smaller values are considered safer. For the other three measures, larger values are considered safer. The following measures were used in analyzing rejected gaps:

1. *80th percentile rejected gap*. All rejected gaps for all participants were aggregated by condition and by lanes (northbound and southbound lanes). The 80th percentile rejected gap was calculated for each condition and each set of lanes. A higher value indicates safer driving behavior. In Rakauskas et al. (2009), a difference greater than 0.5 s in 80th percentile rejected gap was considered significant. The 80th percentile of real-world rejected gaps was used in determining the warning threshold (Gorjestani et al., 2008). Other than this detail, previous studies do not appear to give a reason for using specifically the 80th percentile (as opposed to 70th, 90th, etc.), or for considering a difference of 0.5 s to be significant.
2. *Aggregated mean rejected gap*. All rejected gaps for all participants were aggregated by condition and by lanes (northbound and southbound lanes), the same as for the 80th percentile rejected gap. The average rejected gap was calculated for each condition and each set of lanes. This method of averaging gave equal weight to each rejected gap. These means were compared via t-tests.
3. *Participant mean rejected gap*. For each condition, each participant's rejected gaps were averaged for each set of lanes (northbound and southbound lanes). Thus, each participant had two averages for each condition: one for the southbound lanes, and one for the northbound lanes. This method of averaging gave equal weight to each participant, regardless of the number of gaps s/he rejected. These means were compared via analysis of variance.
4. *Percentage of rejected gaps smaller than 7.5 s*. All rejected gaps for all participants were aggregated by condition and by lanes (northbound and southbound lanes), the same as for the 80th percentile rejected gap. The percentage of rejected gaps smaller than 7.5 s was calculated for each condition and both sets of lanes (northbound and southbound lanes). A lower percentage indicates safer driving behavior. In

Rakauskas et al. (2009), a difference greater than 2.5% was considered significant, though no reason was given for why this exact number was used. These percentages were also compared via proportion test.

Safety Margin (seconds)—size of the lag when the participant vehicle's rear bumper exited a highway lane with traffic. Simulated highway traffic always drove in the right-hand lane. Thus, for the southbound lanes, the highway lane nearer to the participant had traffic. For the northbound lanes, the highway lane farther from the participant had traffic. Safety margin measures how close the driver came to a collision. Even if a driver accepts a large gap, s/he may have a small safety margin due to crossing the intersection slowly.

Lag at Accelerator Press (seconds)—size of the lag when the participant pressed the accelerator to begin crossing one set of lanes. Recall that the lag is the time until the following vehicle of the accepted gap reaches the intersection. Thus, if the participant began accelerating before the lead vehicle reached the intersection, the lag at accelerator press will be larger than the accepted gap. Lag at accelerator press is a measure of the driver's safety at the moment s/he started crossing the intersection. By knowing the lag at accelerator press in addition to the accepted gap and safety margin, we have a more complete picture of the driver's actions. The driver often waits for part of the accepted gap to pass before entering the intersection. From the experimenter's observations during past studies, it appears that drivers often do not finish deciding whether to proceed until after the lead vehicle has passed. A driver may accept a large gap but have a small lag at accelerator press due to indecisiveness or due to spending time observing a DSS.

Lead Gap at Accelerator Press (seconds)—size of the lead gap when the participant pressed the accelerator to begin crossing one set of lanes. Recall that the lead gap is the time since the lead vehicle of the accepted gap passed the intersection. If the participant began accelerating before the lead vehicle reached the intersection, the lead gap at accelerator press will be negative. A larger (more positive) lead gap at accelerator press may mean the driver spent additional time observing a DSS before proceeding. However, the size of the accepted gap might also affect how promptly the driver chose to cross the intersection. This variable is somewhat redundant since lead gap at accelerator press is equal to accepted gap minus lag at accelerator press, but it was included anyway to give a more complete picture of driver behavior.

Wait Time (seconds)—for the northbound (far) lanes, this was the time between when the participant vehicle's rear bumper exited the southbound (near) lanes and when the driver pressed the accelerator to start crossing the northbound lanes. For the southbound lanes, this was the time between when the vehicle was approximately 72 ft (22 m) ($x = -60$m in simulator coordinates) from the intersection and when the driver pressed the accelerator to start crossing the southbound lanes. The distance of 72 ft (22 m) was chosen because it is as far from the southbound lanes as the southbound lanes are from the northbound lanes. Wait time may reflect time watching traffic, time watching and interpreting the DSS messages, and time making the decision to cross. Since the traffic pattern is randomly generated each trial, wait time partially depends on the resulting sizes of the gaps for that trial. One would expect that a successful DSS may increase wait time by encouraging drivers to wait longer for safer gaps to become available. An unsuccessful DSS might increase wait time if the driver needs additional time to comprehend the DSSs messages. The ideal DSS would increase wait time as a function of safety but not excessively when compared to the control condition.

Movement Time (seconds)—time from when the participant pressed down on the accelerator to begin crossing one set of lanes to when the vehicle's rear bumper exited those lanes. For a given accepted gap size, a slower driver would tend to have longer movement times and lower safety margins than a driver who crosses the intersection quickly.

Frequency of one-stage maneuvers—the number of times participants made one-stage maneuvers in each condition. In a one-stage maneuver, the driver does not stop in the median before crossing the far lanes (northbound lanes). In a two-stage maneuver, the driver does stop in the median. Two-stage maneuvers are considered safer since the driver has more time to assess the traffic in the far lanes. This is not a perfect measure of whether the driver assessed traffic in the far lanes because there may have been a gap that was large enough that the driver could immediately tell that it was safe enough to proceed. At the Minnesota test intersection most crashes occur in the far lanes (Preston et al., 2004), hence the interest in one-stage maneuvers. A maneuver was considered one-stage if the vehicle's speed did not drop below two miles per hour as the participant drove through the median. Two miles per hour was chosen instead of zero miles per hour because not all drivers come to a complete stop in the median even if they do spend several seconds waiting in the median. A good DSS would encourage drivers to make two-stage maneuvers.

Number of Collisions/Conflicts—number of collisions was the number of times the participant's vehicle collided with highway traffic, while number of conflicts was the number of times the participant's vehicle came close to colliding. Before the experiment was conducted, only counting the number of collisions was planned. No collisions occurred during the study, so this variable was changed to number of conflicts (near misses). Further details are explained in the Results subsection *3.3.1.5 Number of Conflicts* below.

3.2.2.7.2 Dependent Variables for Usability

The usability variables describe the driver's perceptions of workload, comprehension of the DSSs, and use of the DSSs.

Workload Questionnaire—After each trial, the participant completed a seven-question workload questionnaire with 5-point Likert scales (see Appendix P Post-driving maneuver questionnaire). The expectation was that if the use of a DSS adds to a driver's workload, s/he may be less willing to use it. Ideally, a DSS would help a driver to make safer decisions, without adding to overall workload.

Post-Condition Questionnaire—After each condition, the participant answered several questionnaires relating to DSS comprehension, DSS use, and their opinions of the DSS (see Appendix Q though Appendix T for copies relating to each condition). The assumption is that DSSs that are more difficult to comprehend may be less likely to be used, and the driver may be more likely to misinterpret the DSS and proceed when the DSS advises otherwise. Additionally, drivers may not use a DSS they do not like. These questionnaires included:

1. Comprehension Question: An open ended questioned asked the participant to describe what s/he thought the DSS meant.
2. Confidence Questionnaire: Ten questions asked about topics such as DSS confusion, DSS understanding, and confidence in DSS use. These questions used five-point Likert scales. Disagreements were coded as lower scores and agreements were coded as higher scores.

3. Use Question: A yes or no question asked whether the participant used the information provided by the system, and an open ended question asked what information they used and how they used it (if they answered "yes") or why they didn't use the information (if they answered "no").
4. An explanation of the DSS's messages was provided.
5. Usability Scale: The usability questionnaire described in Van der Laan, Heino, and De Waard (1997) was used to rate the DSS on Usefulness and Satisfying scales. Both scales have a maximum score of 2 and a minimum score of -2.

During the control condition, this post-condition questionnaire referred to the stop sign at the intersection. However, the post-condition questionnaire items are not meaningful when applied to a stop sign, only when applied to DSSs. Therefore, the post-condition questionnaire was administered during the control condition only to maintain consistency between conditions.

Ranking Questionnaire—At the end of the experiment, after all trials for all conditions had been completed, this questionnaire asked the participant to rank the three DSSs in order of preference, and to describe why s/he chose the rankings for each.

3.2.2.8 Statistical Analyses

A repeated measures analysis of variance (ANOVA) was performed using the DSS condition (control, Icon Sign, Vibrotactile Seat, Side Mirror Displays) as a within-subject variable. The dependent variables for this analysis included: accepted gap, participant mean rejected gap, safety margin, lag at accelerator press, lead gap at accelerator press, wait time, movement time, the workload questionnaire items, the confidence questionnaire, the usability scale questionnaire (Usefulness and Satisfying scales), and the ranking questionnaire. For the confidence questionnaire, the usability scale questionnaire, and the ranking questionnaire, the control condition was not included in the ANOVA because those questionnaires relate to the usability of decision support systems and thus do not apply to stop signs.

Before the ANOVA was performed, a paired-comparison t-test was performed to check for learning effects between the two trials across all conditions. For each trial, the safety margin was averaged over all conditions. These two averages were compared via t-test, and the result indicated no statistically significant differences across the two trials. This procedure was performed for both the southbound (near) lanes safety margin and northbound (far) lanes safety margin, and both t-tests indicated no statistically significant differences across the two trials. Similarly, a check for learning effects within each condition was performed by averaging the safety margin for each trial within each condition. Paired-comparison t-tests between these averages within each condition indicated no statistically significant differences for either the southbound (near) or northbound (far) lanes. Checking for learning effects gave a more complete picture of driver behavior. The goal was to either rule out learning effects or to control for them.

After ruling out learning effects, the two trial values were then averaged for each participant before performing the ANOVA. The variables that had their two trials averaged in this way included the accepted gap, safety margin, lag at accelerator press, lead gap at accelerator press, wait time, movement time, and the workload questionnaire items. Differences between means were considered significant at the $p \leq 0.05$ level. Reported p-values reflect the Greenhouse-Geisser adjustment for sphericity. Tukey's post-hoc test (Howell, 2007, pp. 368-

372) was used to determine differences between means for variables that showed a significant main effect in the ANOVA.

A t-test was performed on the aggregated mean rejected gap, comparing each of the four conditions to each other.

A proportion test was performed on the percentage of rejected gaps smaller than 7.5 s, the frequency of one-stage maneuvers, the number of conflicts, the comprehension question, and the reported use question. The proportion test used was the significance test for comparing two proportions as described in Moore and McCabe (2006, p. 562). Reported confidence intervals for the percentage of rejected gaps smaller than 7.5 s used the large sample confidence interval (Moore & McCabe, 2006, p. 537). Reported confidence intervals for the frequency of one-stage maneuvers, the number of conflicts, the comprehension question, and the reported use question used the plus four confidence interval method (Moore and McCabe, 2006, p. 539).

The t-tests and proportion tests used an alpha value of 0.05. However, since using multiple tests for a single variable increases the chance of having at least one Type I error, a Bonferroni correction (Howell, 2007, pp. 356-357) was applied to the alpha value to control for this increase in chance of a Type I error. Thus, alpha was divided by the number of tests to calculate the correct alpha value.

3.3 Results

3.3.1 Dependent Variables for Performance

The ANOVA yielded no significant results for the accepted gap, participant mean rejected gap, lead gap at accelerator press, wait time, or movement time. The t-test performed on the aggregate mean rejected gap did not show any significant differences. The proportion tests performed on the percentage of rejected gaps less than 7.5 s, frequency of one-stage maneuvers, and number of conflicts did not show any significant differences.

3.3.1.1 Rejected Gaps

The 80th percentile rejected gap and percentage of rejected gaps less than 7.5 s indicated that gap rejection behavior at the stop sign was safer for the Icon Sign than for the other two DSSs. Other results were either not consistent or did not show any differences between conditions.

The ANOVA on the participant mean rejected gap did not yield significant results. The other three rejected gap variables were calculated by aggregating all rejected gaps over all participants. This aggregated rejected gap data was used to calculate the 80th percentile rejected gap, the aggregate mean rejected gap, and the percentage of rejected gaps less than 7.5 s for each condition for when the driver was at the stop sign and for when the driver was in the median. The t-tests performed on the aggregate mean rejected gap showed no significant differences. Other results are described below.

For the percentage of rejected gaps less than 7.5 s, lower values imply safer driving behavior. For the other three rejected gap variables, higher values imply safer driving behavior.

It is desirable for drivers to accept larger gaps and reject smaller gaps. We would assume that if a driver is rejecting small gaps, it is because s/he is waiting for a large gap to accept. However, even if a driver rejects several small gaps, s/he may still accept a small gap. This is the limitation on how well rejected gap behavior approximates safer driving behavior.

Figure 3-5 below and Table 3-5 below show the 80th percentile rejected gaps. Using the criteria from Rakauskas et al. (2009) that a difference of 0.5 s is a significant difference, the Icon Sign's 80th percentile rejected gap at the stop sign is significantly different from the other three conditions. The differences were:

1. The Icon Sign was 0.55 s greater than the control.
2. The Icon Sign was 0.95 s greater than the Side Mirror Displays.
3. The Icon Sign was 0.95 s greater than the Vibrotactile Seat.

When the driver was in the median, the 80th percentile rejected gap values were all within 0.09 s of each other.

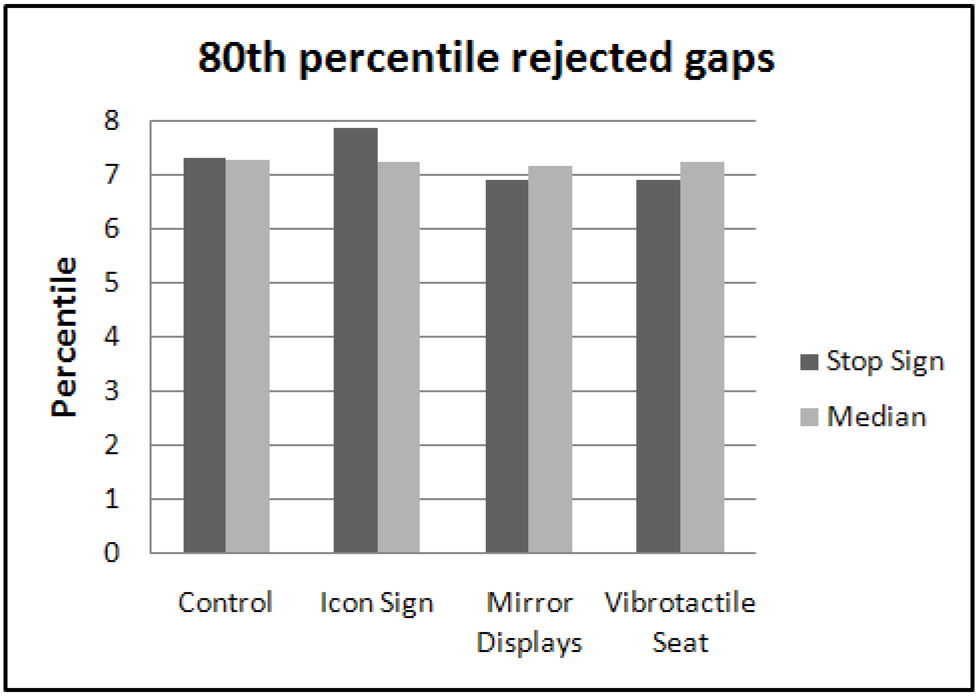


Figure 3-5: 80th percentile rejected gaps.

Table 3-5: 80th percentile rejected gaps.

Condition	Driver At Stop Sign	Driver In Median
Control	7.33 s (184 rejected gaps)	7.27 s (133 rejected gaps)
Icon Sign	7.88 s (193 rejected gaps)	7.24 s (133 rejected gaps)
Side Mirror Displays	6.93 s (218 rejected gaps)	7.18 s (132 rejected gaps)
Vibrotactile Seat	6.93 s (205 rejected gaps)	7.25 s (135 rejected gaps)

Note that the exact percentile calculated can greatly change the result because the rejected gap values were approximately whole numbers. For example, for the rejected gaps in the control condition at the stop sign, the 79th percentile was 6.93 s and the 81st percentile was 7.93 s. Thus, if there was just one more rejected gap, the 80th percentile might be 0.5 s higher or lower, potentially changing whether the control condition was significantly different than the Icon Sign for this variable.

Figure 3-6 below and Table 3-6 below show the percentages of rejected gaps less than 7.5 s. Using the criteria from Rakauskas et al. (2009) that a difference of 2.5% is a significant difference, we see that when the driver was at the stop sign, the Side Mirror Displays and Vibrotactile Seat conditions were significantly higher (by at least 3.6%) than the control and Icon Sign conditions. When the driver was in the median, the Icon Sign and Side Mirror Displays conditions were significantly higher (by at least 2.7%) than the control and Vibrotactile Seat conditions. Recall that a higher percentage indicates less safe driving behavior.

The differences between the percentages of rejected gaps less than 7.5 s were compared via a proportion test (Moore and McCabe 2006, p. 562), which showed no significant differences. Therefore, we should perhaps question whether a difference of 2.5% should be considered significant for this sample size and number of rejected gaps.

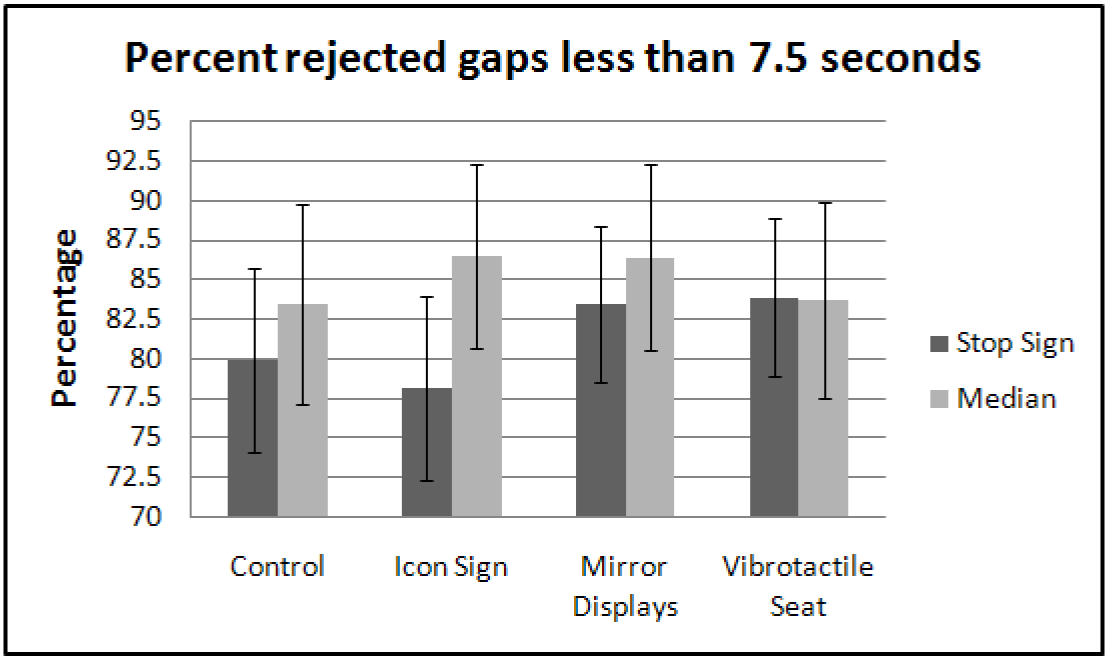


Figure 3-6: Percent of rejected gaps less than 7.5 s (confidence intervals calculated using method described in Moore and McCabe, 2006, p. 537).

Table 3-6: Percent of rejected gaps less than 7.5 s. Confidence intervals calculated using method described in Moore and McCabe (2006) p. 537.

Condition	Driver At Stop Sign	Driver In Median
Control	79.9% ± 5.8%	83.5% ± 6.3%
Icon Sign	78.2% ± 5.8%	86.5% ± 5.8%
Side Mirror Displays	83.5% ± 4.9%	86.4% ± 5.9%
Vibrotactile Seat	83.9% ± 5.0%	83.7% ± 6.2%

The 80th percentile rejected gap and percentage of rejected gaps less than 7.5 s both showed significant differences. For the southbound lanes, the results are nearly consistent, with the Icon Sign performing significantly better than the other DSSs but not always significantly better than the control. For the northbound lanes, the percentage of rejected gaps less than 7.5 s showed differences where the 80th percentile rejected gap did not. As described above, the anomaly in the 80th percentile rejected gap that is due to the whole number values for rejected gaps gives cause to question its validity. The non-significant results for the proportion test on the percentage of rejected gaps less than 7.5 s reduces confidence in that variable as well. Thus, we cannot give much weight to the rejected gap variables for this study.

3.3.1.2 Safety Margin

The safety margin did not show a significant difference between the DSSs and the control condition. For the northbound lanes, the Icon Sign was significantly lower than the Vibrotactile Seat. The Icon Sign had the lowest mean for the southbound lanes (not significant).

There was no significant main effect ($\alpha = 0.05$) for safety margin when the driver crossed the southbound (near) lanes. Figure 3-7 below shows the mean safety margins for the southbound lanes.

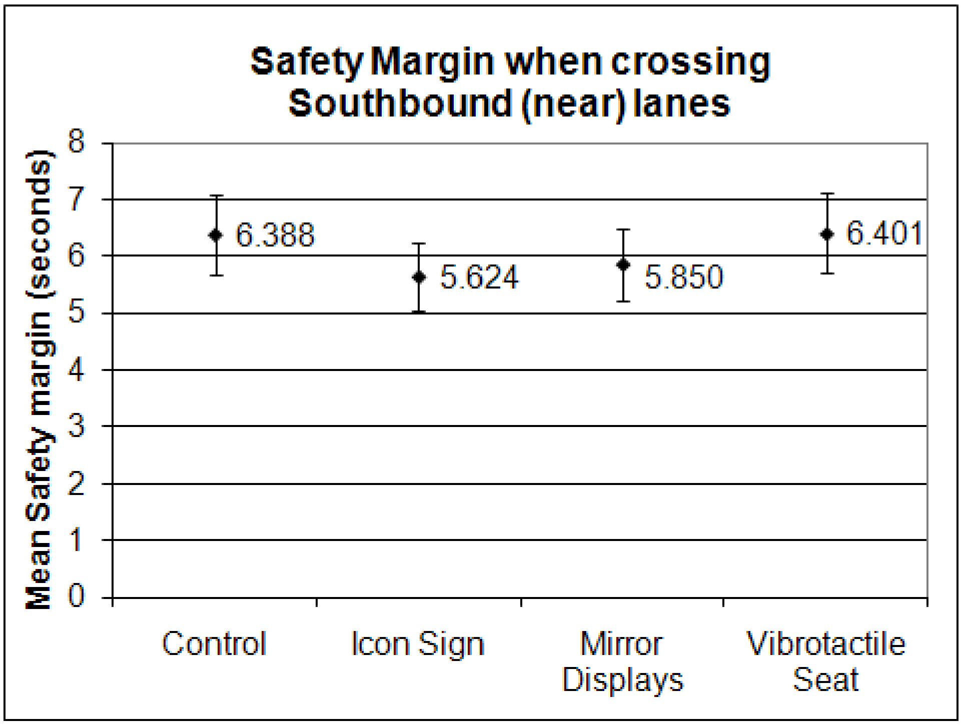


Figure 3-7: Southbound lanes mean safety margins with confidence intervals based on the t-distribution.

When the driver crossed the northbound (far) lanes, there was a significant main effect, $F(3,69) = 4.188$, $p = 0.010$. The post hoc Tukey test showed a significant difference between the Icon Sign (mean = 5.330 s) and Vibrotactile Seat (mean = 6.712 s). The Tukey test indicated the means must be at least 1.147 s apart to be considered significantly different. Figure 3-8 below shows the means and confidence intervals for each condition.

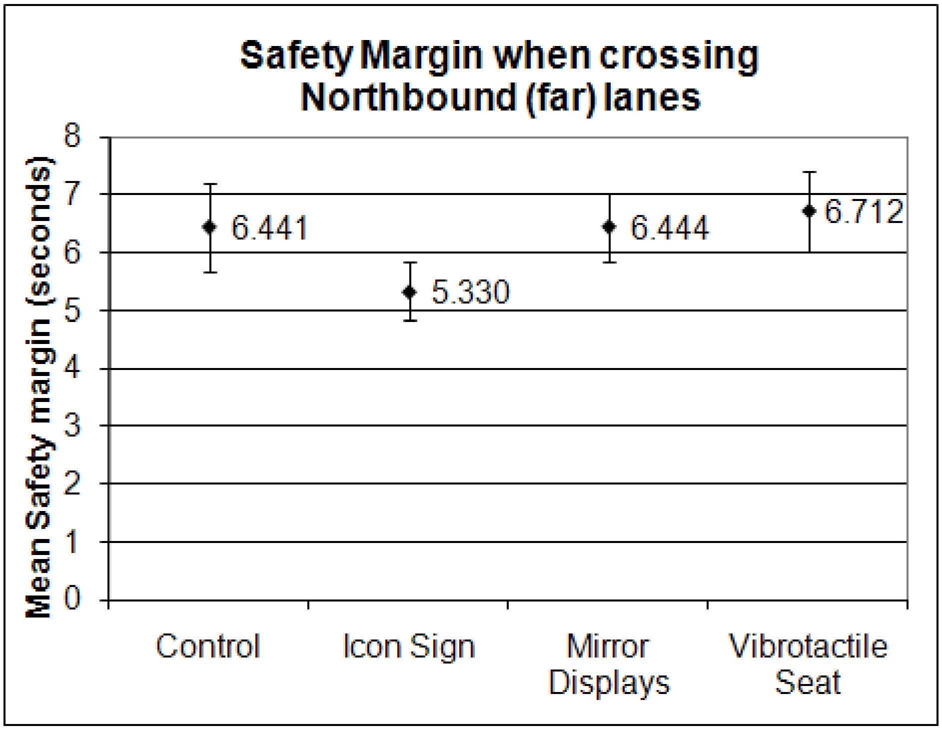


Figure 3-8: Northbound lanes mean safety margins with confidence intervals based on the t-distribution.

For the northbound lanes, the Icon Sign was at least 1.1 s lower than the other three conditions. The other three conditions were less than 0.3 s apart from each other, but the Icon Sign was significantly different from only the Vibrotactile Seat.

While not a statistically significant effect, the Icon Sign resulted in different safety margins than expected. The mean safety margin for the Icon Sign was lower than for the control condition (0.764 s difference for the southbound lanes and 1.111 s for the northbound lanes). The current study's procedure was based on Creaser et al. (2008), and also used the same traffic pattern. The direction of the two studies' results is consistent, but Creaser et al. (2008) found smaller differences (0.344 s for the southbound lanes and 0.564 s for the northbound lanes). Creaser et al. (2008) used night as well as day lighting, but if this is what caused the difference then we would have expected Creaser et al. (2008) to find an interaction between the lighting condition and the DSS condition.

3.3.1.3 Lag at Accelerator Press

Similar to the safety margin, the lag at accelerator press did not show a significant difference between the DSSs and the control condition. There was no significant main effect for Lag at Accelerator Press when the driver crossed the southbound (near) lanes (see Figure 3-9 below for the means and confidence intervals for each condition). For the northbound lanes, the Icon Sign was significantly lower than the Vibrotactile Seat. The Icon Sign had the lowest means for the southbound lanes (not significant).

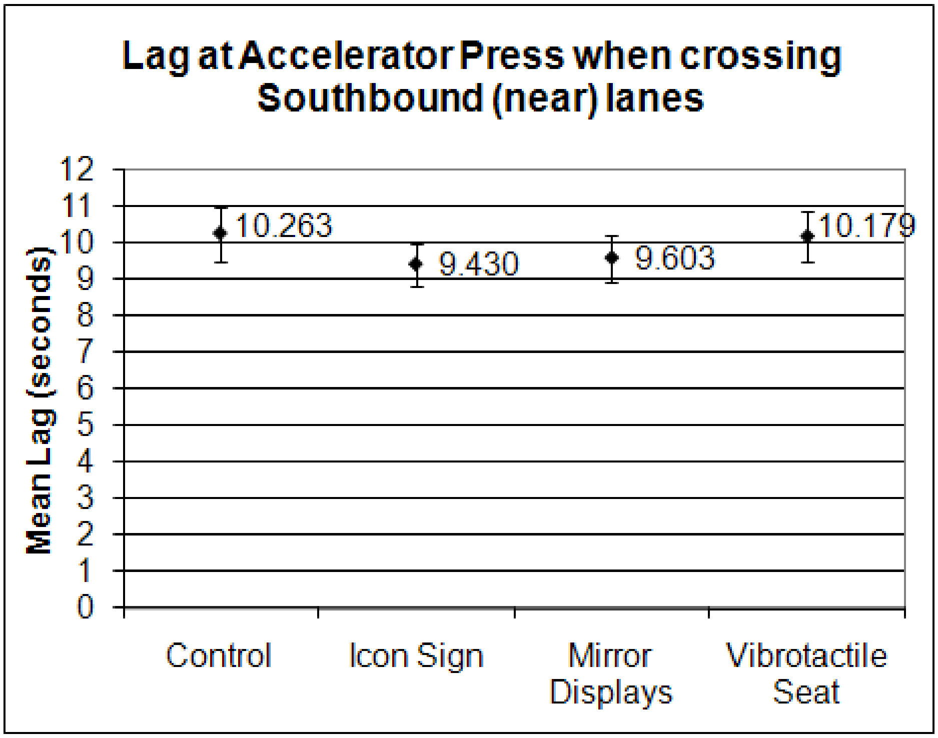


Figure 3-9: Southbound lanes mean lag at accelerator press with confidence intervals based on the t-distribution.

When the driver crossed the northbound (far) lanes, there was a significant main effect, $F(3,69) = 2.974$, $p = 0.040$. The post hoc Tukey test showed a significant difference between Icon Sign (mean = 9.217 s) and Vibrotactile Seat (mean = 10.459 s). The Tukey test indicated the means must be at least 1.217 s apart to be considered significantly different. Figure 3-10 below shows the means and confidence intervals for each condition.

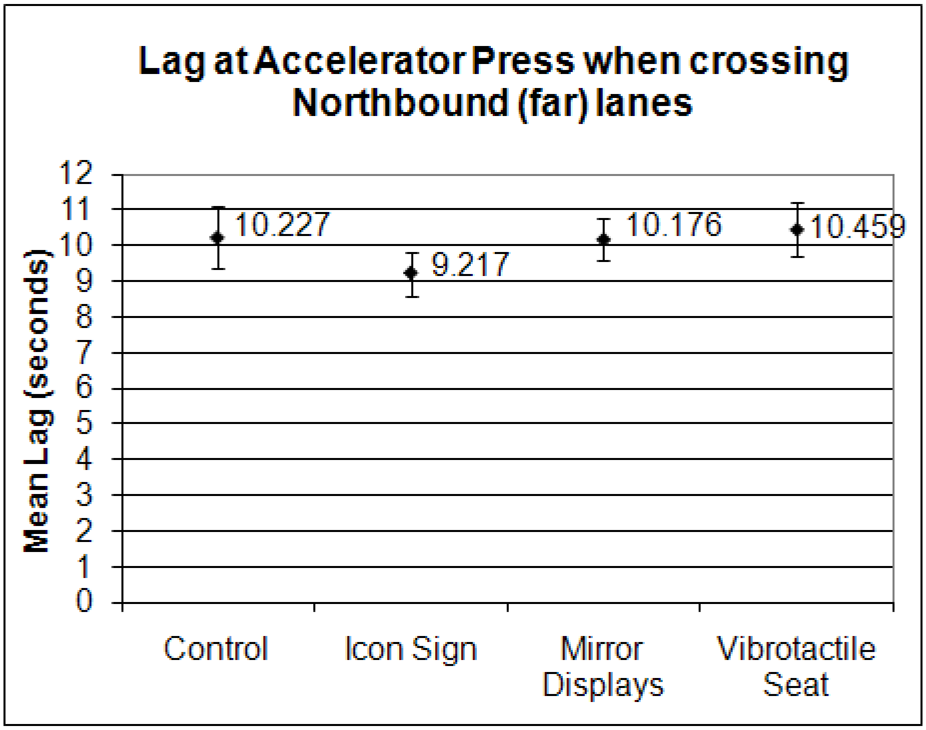


Figure 3-10: Northbound lanes mean lag at accelerator press with confidence intervals based on the t-distribution.

The results for the lag at accelerator press were much like the results for the safety margin. For the northbound lanes, the Icon Sign was at least 0.9 s lower than the other three conditions. The other three conditions were less than 0.3 s apart from each other, but the Icon Sign was significantly different from only the Vibrotactile Seat.

For the northbound lanes we have seen a significant difference between the Icon Sign and the Vibrotactile Seat for both the safety margin and the lag at accelerator press, but not for the accepted gap or movement time. These results suggest that for the Icon Sign, the drivers waited longer after the accepted gap became available before they proceeded. One explanation for this would be that the drivers spent longer observing the Icon Sign than the Vibrotactile Seat before they crossed the northbound lanes.

3.3.1.4 Frequency of One-Stage Maneuvers

One-stage maneuvers are typically less safe than two-stage maneuvers. Participants performed more one-stage maneuvers during the three DSS conditions than during the control condition (no DSS). Participants performed the most one-stage maneuvers when the Side Mirror Displays were present. However, the proportion test yielded no significant differences.

A maneuver was classified as a one-stage maneuver if the vehicle speed did not drop below two miles per hour as the participant drove through the median. Figure 3-11 below and Table 3-7 below show the percentage and number of one-stage maneuvers performed in each condition. For Figure 3-11, the plus-four confidence interval method (Moore and McCabe, 2006, p. 539) was used, which estimates both the percentage and confidence interval after adding two “successes” and two “failures” (or in this case, adding two one-stage maneuvers and adding two two-stage maneuvers). Thus, the percentages in Figure 3-11 are different than those in

Table 3-7, which simply used the number of one-stage maneuvers and the total number of maneuvers to calculate percentages.

It is interesting to note that two participants always performed one-stage maneuvers and 12 participants always performed two-stage maneuvers. Therefore, the experimental condition only had an effect on the behavior of 10 of the 24 participants.

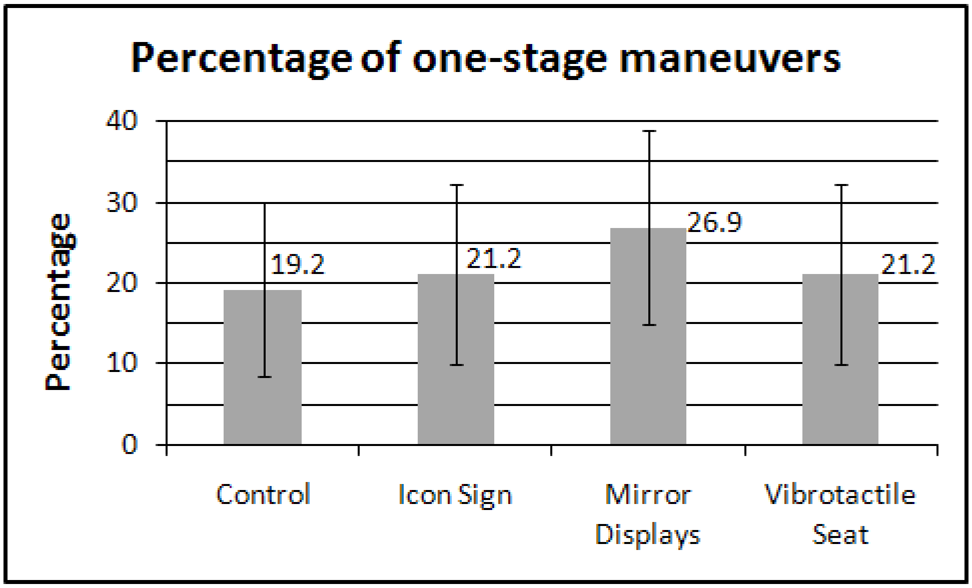


Figure 3-11: Percentage of one-stage maneuvers. Percentages and confidence intervals reflect the plus-four confidence interval method described in Moore and McCabe (2006), p. 539.

Table 3-7: Frequency of one-stage maneuvers.

Condition	Number of one-stage maneuvers
Control (48 maneuvers)	8 (16.7%)
Icon Sign (48 maneuvers)	9 (18.8%)
Side Mirror Displays (48 maneuvers)	12 (25.0%)
Vibrotactile Seat (48 maneuvers)	9 (18.8%)

One-stage maneuvers are considered a more risky behavior than two-stage maneuvers, since the driver in the median may not take as much time to evaluate traffic before crossing the northbound (far) lanes. However, a driver may not necessarily need much time to evaluate traffic. There may be a northbound gap so large that the driver can quickly perceive that conditions are relatively safe to proceed. A DSS may aid the driver in quickly perceiving the gap size. Figure 3-12 below compares the mean and standard deviation of accepted gap, safety margin, and lag at accelerator press for northbound gaps for the one-stage and two-stage maneuvers performed during this study.

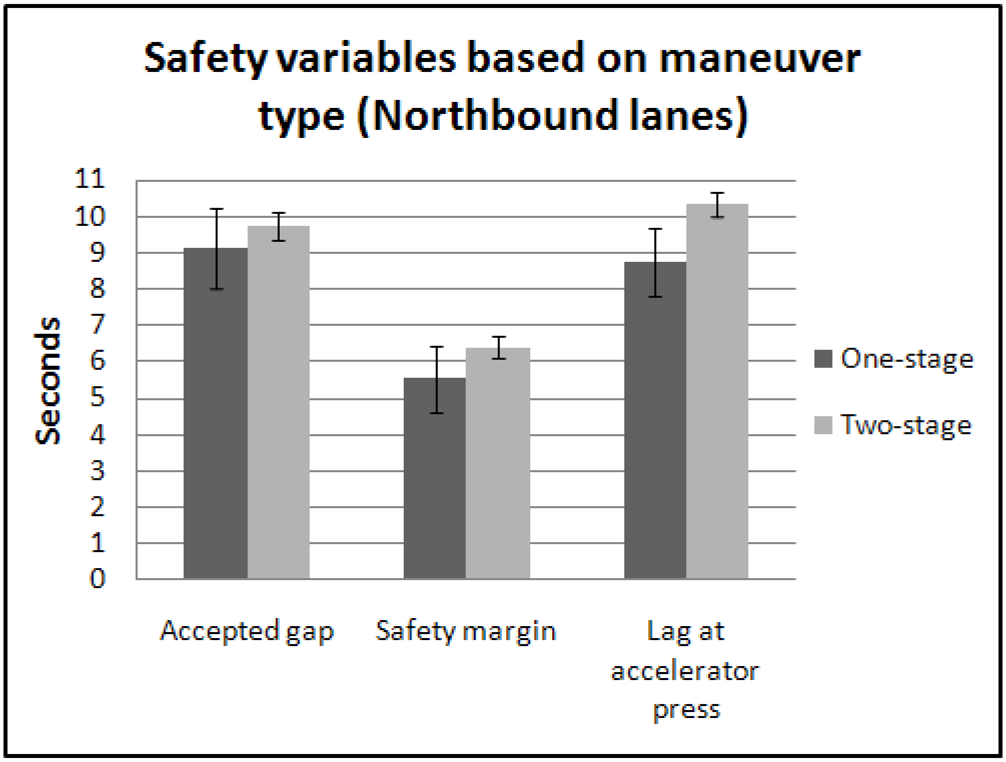


Figure 3-12: Safety variables based on maneuver type. The confidence intervals for two-stage maneuvers are much smaller due in part to the larger number of such maneuvers.

The means of these three variables were larger for two-stage maneuvers, indicating that one-stage maneuvers were generally less safe. Performing t-tests between the one-stage and two-stage maneuvers for these three variables, only the lag at accelerator press is significant, $t(37) = 3.297$, $p = 0.001\ 1$. Thus, it is difficult to say whether one-stage maneuvers were significantly less safe. When we also consider that the proportion test between the percentages of one-stage maneuvers showed no significant results, it is unclear whether the frequency of one-stage maneuvers shows any significant difference between the conditions.

3.3.1.5 Number of Conflicts

Before the experiment was conducted, only counting the number of collisions was planned. No collisions occurred during the study, so this variable was changed to number of conflicts. The number of conflicts (near misses) was counted by searching for especially small values of the safety margin variable (since safety margin measures how close the driver came to a collision). Based on this search, safety margins of two seconds or less were considered conflicts. However, the Minnesota Driver's Manual (State of Minnesota Department of Public Safety, 2008) advises three seconds of headway when following another vehicle on the highway. Safety margins of two seconds and three seconds were both considered when counting the number of conflicts. Thus, for each condition there are two counts, one for safety margins less than two seconds and one for safety margins less than three seconds. Note that each maneuver has two potential conflicts since the driver must cross two sets of lanes.

Figure 3-13 below and Table 3-8 below show the number and percentage of conflicts for each condition. As with number of one-stage maneuvers, the plus four confidence interval method (Moore and McCabe, 2006, p. 539) was used when calculating the percentages and confidence intervals for Figure 3-13. Thus, two conflicts and two non-conflicts were added to the data set used for Figure 3-13, while the percentages in Table 3-8 were simply calculated using the number of conflicts and the total possible conflicts.

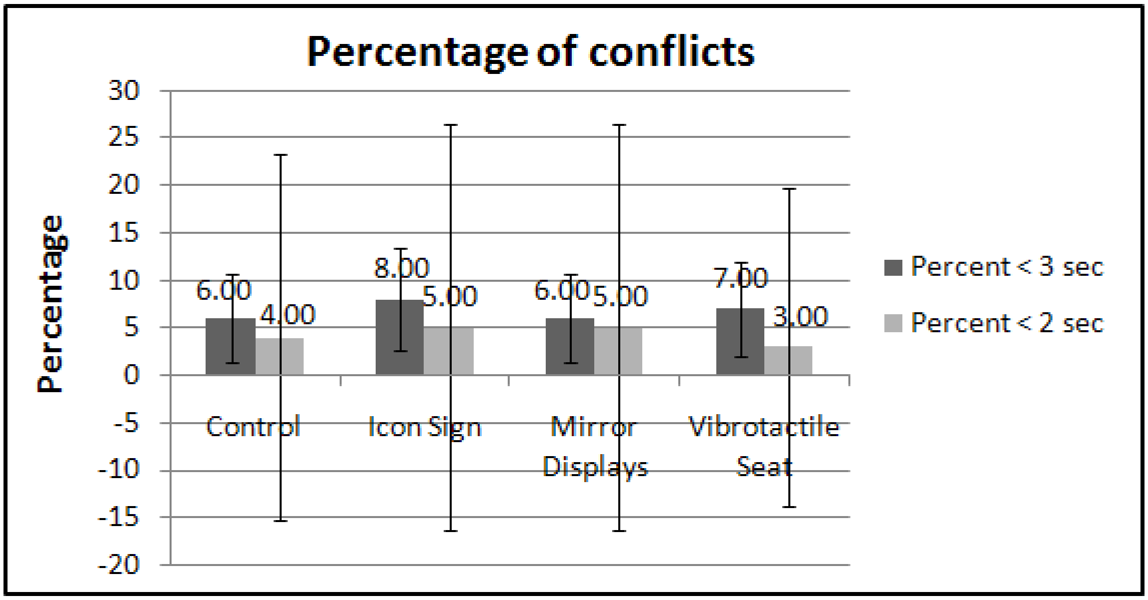


Figure 3-13: Percentage of maneuvers that were considered conflicts if the safety margin was less than three seconds or less than two seconds. Percentages and confidence intervals reflect the plus-four confidence interval method described in Moore and McCabe (2006), p. 539.

Table 3-8: Number of conflicts.

Condition	Number of conflicts, Safety Margin < 2 s	Number of conflicts, Safety Margin < 3 s
Control (96 lane crossings)	2 (2.08%)	4 (4.17%)
Icon Sign (96 lane crossings)	3 (3.13%)	6 (6.25%)
Side Mirror Displays (96 lane crossings)	3 (3.13%)	4 (4.17%)
Vibrotactile Seat (96 lane crossings)	1 (1.04%)	5 (5.21%)

Whether a limit of two seconds or three seconds is used greatly affects which conditions result in the most appropriate driving behavior. For a limit of two seconds, the Vibrotactile Seat is the safest, but for three seconds it is not even tied for safest. The Side Mirror Displays are tied for least safe for two seconds but are tied for most safe for three seconds. Additionally, the proportion test performed on the number of conflicts showed no significant differences for either two seconds or three seconds. Thus, it appears there were no significant differences between the conditions in terms of the number of conflicts.

3.3.2 Dependent Variables for Usability

The ANOVA yielded no significant results for the workload questionnaire, the confidence questionnaire, the usability scale questionnaire, or the ranking questionnaire. The proportion tests performed on the comprehension question and the use question did not show any significant differences.

3.3.2.1 DSS Comprehension

At the time the participants answered the comprehension question, they only knew that the DSSs monitored traffic and provided information to help them decide when to cross the intersection.

Based on the participants' written descriptions of what they thought the DSSs meant, it appears the Side Mirror Displays were most frequently comprehended (87.5%) and the Vibrotactile Seat was least frequently comprehended (58.3%). However, the proportion test showed no significant differences between the DSS comprehension rates. Table 3-9 below shows the percentages for each decision support system, and Figure 3-14 below shows the estimated percentages and confidence intervals (based on the plus four confidence interval method, Moore and McCabe, 2006, p. 539).

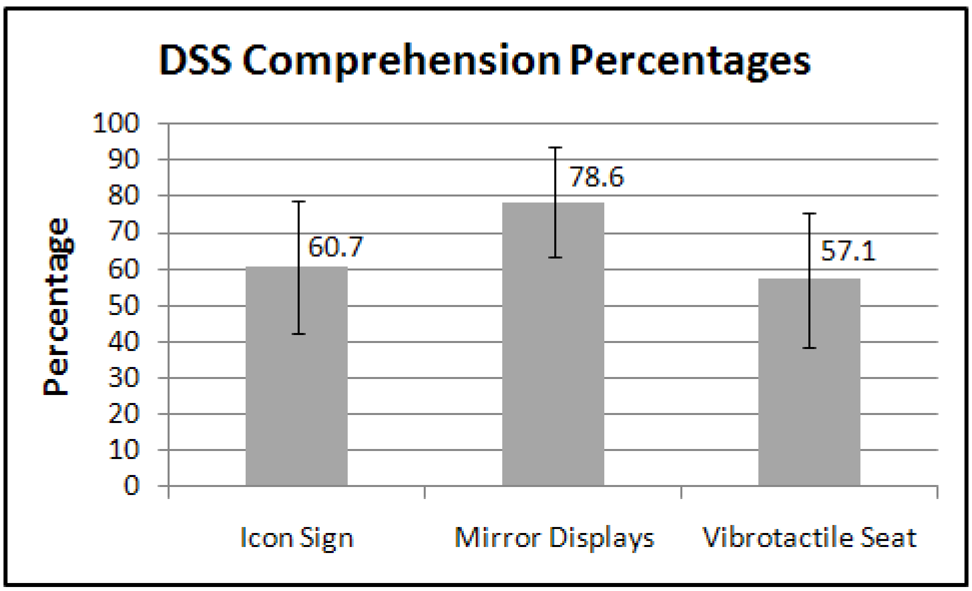


Figure 3-14: Decision support system comprehension. Percentages and confidence intervals reflect the plus-four confidence interval method described in Moore and McCabe (2006), p. 539.

Table 3-9: DSS comprehension (percentage).

Decision Support System	Percent Comprehension (at least partial comprehension)
Icon Sign	62.5% (15 of 24 participants)
Side Mirror Displays	83.3% (20 of 24 participants)
Vibrotactile Seat	58.3% (14 of 24 participants) – This includes the 16.7% that mistakenly thought the vibration intensity varied based on the distance to the approaching vehicles, but the intensity was in fact constant.

Some of the participants' responses were ambiguous or vague, making it difficult to determine whether they comprehended the DSSs. Perhaps they rushed through the question or did not elaborate as much as they could have. The Icon Sign was particularly complex, and many participants did not give enough detail for us to be sure they understood every part of it. Thus, the percentages shown include partial comprehension. Portions of the Icon Sign are redundant, so perhaps partial comprehension is all that is needed to properly use the Icon Sign. Appendix V has a complete list of all the participants' responses and whether each response was considered to indicate comprehension.

The Side Mirror Displays may have been comprehended the most because the display continuously changed while traffic was within 7.5 s. The Icon Sign only changed appearance when traffic crossed the 11 s or 7.5 s thresholds, and the Vibrotactile Seat only changed when traffic crossed the 7.5 s threshold. Thus, if the traffic stream had a long series of gaps less than 7.5 s, the Icon Sign and Vibrotactile Seat would appear to never change state, making them more difficult to interpret. In the same situation, the fill bar on the Side Mirror Displays would be providing continuous feedback about traffic.

It was anticipated that the Vibrotactile Seat might be more difficult to interpret because drivers are not as used to haptic and vibrotactile warning systems compared to visual warning systems. Looking at the participant comments (listed in Appendix V), it appears there were a number of interpretations of the meaning of the Vibrotactile Seat, such as:

1. To alert the driver of the upcoming intersection.
2. To tell the driver which direction to turn the wheel.
3. To wake up a sleepy driver.

3.3.2.2 DSS Use

At the time the participants answered the use question, they only knew that the DSSs monitored traffic and provided information to help them decide when to cross the intersection.

Based on the participants' responses to the yes/no question "Did you use the information from this system to help you make your crossing decisions?", the Side Mirror Displays were used most often (54.2%) and the Vibrotactile Seat was used least often (45.8%). Note that exactly half (12) of the participants reported using the Icon Sign, just over half (13) reported using the Side Mirror Displays, and just less than half (11) reported using the Vibrotactile Seat. The proportion test showed no significant differences between the DSSs. Thus, it appears there was little difference in participants' self-reported use of the DSSs.

Table 3-10 below shows the percentages of participants that reported using the information from each DSS, and Figure 3-15 below shows the estimated percentages and confidence intervals (based on the plus four confidence interval method, Moore and McCabe, 2006, p. 539). Participants were also asked to explain their answer. If they answered "yes", they were to explain what information they used or how they used the information to make their decision of when to cross. If they answered "no", they were to explain why they did not use the information.

Appendix W lists the complete results for this item, including the participants' yes/no answers and explanations for each DSS. Looking at the explanations, it appears some participants seemed to interpret the question "Did you use the information from this system…?" as asking whether they used the DSS exclusively or used it more than their own judgment. The question was meant to ask whether the DSS assisted even if the participant used his/her own judgment in the end. It may be worth changing this from a yes/no question to a Likert scale that asks the participant to report the degree to which s/he used the DSSs.

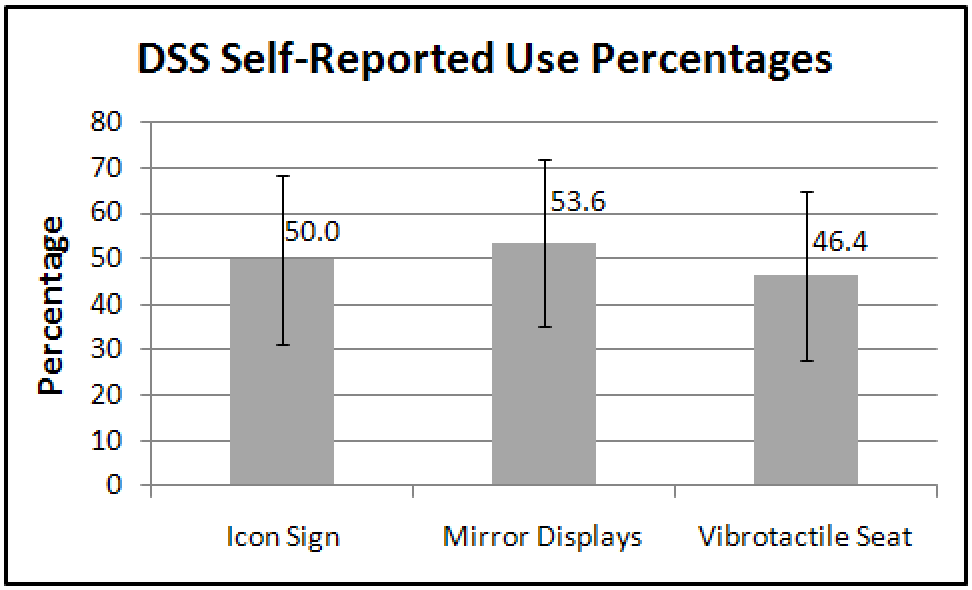


Figure 3-15: DSS self-reported use. Percentages and confidence intervals reflect the plus-four confidence interval method described in Moore and McCabe (2006), p. 539.

Table 3-10: Reported DSS use.

Decision Support System	Percentage of participants that reported using the information from the DSS
Icon Sign	50.0% (12 of 24 participants)
Side Mirror Displays	54.2% (13 of 24 participants)
Vibrotactile Seat	45.8% (11 of 24 participants)

It is interesting that the reported use rates are so similar to each other while the comprehension rates were not. Calculating the correlation between the two variables, we get the results shown in Table 3-11 below.

Table 3-11: Correlation between comprehension and use.

Decision Support System	Comprehension	Reported Use	Correlation between comprehension and reported use
Icon Sign	62.5%	50.0%	0.430
Side Mirror Displays	83.3%	54.2%	0.262
Vibrotactile Seat	58.3%	45.8%	0.438

There are a few cases where a participant misinterpreted a DSS but reported using it. The cases where a participant correctly interpreted a DSS but reported not using it are more frequent.

The correlation is especially low for the Side Mirror Displays, with many more participants comprehending them than using them. This may be because the participants preferred a clear advisory message, such as the Icon Sign's red symbols, or the Vibrotactile Seat's vibration when it was unsafe to proceed.

3.3.2.3 Usability Scale: Usefulness and Satisfying

At the time the participants answered this usability questionnaire, they had read a description of the meaning of the DSS they had encountered during the most recent experimental condition.

The ANOVA did not show significant differences between the DSSs for either the Usefulness or Satisfying scales.

The usability questionnaire described in Van der Laan, Heino, and De Waard, (1997) was used to rate the DSSs on Usefulness and Satisfying scales. Table 3-12 below lists the results for each DSS, and Figure 3-16 below plots them. The maximum score for both scales is 2 and the minimum score is -2.

Table 3-12: Usability scales – usefulness and satisfying.

Decision Support System	Usefulness	Satisfying
Icon Sign	1.06	0.55
Side Mirror Displays	0.41	0.11
Vibrotactile Seat	0.62	-0.16

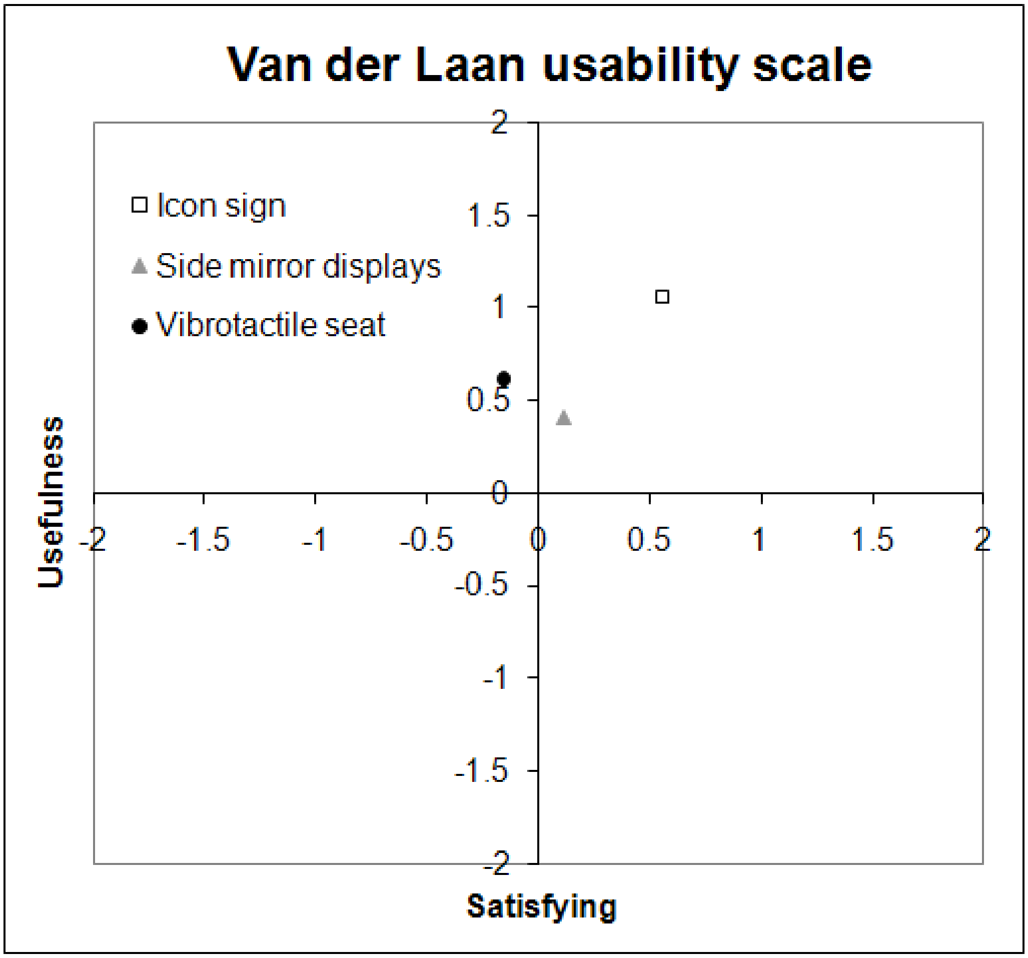


Figure 3-16: Usability scales – usefulness and satisfying.

The Icon Sign was ranked as most useful and most satisfying. The Side Mirror Displays and Vibrotactile Seat appear to be rated nearly equally overall, with the Side Mirror Displays rated higher on satisfying and the Vibrotactile Seat rated higher on usefulness.

It is not surprising that the Vibrotactile Seat was rated as low as it was on both scales considering the number of participants who commented it was confusing or annoying (comments are listed in Appendix W). It is odd that the Side Mirror Displays were rated lowest on usefulness after having the highest rates of comprehension and reported use. Because this questionnaire was answered after the participants read explanations of the meanings of the DSSs, it could be that the participants decided the Icon Sign was worth rating high, even if they did not understand it at first.

3.3.2.4 DSS Ranking

At the time the participants answered the ranking questionnaire, they had read descriptions of the meanings of all the DSSs in the experiment.

The ranking questionnaire asked the participants to rank order each DSS, giving one DSS a ranking of 1 (most preferred), another DSS a ranking of 2 (second most preferred), and another

DSS a ranking of 3 (least preferred). Participants were asked to explain why they chose the ranking for each DSS.

Table 3-13 below lists the mean ranking for each DSS and how often each DSS received each ranking. Appendix X has a complete list of the rankings and explanations.

The Icon Sign was most preferred by a large margin. The Vibrotactile Seat was preferred over the Side Mirror Displays by a small margin. Although the ANOVA only approached statistical significance ($F(2,46) = 2.724$, $p = 0.078$), the Icon Sign was ranked as most preferred twice as often as the other two DSSs, so it appears clear that the Icon Sign was most preferred. The explanations for the rankings (in Appendix X) contain several comments that imply the drivers preferred the Icon Sign because they are more used to getting information from traffic signs:

1. Icon Sign: "Most familiar / easy"
2. Icon Sign: "Least confusing. Very easy to understand. Relates to stoplight experience."
3. Side Mirror Displays: "Confusing at first. Not where I would look for information."

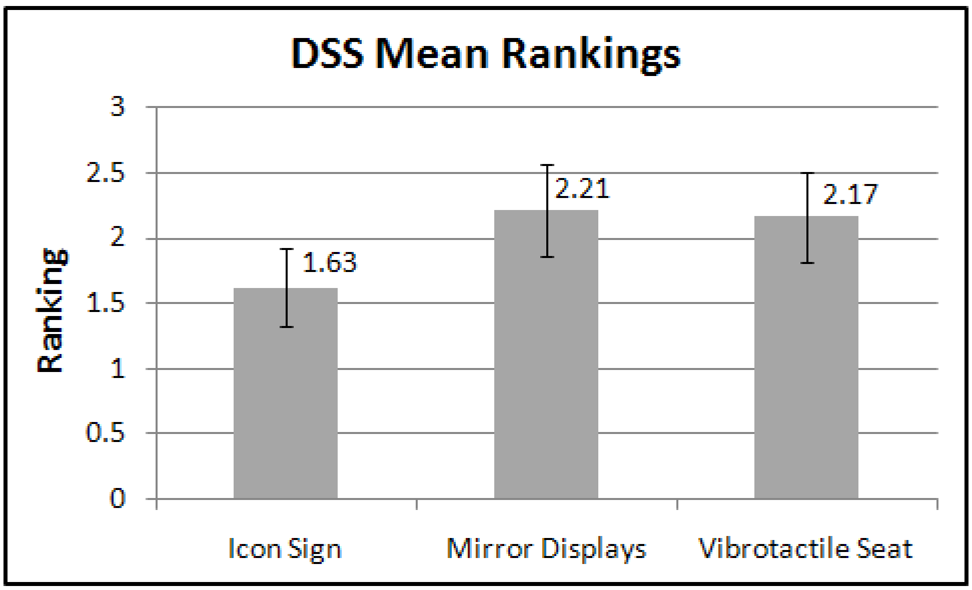


Figure 3-17: Mean rankings for each DSS with confidence intervals based on the t-distribution.

Table 3-13: Ranking questionnaire results.

	Icon Sign	Side Mirror Displays	Vibrotactile Seat
Mean ranking	1.63	2.21	2.17
Percentage ranked “1” (most preferred)	50.0%	25.0%	25.0%
Percentage ranked “2” (second most preferred)	37.5%	29.2%	33.3%
Percentage ranked “3” (least preferred)	12.5%	45.8%	41.7%

3.4 Discussion

3.4.1 General

The DSSs tested in this study differed in the amount of information they provided. Due to simulator hardware limitations, it was not possible to design the in-vehicle systems to have the same amount of information as the Icon Sign. As a result, it is not possible to know for sure whether differences between the DSSs were due to modality and location (inside or outside the vehicle), or due to differences in amount of information.

None of the DSSs were statistically significantly different from the control condition for any of the variables. The rejected gap variables imply differences from the control and differences between the DSSs, but there is cause to be skeptical of these variables, as explained in the next paragraphs. One possible explanation for the lack of differences from the control would be that the DSSs distracted the drivers as much as they helped. In other words, the DSSs (whether visual or not) assisted the drivers, but simultaneously consumed enough of the driver’s attention resources that driver performance was reduced, cancelling out the assistance.

The past standards were that a difference of 0.5 s in the 80th percentile rejected gap was considered significant, and a difference of 2.5% in the percent of rejected gaps less than 7.5 s was considered significant (Rakauskas et al., 2009). There is cause to question whether these standards can apply to the current study due to its sample size and traffic simulation, which used gap sizes that were approximately whole numbers. The current study had a much smaller sample size than Rakauskas et al. (2009), which noted the need for large samples to draw generalizable conclusions for these variables. The study performed by Rakauskas et al. (2009) was an on road study, thus the gap sizes were positive real numbers instead of approximate whole numbers. Considering there were about 200 rejected gaps at the stop sign in each condition, each maneuver accounted for 0.5%, thus the addition of only a few rejected gaps could alter the percentage of rejected gaps less than 7.5 s by 2.5%. Note that a few rejected gaps could have been added if just one participant had waited slightly longer (perhaps 30 seconds longer) during a single trial. Adding only a few rejected gaps could also change the 80th percentile rejected gap by as much as one second since the gaps were approximately whole numbers. It is possible that this causes other less-apparent quirks in the data as well. Altering the traffic generation algorithm to include gap sizes of decimal values (perhaps increments of 0.1 s) may reduce this problem.

Another quirk to the rejected gap variables is that they only partially reflect driver behavior. The rejected gap variables partially reflect driver behavior and partially reflect traffic conditions. The rejected gap data set is whatever portion of the traffic stream the driver rejected before crossing the intersection. For example, suppose there was a stream of traffic gaps less than 7.5 s, and the driver accepted the first gap above 7.5 s. The percentage of rejected gaps less than 7.5 s would be 100% (with high values indicating unsafe behavior for this variable), even though the driver accepted a safe gap.

Future work should consider more complex data analysis methods, such as:

1. Investigating significance testing methods for the rejected gap variables.
2. Comparing and correlating variables:
    a. Wait time vs. accepted gap – Do drivers accept smaller gaps if they have been waiting longer?
    b. Accepted gap vs. rejected gap – Is it true that if a driver rejects unsafe gaps that s/he will also accept safe gaps? In each trial, how often is the accepted gap higher than the largest rejected gap?
    c. Rejected gap vs. safety margin – Is it true that if a driver rejects unsafe gaps that s/he will not come close to having a collision?

    These comparisons were not made for this study because the focus was on the DSSs tested. Ideally, these comparisons and correlations would be done using data from many CICAS-SSA studies with larger sample sizes than this study.
3. Developing a way to estimate how long a driver would have had to wait if s/he did not accept a gap (the simulator data collection was not set up in a way that allowed this variable to be calculated). The correlation between this "wait time for next safe gap" and the accepted gap could prove informative. The researcher's observations while assisting with on-road CICAS-SSA studies (the studies discussed in Gorjestani et al., 2008; and Rakauskas et al., 2009) suggest that drivers may accept smaller gaps if they are going to have to wait a long time for another safe-sized gap to arrive.

In this and previous studies, participants were told little about what the DSS messages meant. Designing a DSS that is quickly intuitive and benefits a driver right away has been the focus. However, it could be useful to examine driver performance both before and after the DSSs have been explained to them. An experiment could have four trials per condition instead of two, and explain the DSS after the first two trials. By also examining the best case scenario in which the driver knows how to use the DSS, we would have a clearer picture of the advantages and disadvantages of each DSS. If a DSS is helpful only after a driver fully understands it, it could be redesigned to be more intuitive instead of being thrown out altogether. Alternatively, more efforts could be put towards a training program for future users of the DSS. Likewise, if a DSS is less than helpful once it is fully understood, this knowledge would be helpful in making informed decisions on whether to keep, throw out, or redesign the DSS.

Due to the difficulty of interpreting the results of the open-ended comprehension question, it could be useful to have more comprehension related questions, such as:

1. "How well do you feel you understand [this DSS]?" This question would be answered on a Likert scale, and would be asked before the participant read the full explanation of the DSS.
2. "Now that you have read the description of [this DSS], how well did your interpretation match the description?" This question would be answered on a Likert scale, and would be asked after the participant read the full explanation of the DSS.

3. "Which parts of [this DSS] were mentioned in the description but were not included in your own interpretation?" This would be an open-ended question.

The participants' comments on the reported use question (see Appendix W) often seem to indicate a reluctance to even give the DSSs a try: "I use my eyes", "don't like the system, ignored it". Occasionally there were comments such as "I use both system and eyes", which is the intended design. Drivers are not expected to use the DSSs to the exclusion of their own judgment, but should strongly consider following the advisory messages of the DSS if their own judgment indicates it is safe to proceed.

3.4.2 Icon Sign

It was important to include the Icon Sign as a reference since if an in-vehicle DSS were to be designed with the intent of putting it on the market to be used for rural intersection navigation, the in-vehicle DSS would most certainly be compared to the Icon Sign.

As mentioned in the results section, there was a significant difference between the Icon Sign and the Vibrotactile Seat for both the safety margin and the lag at accelerator press, but only for the northbound lanes (i.e. when the participant was in the median and then crossed the far lanes). However, there were no significant differences for the accepted gap and movement time. This means that for the Icon Sign, participants accepted the same size of gaps, but once the gap was available they delayed before proceeding. We can estimate that this additional delay was approximately 1.242 s. This time is the difference between the Icon Sign and Vibrotactile Seat for the mean lag at accelerator press for the northbound lanes. The mean wait times for the northbound lanes were on the order of 10 s with a standard deviation of 3 s, thus this delay was not enough to show up as a significant difference in the wait time variable. Note that this delay was not sufficient to indicate a significant difference between the Icon Sign and the control condition.

Participants may have delayed to spend more time observing the Icon Sign. This could be due to the physical limitation of watching both the Icon Sign and approaching traffic. Once the participants decided a gap in traffic was large enough to proceed, they shifted their gaze to the Icon Sign to confirm their decision before proceeding. When using the Vibrotactile Seat, the participants did not have to shift their gaze to receive information from the DSSs and thus did not experience this delay. However, this still raises the question of why there is only a difference between the Icon Sign and Vibrotactile Seat in the northbound lanes. One possible explanation is that since only one pad was vibrating while in the median, participants were better able to interpret the seat's messages and thus follow the seat's advice and make safer decisions. In the comprehension question (see Appendix V), very few participants commented that the Vibrotactile Seat had both left and right vibrations, especially the comments of those that misinterpreted the Vibrotactile Seat. Thus, it appears possible that many participants were not aware of the left and right vibrations, which would make the Vibrotactile Seat more confusing for the southbound lanes than the northbound lanes.

Although not a statistically significant difference, it is surprising that the mean safety margin for the Icon Sign was lower than the control condition. The mean safety margin for the Icon Sign was 0.764 s lower for the southbound lanes and 1.111 s lower for the northbound lanes. The differences in the Creaser et al. (2008) simulator study were 0.344 s for the southbound lanes and 0.564 s for the northbound lanes. The current study and Creaser et al. (2008) used many of the same procedures and the same traffic randomization algorithm. Creaser et al. (2008) used night as well as day lighting, but if this is what caused the difference then we would expect Creaser et al. (2008) to have found an interaction between the lighting condition and the DSS condition. It appears the only other explanation would be the larger sample size of the Creaser et al. (2008) study, which provided a more stable estimate of performance compared to the current study.

The Icon Sign was clearly preferred over the other two DSSs. The Icon Sign was ranked as most preferred more often, and was rated higher on the Usefulness and Satisfying scales. However, the Icon Sign was not comprehended as often as the Side Mirror Displays. The comprehension percentage for the Icon Sign was somewhat higher than for the Vibrotactile Seat, and there appears to be more misinterpretation of the Vibrotactile Seat. Participants sometimes thought the Vibrotactile Seat meant something it did not, whereas the Icon Sign and Side Mirror Displays were either correctly interpreted or had no clear meaning.

3.4.3 Side Mirror Displays

It is interesting that for the Side Mirror Displays, the safety margins are much higher for the northbound lanes than for the southbound lanes. The lag at accelerator press shows the same trend. Out of all four conditions, the Side Mirror Displays show the greatest difference between the northbound and southbound lanes for these two variables. The highway intersection forms an angle of 100 degrees (as opposed to 90 degrees), and the participant's vehicle tends to be facing slightly away from the southbound traffic and slightly toward the northbound traffic. Because the Side Mirror Displays are attached to the car, this would mean the visual angle between northbound traffic and the right Side Mirror Display is smaller than the visual angle between southbound traffic and the left Side Mirror Display. Perhaps this allowed the participants to more easily monitor northbound traffic and the right Side Mirror Display than to monitor the southbound traffic and the left Side Mirror Display.

The Icon Sign was clearly preferred over the Side Mirror Displays. Some participants commented (see Appendix X) that the Icon Sign was easy to see and that the Side Mirror Displays were not, and some participants commented the exact opposite. However, as mentioned in the ranking questionnaire results, (*3.3.2.4 DSS Ranking*) it appears that at least some participants were biased towards the Icon Sign simply because it is a traffic sign. For example, one participant said the Icon Sign was "Least confusing. Very easy to understand. Relates to stoplight experience." and another commented it was "most familiar / easy."

Participants' comments (see Appendix W and Appendix X) also seem to indicate they would have preferred the Side Mirror Displays to have a clear advisory message. For example, one participant commented "I wasn't sure how much of a red bar I needed to be safe", and another noted it "didn't tell you anything you couldn't see". The Side Mirror Displays were meant to be a sensory augmentation rather than an advisory, the hypothesis being that it may be easier to perceive movement of the bar gauge than it is to perceive movement of the approaching car. However, even though the same information is presented by watching the bar gauge and by watching traffic, the novel context of the bar gauge may make the information more difficult to process.

The experimenter has noticed that the simulator chassis's right A-pillar can completely block the driver's view of a car approaching from the right. One participant verbally commented that on one occasion the right mirror display indicated the presence of a car she did not see. Although she did not say whether this was because the A-pillar was blocking her view, this demonstrates that the Side Mirror Displays can in some cases serve as a sensory augmentation, alerting the driver to the presence of a vehicle she would not otherwise see. However, as this is only one case, no strong conclusions can be drawn.

Another reason for the preference for the Icon Sign over the Side Mirror Displays could be that the Icon Sign provided information about traffic as far as 11 s away, whereas the Side Mirror Displays only provided information out to 7.5 s. Participants may have noticed this, consciously or unconsciously, and decided the Side Mirror Displays were not as helpful.

Although the Icon Sign was clearly preferred over the other DSSs, the comprehension results seem to indicate the Side Mirror Displays were most easily understood. One possible reason for this is that the display on the Side Mirror Displays continuously changes (as long as traffic is within 7.5 s), while the Icon Sign and Vibrotactile Seat may appear static. The Icon Sign and the Vibrotactile Seat change their displays when a gap larger than 7.5 s becomes available to the driver, and the Icon Sign also changes when a gap larger than 11 s becomes available to the driver. If there is a long line of gaps less than 7.5 s from both sides, these displays may appear to never change state. Even if a gap of 8 s becomes available, the displays will only change state for 0.5 s, reverting back to their warning states once the approaching vehicle is 7.5 s away. Based on verbal and written comments (see Appendix V) from participants and from observations during the experiments, it appears this brief change (of warning to caution and back to warning) can be easy to miss. For example, one participant's answer to the Icon Sign comprehension question was "the sign tells you that the highway is divided and not to turn into oncoming traffic". The participant may have simply neglected to write a more complete explanation, but the comment as written describes any divided highway sign, not just the Icon Sign. This causes some doubt as to whether the participant realized the Icon Sign display could change. Another participant answered that the purpose of the Vibrotactile Seat was to "alert driver of upcoming intersection", a statement which does not suggest that the vibration will change based on traffic. Thus, the Icon Sign and Vibrotactile Seat have the weakness of sometimes appearing to never change state, and drivers that are less safe (accepting gaps less than 7.5 s), are less likely to see the state change.

Future studies testing the Side Mirror Displays should extend the fill bar gauge out to 11 s and incorporate advisory messages for the 11 s and 7.5 s thresholds. These features were not included in the current study so that the simpler design could be more easily evaluated, determining which of its features worked and which didn't. In retrospect, it may have been preferable for the Side Mirror Displays to turn blank when no vehicle was within 7.5 s, instead of having the bar gauge remain empty. This would make it immediately apparent that no vehicle was close, as opposed to drivers having to wait an extra moment to see whether the fill bar remained empty. Perhaps the display turning blank in this way would have served as the advisory message that the participants seemed to want.

Lastly, there is no evidence that the participants calibrated the Side Mirror Displays to their current behavior as they did with the Countdown Sign described in Creaser et al. (2008, 2007). Section *3.2.2.3.2.1 Reasoning Behind Side Mirror Displays* elaborates on this, but essentially the participants used the timer on the Countdown Sign to justify their current behavior instead of following the Countdown Sign's warnings. Creaser et al. (2005, pp. 59, 174) hypothesized that using a non-absolute measure for time-to-arrival (such as a fill bar) might prevent this trend, and so far this appears to be the case. If future studies extend the bar gauge out to 11 s, it will be important to continue checking for this sort of calibration.

3.4.4 Vibrotactile Seat

The Vibrotactile Seat was rated higher on Usefulness but lower on Satisfying compared to the Side Mirror Displays, so they appear approximately equal in total. These two DSSs were also rated similar on the ranking questionnaire, thus there appears to be equal preference for the two. However, the Vibrotactile Seat was the least comprehended of the three DSSs. As mentioned in the results section on comprehension (*3.3.2.1 DSS Comprehension*), the comments (see Appendix V) showed a number misinterpretations of the Vibrotactile Seat. The Vibrotactile Seat was misinterpreted more often than the other DSSs. For example, one participant reported that the seat was indicating which direction to turn the steering wheel, and a few participants thought the seat's only function was to make them more alert or warn them of the upcoming intersection. Several participants commented in the ranking questionnaire (see Appendix X) that the Vibrotactile Seat was annoying or irritating. A portion of these comments were from participants who appeared to comprehend the Vibrotactile Seat. Only one participant commented that the Side Mirror Displays were annoying, and there were no such comments for the Icon Sign. Future studies should try to determine what it is about the Vibrotactile Seat that is annoying and whether these annoying aspects can be changed.

As mentioned above in *3.4.3 Side Mirror Displays*, the Icon Sign provided information about traffic as far as 11 s away while the Side Mirror Displays did not, which may be why the Icon Sign was the more preferred of the two. The same explanation could apply to why the Icon Sign was preferred over the Vibrotactile Seat, since both the Side Mirror Displays and Vibrotactile Seat only provide information about traffic as far as 7.5 s away.

As mentioned above in the discussion on the Icon Sign (*3.4.2 Icon Sign*), it appears that perhaps participants were more able to interpret the Vibrotactile Seat in the median than at the stop sign because only one pad was vibrating. Therefore, spacing the vibrational pads farther apart may allow drivers to discern the left and right vibrations more easily

Although previous literature notes that haptic signals can result in faster reaction times, it appears that haptic displays can be more difficult to interpret. The vibrotactile warning studies mentioned in *1.4.1 Tactile Displays Literature* may have had more explanation of what the vibration meant, whereas this study only explained that the system was meant to help the driver make decisions about when to cross the intersection. Due to the novelty of such systems, more explanation of a vibrotactile system may be necessary for participants to comprehend and make good use of it, or it could be that this particular application (thru-stop intersections) is not well-suited for vibrotactile warnings. As mentioned in the general discussion above (*3.4.1 General*), it could be worthwhile to test a vibrotactile system in an experiment that compared participants' behavior before and after a detailed explanation of how the DSSs worked.

3.5 Larger Scale Study Conclusions

In-vehicle DSSs appear to be feasible for the purposes of assisting drivers with navigating rural thru-stop intersections. None of the DSSs, in-vehicle or extra-vehicle, showed a statistically significant difference in driver behavior compared to the control condition.

The Icon Sign was most preferred and was rated most usable but was not the most comprehended DSS. The Icon Sign may have been preferred because drivers are more accustomed to gaining information from traffic signs and signals than from other systems. The Side Mirror Displays' high comprehension rate shows that it has potential for future studies. The high comprehension rate could have been because the Side Mirror Displays continuously changed as long as traffic was within 7.5 s. Future iterations could provide information about traffic as far as 11 s away, and add advisory messages for when approaching traffic is 7.5 s away and 11 s away. The Vibrotactile Seat was least comprehended and most often misinterpreted. Future studies may be able to improve comprehension by spacing the vibrational pads farther apart.

Despite the higher comprehension rates for the Icon Sign and the Side Mirror Displays, it is important to remember that they are visual and thus force the driver to shift his/her gaze between the display and the road. This may be a challenge for these systems that could be addressed in future research and development. Haptic displays such as the Vibrotactile Seat do not have this problem, though they are less readily comprehended.

Future studies should consider examining driver behavior both before and after an explanation of the DSSs is provided. This study and previous studies in the CICAS-SSA program have focused on designing intuitive systems that need no explanation. However, with the proper design and implementation of training programs, non-intuitive DSSs could be helpful as well. Such non-intuitive DSSs would have to be very helpful indeed for their added benefits to offset the added cost of training programs, but perhaps it is worth investigating nonetheless.

The general discussion section above (*3.4.1 General*) mentioned several concerns regarding the rejected gap variables used in this study and in previous studies. The rejected gap variable is unusual because it results in a varying number of data points per trial. Future work could explore ways to analyze the rejected gaps to determine which analysis method is most valid. Future work could also examine how well the rejected gap variables predict the driver's behavior once the driver decides to proceed.

Revisiting the research questions:

Research question 1: What sorts of information are useful to a driver navigating a rural thru-stop intersection?

We have learned that a continuously changing display may assist with rapid comprehension of what exactly the display is providing information about. Drivers also seem to prefer clear advisory messages.

Research question 2: Is there potential for in-vehicle decision support systems to be helpful for navigating rural thru-stop intersections? If so, what sort of in-vehicle decision support system would be best?

The in-vehicle aspects of the Side Mirror Displays and Vibrotactile Seat are confounded with their individual designs, thus we cannot draw any strong, generalized conclusions about in-vehicle systems. However, because the Mirror Display and Vibrotactile Seat were not significantly different from the control condition, and because they were outperformed by the Icon Sign only in terms of preference, there do not appear to be any caveats for in-vehicle DSSs that make them an inherently poor choice.

Results so far indicate that a visual display would be easier to comprehend than a vibrotactile display when no training or explanation is provided.

Chapter 4. Focus Group Study

4.1 Purpose

Our goal in the focus group study was to find ways in which to improve on the most promising of the DSS displays: the vibrotactile seat, and the side mirror display; and to explore additional options which we had not previously considered, or had not considered seriously, such as auditory warnings (which we rejected initially because of a concern of interference from the many other noise sources in the vehicle and possible annoyance to the driver. We used observations of and comments from participants gathered during the previous study to provide ideas of design modifications to the existing displays, or to create new displays.

The simulator studies yielded both driving performance data and usability data. The usability data was primarily quantitative. The few qualitative usability questions asked the participants what they thought each DSS meant, whether they used the DSS in deciding when to cross the intersection, and why they preferred one DSS over another. The Focus Group Study was conducted to gather further qualitative data on the DSSs, including:

- Strengths of each interface,,
- Weaknesses, and
- Ideas to improve user comprehension, user acceptance, and usefulness of the DSSs.

The Focus Group Study used participant small group discussions (i.e. focus groups) and paper prototypes of the DSSs to quickly get feedback in a setting where the participants could discuss their opinions and ideas could emerge from the group. Using paper prototypes of the DSSs instead of building the DSSs into a driving simulator had the downside that participants would not be able to see the DSS displays change in real time in response to changing traffic conditions. While seeing the DSSs only on paper limited the participants' ability to evaluate them, it allowed more DSSs to be evaluated without expending the resources needed to create a driving simulation. The DSSs evaluated included:

1. DSSs tested in the previous simulator study.
2. Ideas for improvements to the existing DSSs.
3. Ideas not tested in the previous simulator study due to time and resource limitations.

4.2 Methods

The study was conducted on April 15, 22, and 29 (year 2010). On each day, a group of participants discussed the topics for approximately two hours, from 10 AM to 12 PM. Different participants attended on each day. Seven participants attended on April 15 and 29, and six participants attended on April 22, for a total of 20 participants across the entire study. Participants were paid $30 each. These sessions were used to iteratively improve the designs, and receive feedback on the changes. Specifically, feedback from the first two sessions was used to revise some of the displays prior to the April 29th session, so that those suggestions could be tested.

All were evaluated as paper prototypes, e.g. drawings of the displays and descriptions of what they do. Paper prototypes are often an effective way to elicit feedback because participants are often more willing to provide comments and revision suggestions for designs on paper then for implemented systems (Walker et al, 2002). People perceive paper prototypes as "less finished" than implemented prototypes, and therefore more amenable to any suggestions for change which they might offer. One issue we found is that paper prototypes are more effective for representing visual displays (which can be shown as a picture) than they are for representing haptic (vibrotactile) or auditory displays. Thus, the majority of design variations explored in the pilot study were visual, although we would have liked to explore more variations of the haptic display. We still included the haptic and auditory displays as paper prototypes in which we included pictures of the interface (such as Figure 4.11) coupled with descriptions of what they do or say.

4.2.1 Decision Support Systems Evaluated

The following DSSs were evaluated via paper prototypes:

Side Mirror Displays – A visual display with a bar gauge showing the time to arrival of the next highway vehicle. This was the same display used in the simulator study, in which a red gauge bar appeared when a vehicle was within 7.5 seconds of the intersection.

Side Mirror Displays with Color Change – As the Side Mirror Displays, but with a longer bar gauge. The display is yellow when the time to arrival is greater than 7.5 s and red when the time to arrival is less than 7.5 s.

Side Mirror Displays with Warning Icons – As Side Mirror Displays with Color Change, but a warning icon is shown when the time to arrival is less than 7.5 s.

Stream of Lights – A visual display showing the locations of all approaching vehicles from both directions that have a time to arrival of 11 s or less. Each vehicle is represented by a dot on the display.

Vibrotactile Seat – A tactile display consisting of two vibrational pads mounted in the driver's seat. The left pad vibrates when traffic from the left has a time to arrival of 7.5 s or less, and the right pad vibrates when traffic from the right has a time to arrival of 7.5 s or less. This DSS was used in previous simulator studies (previously described in *2.2.3.4.2 Vibrotactile Seat* above and *3.2.2.3.3 Vibrotactile Seat* above).

Speech Message – An auditory display that speaks "wait" once per second when traffic has a time to arrival of 7.5 s or less. The display refers to traffic from the left when the driver is at the stop sign and refers to traffic from the right when the driver is in the median.

These are explained in more detail below. The DSSs were revised for the third session on April 29. Booklets explaining each of the DSSs were given to the participants during the study. The booklet for the first version of the DSSs (used on April 15 and April 22) is included in Appendix Y, and the booklet for the second version of the DSSs (used on April 29) is included in Appendix Z.

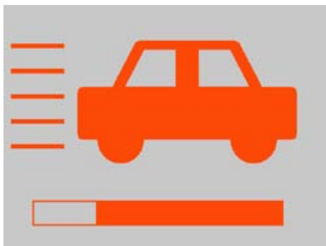
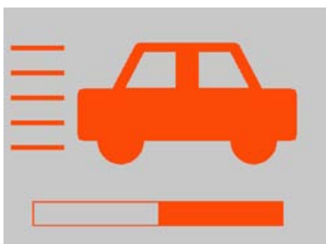
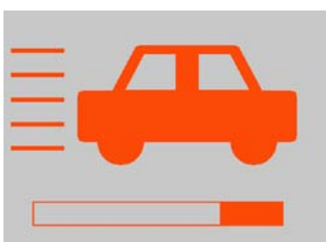
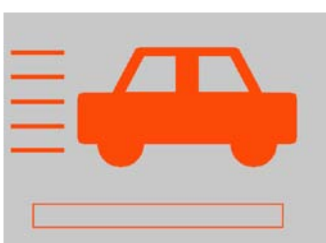
Yellow portions of displays have been changed to white to allow for printing in grayscale.

4.2.1.1 Side Mirror Displays

This visual display is named the Side Mirror Displays because it was mounted on the side mirrors of the vehicle in the previous simulator study. The participants were not told this was the name of the display, nor was it suggested to them that the display could be mounted on the side mirrors of a vehicle.

Various display states of the Side Mirror Displays are shown in Table 4-1 below. There could be two Side Mirror Displays, one for traffic from the left and one for traffic from the right. The display shown in Table 4-1 would be for traffic from the left. When no traffic is within 7.5 s of the intersection, the display is blank. Otherwise, the bar gauge shows the time to arrival of the nearest highway vehicle. The bar gauge would decrease continuously, as quickly as the computer system controlling it would be able to update the information on time to arrival. A bar gauge was chosen because it is a relative measure. Previous research tested a system that displayed the time to arrival numerically, which is an absolute measure (Creaser et al., 2007). This numerical display did not yield favorable driving performance in a driving simulator, and Creaser et al. (2007) hypothesized that a relative measure might be preferable. The car icon above the bar gauge indicates that traffic is approaching and from what direction.

Table 4-1: Various display states of the Side Mirror Displays.

	The bar is full. Traffic is 7.5 seconds away.
	The bar is ¾ full.
	The bar is ½ full.
	The bar is ¼ full.
	The bar is empty. The approaching vehicle is just now passing the intersection.
	The nearest approaching vehicle is farther away than 7.5 s

When the Side Mirror Displays were revised for the April 29 session, the car icon was re-drawn at the suggestion of several participants. The original car icon was very boxy with no distinct front or back which made it hard for participants to tell which direction the car was heading (see Table 4-1). The revised car icon was given a more distinct front and back so that that the direction of travel would be more obvious (see Figure 4-1 below).

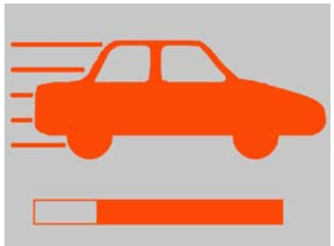


Figure 4-1: Revised car icon for the side mirror displays.

4.2.1.2 Side Mirror Displays with Color Change

This display is similar to the Side Mirror Displays, with two changes:

1. The bar gauge is full when time to arrival equals 11 s instead of 7.5 s.
2. The display is yellow when the time to arrival is greater than 7.5 s and red when the time to arrival is less than 7.5 s.

The purpose of the color change was to add an advisory message to the DSS. Qualitative data from the previous simulator study implied that participants wanted a clear advisory message (discussed in *3.4.3 Side Mirror Displays* above).

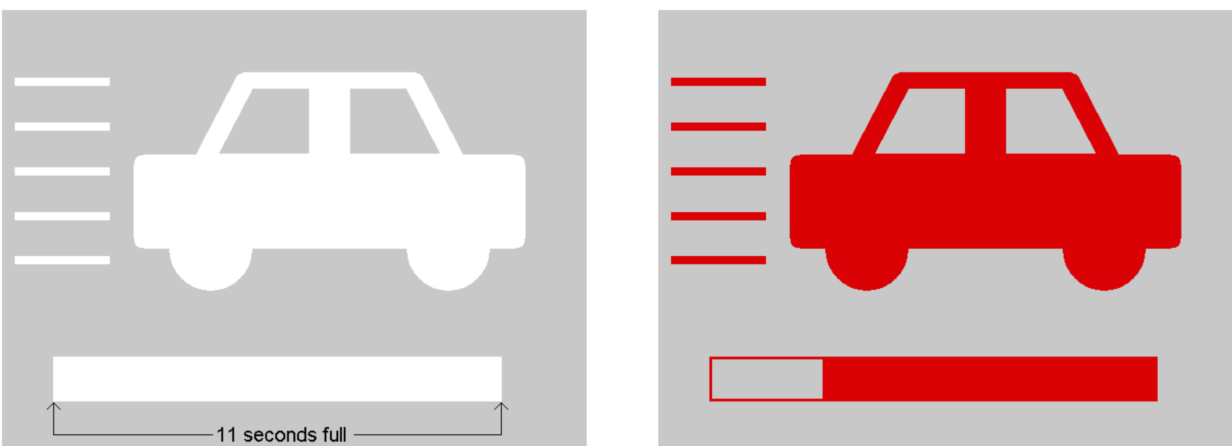


Figure 4-2: Color change added to side mirror displays. The full bar gauge now represents a time to arrival of 11 s (left). When the time to arrival is over 7.5 s, the display is yellow (left). When the time to arrival is less than 7.5 s, the display is red (right).

When the DSSs were revised for the April 29 session, the car icon was re-drawn for the Side Mirror Displays with Color Change as it was for the Side Mirror Displays so that the vehicle's direction of travel would be more obvious (see Figure 4-3 below).

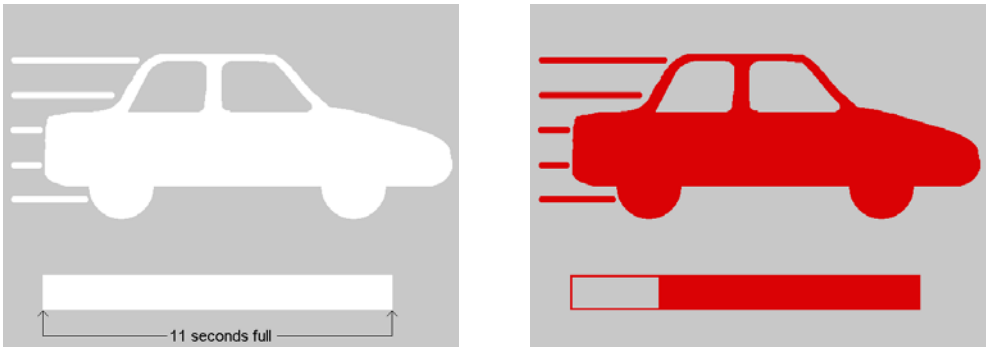


Figure 4-3: Revised car icon for the side mirror displays with color change.

4.2.1.3 Side Mirror Displays with Warning Icons

This display is similar to the Side Mirror Displays with Color Change, but a warning icon is shown when the time to arrival is less than 7.5 s. The warning icon is meant to add a stronger advisory message than the color change (and to assist colorblind users). Two options for the warning icon were considered (see Figure 4-4 below and Figure 4-5 below). The first shows a car about to collide with another from the side. The second shows an actual collision. We had a concern that the second might be a bit morbid, but it is perhaps more clear. Both options were shown to all participants.

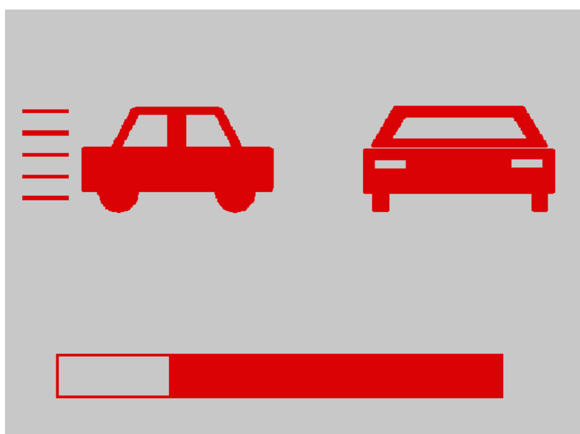


Figure 4-4: First warning icon option for the side mirror displays with warning icon.

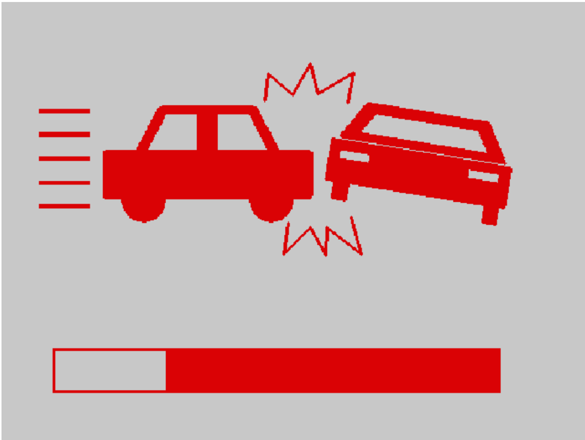


Figure 4-5: Second warning icon option for the side mirror displays with warning icon.

When the DSSs were revised for the April 29 session, the warning icons were re-drawn for the Side Mirror Displays with Warning Icon much the same as the car icon was for the Side Mirror Displays (see Figure 4-6 below).

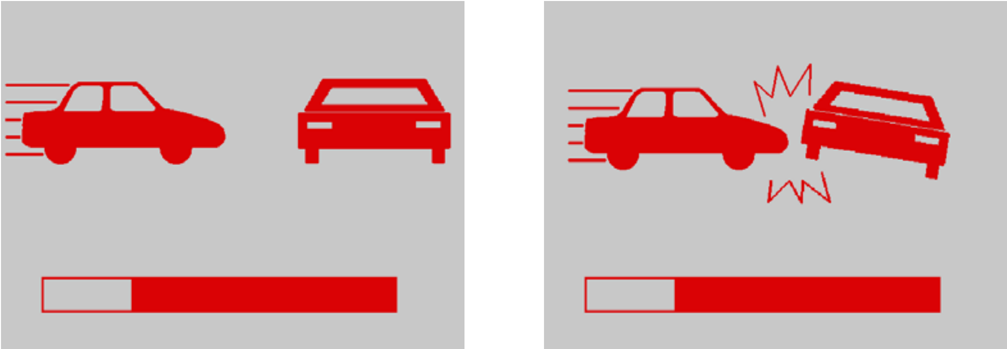


Figure 4-6: Revised warning icon options for the side mirror displays with warning icon.

4.2.1.4 Stream of Lights

The Stream of Lights is a visual display showing the locations of all approaching vehicles from both directions that have a time to arrival of 11 s or less (see Figure 4-7 below). Each vehicle is represented by a dot on the display. The black bar in the center represents the center of the intersection. Dots from either direction disappear when they reach the center. One additional option for this DSS would be to color the dots yellow if they represent vehicles farther than 7.5 s away and color the dots red if they represent vehicles closer than 7.5 s (see Figure 4-8 below). All participants were shown both of these options.

The Stream of Lights provides the most information of any of the DSSs, but perhaps too much information. The Stream of Lights and the Vibrotactile Seat are the only systems in this study that provide information about traffic from both directions on a single display (the Side Mirror Displays require two displays). However, the length of the Stream of Lights restricts the number of locations it can be placed. For example, it would not likely fit on the side view mirrors.

Figure 4-7: Stream of lights.

Figure 4-8: Stream of lights with color change. Vehicles farther than 7.5 s away are represented by yellow dots, while vehicles closer than 7.5 s are represented by red dots.

When the DSSs were revised for the April 29 session, two changes were made at the suggestion of several participants:

1. The dots were replaced with small car icons.
2. The two strips were offset to better show that they referred to two parts of the highway.

Figure 4-9 and Figure 4-10 below illustrate these changes.

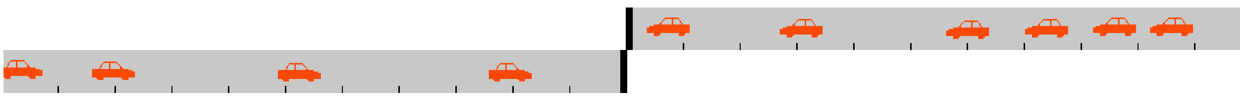


Figure 4-9: Revised stream of lights. The dots are replaced by car icons.

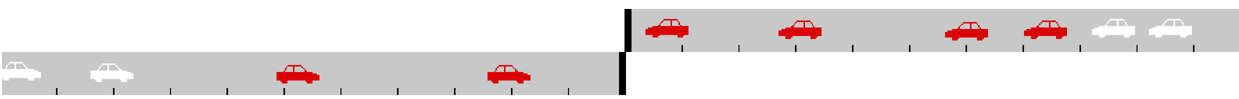


Figure 4-10: Revised stream of lights with color change. Vehicles farther than 7.5 s away are represented by yellow car icons, while vehicles closer than 7.5 s are represented by red car icons.

4.2.1.5 Vibrotactile Seat

The Vibrotactile Seat is a tactile display consisting of two vibrational pads mounted in the driver's seat (see Figure 4-11 below). The left pad vibrates when traffic from the left has a time to arrival of 7.5 s or less, and the right pad vibrates when traffic from the right has a time to arrival of 7.5 s or less.

The reasoning behind the Vibrotactile Seat is that the driver's haptic channel may be less tapped than the driver's visual channel, thus the haptic channel may be a more effective means of delivering information.

Figure 4-11: Vibrotactile Seat.

4.2.1.6 Speech Message

The Speech Message is an auditory display that speaks "wait" once per second when traffic has a time to arrival of 7.5 s or less. The display refers to traffic from the left when the driver is at the stop sign and refers to traffic from the right when the driver is in the median.

The reasoning behind the Speech Message is that the driver's auditory channel may be less tapped than the driver's visual channel, thus the auditory channel may be a more effective means of delivering information. We hypothesized that the participants would consider the Speech Message to be the most irritating system and that participant feedback might suggest a way to reduce this irritation.

When the DSSs were revised for the April 29 session, the booklet included two additional comments below the description of the Speech Message:

1. Does the speech message need to be spoken as frequently?
2. Could a tone, beep, or click be more effective than a spoken message?

These comments were meant to encourage the participants to think about how the Speech Message could be improved.

4.2.2 Experimental Design

4.2.2.1 Participants

Participants were recruited by posting flyers around the University of Minnesota, Twin Cities campus (flyer included in Appendix AA). The participation requirements were:

1. Age 18 years or older.
2. Valid driver's license.
3. 20/40 Vision or better (with or without corrective lenses).

Table 4-2 below shows participant numbers and their age range, as well as several other statistics collected from the demographic questionnaire the participants filled out during the session.

Table 4-2: Participant statistics.

Number of participants	20
Age range	18-58 (mean 29.35)
Number of males / females	11 men, 9 women
Number currently taking college classes	13
Highest education level completed	7 High School 9 Bachelor's Degree 4 Master's Degree
Type of area the participant currently lives	11 Urban 8 Suburban 1 Rural

4.2.2.2 Procedure

Participants were greeted as they arrived. Once everyone had arrived, the informed consent process was completed (consent form included in Appendix BB). Although audio recording the session is mentioned in the consent form, the experimenter did not record any of the sessions. Participants then completed a questionnaire about their driving history and habits (see Appendix CC Demographic Questionnaire). The experimenter then gave an explanation of how the discussion would proceed, explaining that participants were there to share their experiences as drivers. Participants were told:

1. that it was expected that they would have different points of view,
2. that it was okay to disagree,
3. that there were no right or wrong answers, and
4. that the purpose of the study was to hear from each of them.

The experimenter then proceeded with asking the questions. The experimenter recorded comments from participants using handwritten notes. Participant comments were frequently paraphrased.

The experimenter moderated the discussion as described in Krueger and Casey (2009), which states that the moderator's role is to ask questions, to ask for clarification when responses are vague, and to make sure everyone has a chance to share. The moderator should not criticize responses and should not talk so much that the discussion becomes a conversation with the moderator instead of a conversation among everyone.

Below is a listing of all questions along with comments on the purpose of each question or comments on the procedure.

Question 1: What areas do you drive most often?

For this question, the experimenter went around the table to get a response from each person. Krueger and Casey (2009) noted that it is important to get each person to talk early in the session, so that they will be more likely to talk later. This was the primary purpose of this question. After this question, the experimenter explained that future questions would not involve going around the table and asked participants to jump into the conversation whenever they wanted.

Question 2: What do you see as the most dangerous driving situations?

This question was meant to get the participants thinking about driving and to gradually move the topic towards thru-stop intersections. After this question, the experimenter explained what thru-stop intersections are and passed out the participants booklets, the first page of which showed a diagram of a thru-stop intersection. Version 1 of the booklet was used on April 15 and April 22, while version 2 of the booklet was used on April 29 (see Appendix Y Participant booklet, version 1 and Appendix Z Participant booklet, version 2).

Question 3: What are some of your experiences with thru-stop intersections?

The purpose of this question was to get participants thinking about thru-stop intersections. After this question, the experimenter explained that it would be possible to have a computer system keep track of all the traffic at a thru stop intersection.

Question 4: If you were at a thru-stop intersection, at the stop sign waiting to cross or enter traffic, what information would you want?

The purpose of this question was to get participants thinking about what sorts of information are useful for a driver at a thru-stop intersection, and to acquaint them with the idea of having such a system. After this question, the experimenter explained that they would be discussing several systems that provided information about traffic at thru-stop intersections. The experimenter referred the participants to the second page of the booklet, which showed the time to arrival thresholds of 7.5 s and 11 s, and explained that all the systems used one or both of these thresholds.

The experimenter asked questions five through eleven for each DSS, each time referring the participants to the relevant page of the booklet:

Question 5: Are there any general comments on the system?

This question was used for some of the systems during the earliest session. It was omitted in the later sessions since it usually caused participants to start listing weaknesses of the system. The experimenter wanted to make sure to get feedback on the strengths of the DSSs since participants usually had plenty to say about weaknesses and areas for improvement. Krueger and Casey (2009) noted that participants tend to have more difficulty thinking of positive comments if negative comments have been discussed first, hence the omission of this question in later sessions.

Question 6: What are some strengths of this system?

This question was always asked.

Question 7: What are some weaknesses of this system?

This question was always asked.

Question 8: How could the system be improved?

This question was always asked.

Question 9: Does the system communicate the information you need? (if not, what is missing?)

This question was often omitted due to time constraints.

Question 10: What location would be best for this DSS?

This question was often omitted due to time constraints.

Question 11: Would you use the system if it was available to you at no additional cost (perhaps it came with the car)?

This question was often omitted due to time constraints.

Once all the systems had been discussed, the experimenter asked questions twelve and thirteen:

Question 12: Which system do you think is best?

Question 13: We are interested in improving the methods of this study. Do you have any feedback for us? (For example, did we ask the right questions?)

Once the final question had been discussed, participants were compensated $30 each for their participation. They were offered the chance to stay after the study to hear more about the research project and to ask their own questions about the project.

4.2.3 Analysis

The analysis of the participant comments followed these steps:

1. The comments from all the sessions were combined.
2. For each question, the researchers searched for common themes among the comments and sorted the comments into categories accordingly.
3. The researchers wrote a descriptive summary for each question.
4. The researchers summarized the comments as a whole, looking for common themes within each question and across questions.

4.3 Results

Appendix DD lists all the participant comments from all the sessions, categorized and with descriptive summaries. Below are summaries of participant comments for each system. Unless indicated otherwise, all statements about the systems come from participants. For example, the sentence “The system could help in limited visibility cases” means that the participants stated the system could help in limited visibility cases.

4.3.1 General Comments

Participants often seemed to gravitate towards the familiar. For example, they often suggested systems that would give red, yellow, and green advisory messages, as a stoplight does. Participants often wanted advisory messages incorporated into the system. They seem to feel that systems that tell them when to wait should also to also tell them when to go. However, for liability reasons it is not advisable for a DSS to tell a driver when to proceed. The experimenter did not mention this during discussion to avoid appearing critical of anyone's ideas and to avoid stifling discussion.

There were many more negative comments than positive, and also many comments on how to improve the system. There was not much consistency in what participants suggested, other than that they wanted a stoplight or stoplight-like system.

It is interesting to note that no one thought of thru-stop intersections when asked to name dangerous driving situations, though when asked about experiences with thru-stop intersections, participants did express concern and indicated they had experiences with thru-stop intersections.

When participants were asked what information they would want a traffic-monitoring system to provide, they often mentioned speed, distance, time-to-arrival, and presence of approaching traffic. Some even proposed advisory messages telling the driver when to wait. One participant suggested providing information on how long it would take the driver to proceed across the intersection, in addition to providing the speed and distance of approaching traffic.

One participant suggested that the system information could be fed into a GPS, such that the approaching traffic appeared on a GPS map of the intersection. For the Stream of Lights display, one participant noted it would be good to have a landmark on the display; the same might apply to such a GPS display.

Comments on each DSS are summarized below.

4.3.2 Side Mirror Displays Comments

There was some disagreement about whether this system would be intuitive, particularly whether the bar gauge would be intuitive. The system could help in limited visibility cases. The bar should "fill" instead of "empty". A bar that "fills" as traffic approaches would also provide more consistency with the blank display used to indicate that no traffic is currently with in caution or warning range. This consistency would increase the understandability of the display. There was one suggestion to use a "progressing dot instead of a bar gauge to represent and approaching vehicle. Many participants expressed the desire for an advisory message of some sort, such as a discrete color change to indicate level of danger, flashing lights, a caution message, or a "don't go" message. Participants ideas for locations in which to put an advisory message included:

1. Overhead, like a stoplight.
2. By the stop sign.
3. To the left at the stop sign, and to the right in the median.
4. On the side mirror displays.
5. On the dashboard.
6. On or above the center console.

4.3.3 Side Mirror Displays with Color Change Comments

Participants thought the color change and longer bar were both improvements. Participants felt that the color change was more important than the bar gauge, and some participants still thought the bar gauge was superfluous. They also felt that there should be some sort of indicator in addition to the color change. The system should not have a blank screen unless there is some other way to indicate the display is working and not broken.

4.3.4 *Side Mirror Displays with Warning Icons Comments*

The second (more morbid) icon showing a collision was more understandable of the two. Having an icon for a time to arrival less than 7.5 s is good for colorblind people. Both warning icons were somewhat confusing, and some participants considered them to be too extreme. There were a few more comments that the bar was unnecessary and that the color change and icon change would be sufficient.

4.3.5 *Stream of Lights Comments*

A few participants suggested a system like the Stream of Lights before seeing it (though they could have looked ahead in the booklet to get the idea). For example, some participants suggested having an overhead view for the Side Mirror Displays, and one pointed out that the Side Mirror Displays only showed information about the nearest car, and there could be another car right behind that one.

Participants tended to agree that the two strips should be offset, and this change was made before the April 29 session. There was also a suggestion that the dots be changed to car icons, and this change was made as well. This system has more information (showing multiple vehicles with multiple speeds), but maybe too much information (it could also be distracting or hard to see). Participants preferred the color change option. They pointed out the display does not account for left-turning highway traffic (researcher note: none of the systems account for left-turning traffic, but all could be made to do so). There is no concept of scale on the display (researcher note: in practice, you would be able to see the dots/cars moving, so you might not need a scale). Participants suggested showing multiple lanes of traffic and suggested adding a landmark to the display to give a concept of scale. Participants again commented that they would like an advisory message.

4.3.6 *Vibrotactile Seat Comments*

The advantages are that it doesn't have to be watched, and would be more attention-grabbing than other modalities. The downsides are that it is novel (drivers are not used to getting information this way, thus it could be confusing), that it might not be noticed due to other vibrations (cell phone, music, car's normal vibrations, etc.), and that the driver's position in the seat would affect whether s/he would be in contact with the vibrational pads. Despite this, the participants also seemed to think the system would communicate the needed information if the driver expected it and was able to notice the vibration. Some suggestions for improvement included relocating the system, though no suggested location would solve the problem of dependency on the driver's position. There were a couple suggestions that an auditory system would be better, such as a beeping or a sound similar to a turn signal.

4.3.7 *Speech Message Comments*

Between the second and third session, the description of the auditory system was revised to include suggestions alternatives to the speech warning message (e.g. a tone, buzzer, or clicking sound, or a speech message spoken less frequently).

Participants commented that an auditory system would not occupy the visual channel of the driver. A visual system could also be blocked from the driver's view (such as if the display was on a roadside sign that was iced over). They expected the system would be irritating, could easily be drowned out by other noise, and would not be useful for deaf drivers. Participants seemed to want a stronger advisory message, either one that indicated level of danger or indicated when to proceed. They suggested a number of ideas for tones, buzzers, clicking sounds, or different speech warnings (researcher note: it is important to remember that these ideas were not evaluated as critically, merely suggested off the top of their heads without much discussion). From the participant comments, it appears drivers might accept something low-key, for example something that sounds like a turn signal – noticeable but not too annoying.

4.4 Discussion

Participants often wanted what was already familiar to them, as shown by their suggestions for stoplights or stoplight-like systems. This may indicate that it will take time for any new in-vehicle DSS to be accepted by users. Although participants were critical of many of the DSSs, frequently listing many more weaknesses than strengths, they did not seem to dislike the idea of having a DSS. This further supports the notion that drivers may be willing to accept intersection decision support systems, given time.

Qualitative data from the previous simulator study suggested that participants wanted a clear advisory message. Participant comments from the current study confirm this: advisory messages such as color changes were often praised by participants, and participants made many suggestions to add other advisory messages to the DSSs, which would draw attention or be easy to notice.

Participants were thorough in pointing out all the ways in which an auditory or vibrotactile signal could fail to reach the driver. For example, the signal could be masked by other sound or vibration. Auditory and vibrotactile systems must take into account all of these failure modes. Participants commented that such systems must be noticeable but not irritating. One participant suggested using a sound similar to a turn signal's clicking for an auditory alarm. Such a system might be less irritating, but a driver might unconsciously tune out the clicking sound.

One of the reasons auditory systems were not tested in previous simulator studies were the assumptions that there is already much noise in a driving environment with which and auditory alarm must compete (including radios and cell phones), and that drivers might find them annoying. Participant comments in the focus groups confirmed that they also expected that auditory systems would be annoying.

Participants suggested the Stream of Lights might be too much information, and they did not prefer it over the other visual displays. As explained previously (e.g. in *1.4.2 Visual Displays Literature* above), a visual DSS should be located where the driver can easily watch both the display and the approaching traffic. Due to the size of the Stream of Lights display, it would be more difficult to place in a location where the driver could watch both traffic and the display. For these reasons, we decided that it is probably not an appropriate candidate for further testing.

4.4.1 Focus Group Study Conclusions

It was clear that participants wanted the DSSs to include some form of advisory message. They often suggested that systems should indicate both: when to proceed, and when to wait. Howevere, for liability reasons, a "proceed" message is not something that should provide at thru-stop intersection. Participants still seemed to like the idea of advisory messages even if the messages only indicated when to wait.

Interfaces eliminated. There were also several displays that we eliminated from future consideration for this application based on focus group feedback. In particular, we eliminated:

- *auditory warnings* based on concerns that they would annoy drivers,
- *stream of lights* because of concerns that it would be too much information, and the display would take up too much space,

4.4.2 Future Work Based on Focus Groups' Feedback

Alternative displays. One or two participants suggested integrating the DSS into the display on a GPS. However, the GPS in a vehicle is often mounted in the center of the dashboard or built into the center console, making it difficult for the driver to watch the display while also watching traffic approaching from the left or right. However, a GPS-DSS might be more easily accepted than a stand-alone DSS. By integrating the DSS into a gadget that is already familiar to users, they may be more willing to try the DSS. Users have little choice in what features a manufacturer adds to a GPS, thus if the next generation of GPSs all included DSSs that provide advisor warnings at thru-stop intersections, the DSS would be availible to users even if they did not initially use them. Over time, users might begin to use the DSSs as they got used to them, perhaps by convincing themselves that they should get their full money's worth out of the GPS.

Improvements to the Side Mirror Displays. Based on comments from the focus groups, future versions of the Side Mirror Displays might extend the 7.5 second warning bar gauge to 11-seconds. A an explicit advisor message should also appear when the time to arrival is less than 7.5 s. The warning icon could be a red "X" (as suggested by a participant), a circle with a slash through it, or a hand icon (as seen at crosswalk signals).

Improvement to the Vibrotactile Seat. For the Vibrotactile Seat, placing the vibrational pads in the seat bottom seems to be as good of an option as anything described by participants. It would be difficult for a driver to assume a position in which his/her body was not in contact with the seat bottom. The size of the vibrational pads may need to be increased as well so that they are more noticeable regardless of the driver's position. The vibration would need to be of a frequency and amplitude that it is not masked by other sources of vibration.

Chapter 5. Limitations, Challenges, Future Work

5.1 Limitations

Thus far, our studies have focused primarily on understanding to what degree the various warning systems will help the average driver in an average driving situation under daytime road conditions, on a fairly flat and straight Midwest highway. Under these conditions, we did not find that any of the warning system interfaces improved safety margins relative to those drivers who had no warning system, perhaps because drivers could see on-coming traffic clearly at a fairly great distance.

However, one might see very different results under more marginal visibility conditions, with drivers who have reduced vision or impaired judgment, or under poor weather conditions in which drivers may misjudge the need for caution (e.g. they must wait for larger gaps between vehicles before they pull into traffic due to slippery conditions). Reduced visibility may arise from several causes: lighting (twilight and night driving situations), weather (heavy rain or snow), topography (hills and twisting roads), and vegetation (trees and bushes) that blocks the driver's view of the main road from the side road. Drivers with reduced vision may include the elderly (particularly at night) and those with various medical conditions. Impaired judgment may arise from driver fatigue, age, use of alcohol or drugs (including some prescription drugs), or impatience, for example when traffic is heavy and the driver has been waiting a long time for a gap, or when he or she is in a hurry. (While the latter is common in real-world driving situations it is harder to reproduce in the laboratory).

In summary, while our study provides a baseline for performance under average conditions for average drivers, some of the limitations of our study are that it has not examined:

- **Low visibility conditions**, including twilight, night time, or visibility reducing weather conditions,
- **Topography and vegetation that reduce visibility** by blocking drivers view of the road either near or far,
- **Drivers with reduced vision**, such as the elderly, or those with medical conditions affecting vision,
- **Judgment impaired drivers** due to fatigue, age, or use of alcohol or drugs, or cell phone use (which divides their attention between the conversation and the road).
- **Conditions that result in impatience** including heavy traffic, or driver's personal schedules.
- **False alerts and nuisance alarms** and their effect on participants'' trust in the DSS,
- **The "annoyance factor**" where by some drivers may be motivated to turn-off warning systems, or tune them out if they find them annoying due to too much buzzing, beeping or too much insistence.

Finally, simulator experiments cannot provide the richness or variability of traffic and driving conditions in the real world. Drivers may be more careful in a simulator when an experimenter is watching, and it may be harder to produce feelings of impatience or being rushed. They may also be unwilling to exhibit certain types of behaviors such as turning off the warning system, or road rage.

5.2 Challenges

Eye tracking is especially challenging for this intersection layout. It must be precise, since the Icon Signs take up a small visual angle. The challenge is capturing a wide field of view accurately without requiring the subject to wear a lot of distracting gear. Using an eye tracking system raises the question of whether the eye-tracker data can be processed numerically or whether an analyst must watch all of the video. Processing the data numerically typically requires a more elaborate setup or more equipment. If the data is processed by an analyst watching the videos, the process of analysis is much more time-consuming and possibly more vulnerable to errors (e.g. if using a stopwatch to measure time variables). If using an eye tracker, one possibility would be to track the amount of time the participants watched the DSSs vs. the amount of time the participants watched traffic, and compare this to performance variables such as safety margin.

5.3 Future Work

Possible avenues. There are many possible directions for future work. These studies have laid the ground work for a wide range of future work. All of the issues described in the "Limitations" section could be studied in more detail. Since warning systems may be more needed when visibility is reduced one might find that one all of the DSSs have a greater positive impact on safety margins under these conditions. Similarly, drivers with impaired vision or judgment may derive more benefit from the DSSs. Additionally, other types of interfaces could be tested, such as augmented reality displays which use a head-up display or the windshield on which to "mark" vehicles to which drivers should pay attention. Such displays have the advantage that, unlike the visual displays explored in the experiment, augmented reality displays would not require drivers to take their eyes off the road. In fact they would help to draw driver's eyes towards the hazard. Downsides may be visual clutter, or failure of the driver to notice the markings, particularly if their gaze is elsewhere.

Haptic interfaces to deliver warnings. Of all these possible future directions, however, we feel that haptic warning systems are likely to be most fruitful for this application, particularly in the near term. They are relatively simple to implement; and our results showed the haptic interface (vibrating seat) to produce the greatest improvement in safety margins. Finally, there is much supporting evidence from prior work that suggests that haptic interfaces are especially good at getting drivers' attention, and that reaction time with them is faster than with visual or auditory warnings. In contrast, almost any visual warning system, no matter how well designed, must either take the driver's attention from the road or is use much needed visual resources.

Possible next steps include evaluation of haptic warning systems under reduced visibility conditions, and improvement of the haptic interface to determine whether it can produce significant safety improvements even under dry, daylight conditions.

Combinations of haptic and other warning systems. Finally, it may be worth exploring some combination of haptic and visual warnings, or haptic and auditory warnings. The combination may prove more effective than either alone; the haptic part serving to get the driver's attention, while a visual display or auditory can provide more specific information.

Experiments underway to gain more insights into the results. While it is clear the the haptic DSS resulted in better safety margins, multiple factors may have contributed to the effect. For example, the interfaces differed along multiple parameters: proximity to the driver (in the intersection versus on the vehicle), position of the interface in the visual field, the information content of each display, and the modality (visual or haptic). Thus, we do not know precisely whether the better performance with the vibrotactile seat over the Icon Sign was due to the fact that the haptic seat provided less information (and therefore its warnings were faster and easier to process), or because a haptic interface is more effective then a visual interface when the driver's visual channels are already in use.

Ideally we would have liked to design the experiment so that only one parameter was varied between each condition, but that was not possible given the tight constraints of the experimental setup. For example, we would have liked to vary only the proximity of the display from outside to on the vehicle, while keeping the displays identical. However, that was not possible. Because of the tight space constraints inside the vehicle, it the display for that condition had to be kept small, and an exact reproduction of the Icon Sign (placed outside the vehicle) was too small to be easily legible when mounted on the car for the Mirror display. Thus, because of the constraints of the simulator environment, it was difficult to create setups that would allow us to study each of the variables separately.

To do so, we are in the process of creating a simplified experimental setup that will allow us to study the impact on safety margins due to 1) a change in the information content of the display and 2) a change in mode from visual to haptic. This set up is a greatly simplified version of the simulator. While it will provide a less rich, and more artificial environment than the simulator, it will allow us greater control of the variables; in general there is a trade-off between the richness and realism of an experimental context, and the ability of experimenters to control the variables (Zsambok & Klein, 1997). In this new setup (a simulator "lite") subjects will sit in a regular office chair between three screens. Video images taken in the simulator will be projected on the screens to show a stream of traffic. Visual DSS warnings will also be projected on the screen. Two programmable vibrating pads are placed on the chair to create a vibrotactile seat.

This setup will allow us to perform further, more tightly controlled experiments in which we independently examine the effects of 1) varying the information content of the display, and 2) visual versus haptic warnings. Through these experiments we will be able to conclude with more confidence why the vibrotacile seat produced better safety margins than the Icon Display; was it primarily due to the reduced information content of the haptic display, the shift from a visual to a haptic modality, or some combination?

Chapter 6. Conclusions and Recommendations

The significantly higher safety margins (in the far lanes) for the Vibrotactile Seat compared to the Icon Sign suggest that haptic DSSs inside the vehicle may have more safety benefits than visual DSSs outside the vehicle. Further investigation is needed to determine what properties of the haptic interface are responsible for the advantage – reduced interference with visual driving tasks, message salience, simplicity, or some combination of these properties. Although participants in the Focus Group Study were often critical of the DSSs shown to them, they did not seem to dislike the idea of having such a DSS. Thus, it appears that drivers could, given time, come to accept the addition of such DSSs to vehicles. The results from the driving simulator studies combined with results from the Focus Group Study suggest possible future revisions for the in-vehicle DSSs evaluated in these studies.

The driving simulator studies did not show a clear change in driving performance when using a DSS (whether the DSS was located inside or outside the vehicle) compared to driving without a DSS. It is possible that the DSSs required additional mental attention (and additional visual attention in the case of the visual DSSs) that caused the drivers to spend additional time monitoring the DSSs and delay proceeding. This delay may have canceled out the benefits of the DSSs enough that no significant change was observed. In the driving simulator studies, the Icon Sign was most preferred and was rated most usable but was not the most comprehended DSS. The Icon Sign may have been preferred because drivers are more accustomed to gaining information from traffic signs and signals than from other systems. In the Focus Group Study, participants' comments also seemed to express a preference for what is familiar.

In the simulator studies, the Side Mirror Displays were most often comprehended, which shows they have potential for future studies. They may have been easier to comprehend because the display continuously changed as long as traffic was within 7.5 s. Comments during the simulator studies suggested that participants wanted stronger advisory messages for systems such as the Side Mirror Displays, and the Focus Group Study confirms this. This desire for clear advisory messages was a common theme throughout the participants' responses during the Focus Group Study. The Focus Group Study evaluated three potential modifications to the side mirror displays:

1. Extend the bar gauge to provide information about traffic as far as 11 s away.
2. Change the color of the display when traffic is within 7.5 s.
3. Change the icon on the display to a prohibitive symbol when traffic is within 7.5 s.

Participant comments on these were generally positive, but they didn't seem to like the prohibitive symbols chosen by the researchers. They suggested using a red X, a circle with a slash, or a hand symbol (the same as is used at crosswalks).

Results from the simulator studies suggested that when using the Vibrotactile Seat, some participants had trouble distinguishing the left and right vibrational pads. In future work, the pads will need to be spaced far enough apart that almost all drivers can distinguish the two vibrations. Comments from the Focus Group Study suggested several other issues that should be addressed. Participants commented that the driver's posture might affect whether the driver could feel the pads vibrating. Future work should insure that the vibrational pads are of optimal size and location to be felt by the driver regardless of the driver's physical size or posture. Participants also commented that the Vibrotactile Seat could be drowned out by other vibrations, such as from a cell phone, from the vehicle's speakers, or from the vehicle's normal vibrations.

Further work should investigate if a particular frequency and amplitude of pad vibration would be clearly discernable when these other sources of vibration are present.

Future studies should consider examining driver behavior both before and after an explanation of the DSSs is provided. This study and previous studies in the CICAS-SSA program have focused on designing intuitive systems that need no explanation. However, with the proper design and implementation of training programs, non-intuitive DSSs could be helpful as well. Such non-intuitive DSSs would have to be very helpful indeed for their added benefits to offset the added cost of training programs, but perhaps it is worth investigating nonetheless.

The in-vehicle aspects of the Side Mirror Displays and Vibrotactile Seat are confounded with their individual designs, thus we cannot draw any strong, generalized conclusions about in-vehicle systems. However, because the Mirror Display and Vibrotactile Seat were not significantly different from the control condition, and because they were outperformed by the Icon Sign only in terms of preference, there do not appear to be any caveats for in-vehicle DSSs that make them an inherently poor choice. Results so far indicate that a visual display would be easier to comprehend than a vibrotactile display when no training or explanation is provided.

References

Abe, G., & Richardson, J. (2004). "The effect of alarm timing on driver behaviour: An investigation of differences in driver trust and response to alarms according to alarm timing." *Transportation Research Part F: Traffic Psychology and Behaviour*, *7*(4-5), 307-322.

Abe, G., & Richardson, J. (2005). "The influence of alarm timing on braking response and driver trust in low speed driving." *Safety Science*, *43*, 639-654.

Abe, G., & Richardson, J. (2006). "Alarm timing, trust and driver expectations for forward collision warning systems." *Applied Ergonomics*, *37*, 577-586.

American Association of State Highway and Transportation Officials. (1997). *Highway safety design and operations guide*. Washington, D.C.

Bao, S. & Boyle, L. (2008). "Driver performance at two way stop controlled intersections with median divided highways." *Transportation Research Record, 2069,* 26-32.

Bao, S. & Boyle, L. (2009a). "Age-related differences in visual scanning at median-divided highway intersections in rural areas." *Accident Analysis and Prevention, 41,* 146-152.

Bao, S. & Boyle, L. (2009b) "Driver safety programs: The influence on the road performance of older drivers." *Transportation Research Record, 2096,* 76-80.

Belz, S.M., Winters, J.J., Robinson, G.S., & Casali, J.G. (1997). "A methodology for selecting auditory icons for use in commercial motor vehicles." *Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting,* Santa Monica, CA, 939-943.

Belz, S.M., Winters, J.J., Robinson, G.S., & Casali, J.G. (1998). "Auditory icons: a new class of auditory warning signals for use in intelligent transportation subsystems." *Society of Automotive Engineers 1997 Transactions – Journal of Commercial Vehicles/Section 2, 106*, 431-439.

Brown, S.B. (2005). "Effects of haptic and auditory warnings on driver intersection behavior and perception." Unpublished doctoral dissertation. Blacksburg, VA: Virginia Polytechnic Institute and State University.

Burnett, G.E. (2004). "An evaluation of different positions for an in-vehicle navigation display." *Proceedings of the International Conference of Traffic and Transport Psychology*, Nottingham, U.K.

Chovan, J.D., Tijerina, L., Pierowicz, J.A., & Hendricks, D.L. (1994). *Examination of non-signalized intersection, straight crossing path crashes and potential IVHS countermeasures.* (Rep. No. DOT HS 808 152). Cambridge, MA: National Highway Traffic Safety Administration.

Cooper, P.J., & Zheng, Y. (2002) "Turning Gap Acceptance Decision-Making: The Impact of Driver Distraction." *Journal of Safety Research*, *33*, 321-335.

Creaser, J., Manser, M., & Rakauskas, M. (2008). *CICAS HF3: Sign comprehension, rotation, location, and random gap simulation studies: Final report*. St. Paul, MN: Minnesota Department of Transportation, Research Services Section.

Creaser, J., Rakauskas, M., Ward, N., & Laberge, J. (2005). *A simulator-based evaluation of smart infrastructure concepts for intersection decision support for rural thru-stop intersections.* St. Paul, MN: Minnesota Department of Transportation, Research Services Section.

Creaser, J.I., Rakauskas, M.E., Ward, N.J., Laberge, J.C., & Donath, M. (2007). "Concept evaluation of intersection decision support (IDS) system interfaces to support drivers' gap acceptance decisions at rural stop-controlled intersections." *Transportation Research Part F*, *10*(3), 208-228.

Davis, G.A., & Swenson, T. (2004). "Field Study of Gap Acceptance by Left-Turning Drivers." *Transportation Research Record*, *1899*, 71-75.

Deatherage, B. (1972). "Auditory and other sensory forms of information presentation." In H. Van Cott and R. Kinkade (Eds.), *Human engineering to guide equipment design*, revised ed. Washington, D.C.: Government Printing Office.

De Vries, S.C., Van Erp, J.B.F., & Kiefer, R.J. (2009). "Direction coding using a tactile chair." *Applied Ergonomics, 40*(3), 477-484.

Diederich, A., & Colonius, H. (2007). "Modeling spatial effects in visual-tactile saccadic reaction time." *Perception & Psychophysics*, *69*(1), 56-67.

Federal Highway Administration (2004). *Intersection safety facts and statistics*. US Department of Transportation, FHWA. Retrieved January 23, 2008, from http://safety.fhwa.dot.gov/intersections/inter_facts.htm.

Fitch, G.M., Kiefer, R.J., Hankey, J.M., & Kleiner, B.M. (2007). "Toward developing an approach for alerting drivers to the direction of a crash threat." *Human Factors*, *49*(4), 710-720.

Gaver, W.W. (1997). "Chapter 42: Auditory interfaces." In Helander, M., Landauer, T.K. & Prabhu, P.V. (Eds.), *Handbook of human-computer interaction,* 2nd ed., 1003-1041. Amsterdam, New York: Elsevier.

Gibson, J J., & Crooks, L.E. (1938). "A theoretical field-analysis of automobile driving." *American Journal of Psychology*, *51*, 453-471.

Gorjestani, A., Menon, A., Cheng, P., & Shankwitz, C. (2008). *Alert and warning timing for CICAS-SSA: An approach using macroscopic and microscopic data*. St. Paul, MN: Minnesota Department of Transportation, Research Services Section.

Gray, R. (2001). "Looming auditory collision warnings for driving." *Human Factors*, *53*, 63-74.

Ho, C., Reed, N., & Spence, C. (2006). "Assessing the effectiveness of 'intuitive' vibrotactile warning signals in preventing front-to-rear-end collisions in a driving simulator." *Accident Analysis and Prevention*, *38*(5), 988-996.

Ho, C., & Spence, C. (2005). "Assessing the effectiveness of various auditory cues in capturing a driver's visual attention." *Journal of Experimental Psychology: Applied, 11*(3), 157-174.

Ho, C., Spence, C., & Tan, H.Z. (2005). "Warning signals go multisensory." *Proceedings of the 11th Annual Conference on Human-Computer Interaction, 9,* Mahwah, NJ.

Ho, C., Tan, H.Z., & Spence, C. (2005). "Using spatial vibrotactile cues to direct visual attention in driving scenes." *Transportation Research Part F: Traffic Psychology and Behavior, 8*, 397-412.

Ho, C., Tan, H.Z., & Spence, C. (2006). "The differential effect of vibrotactile and auditory cues on visual spatial attention." *Ergonomics*, *49*(7), 724-738.

Horrey, W.J., & Wickens, C.D. (2004). "Driving and side task performance: The effects of display clutter, separation, and modality." *Human Factors*, *46*(4), 611-624.

Howell, D.C. (2007). *Statistical methods for psychology*. Belmont, CA: Thomson Wadsworth.

Kittelson, W.K., & Vandehey, M.A. (1991). "Delay effects on driver gap acceptance characteristics at two-way stop controlled intersections." *Transportation Research Record*, *1320*, 154–159.

Krueger, R.A., & Casey, M.A. (2009). *Focus groups: A practical guide for applied research*, 4th ed. Thousand Oaks, CA: Sage Publications, Inc.

Laberge, J., Ward, N., & Rakauskas, M. (2003). *A review of the human factors of rural intersection negotiation: implications for a Minnesota decision support system*. (Project No. MN DOT 81655). Minneapolis, MN: ITS Institute, University of Minnesota.

Laberge, J.C., Creaser, J.I., Rakauskas, M.E., & Ward, N.J. (2006). "Design of an intersection decision support (IDS) interface to reduce crashes at rural stop-controlled intersections." *Transportation Research Part C, 14*, 39-56.

Lee, J.D., Hoffman, J.D., & Hayes, E. (2004). "Collision warning design to mitigate driver distraction." *Proceedings of the SIGCHI conference on human factors in computing systems,* Vienna, Austria, 65-72.

Lee, J.D., Stoner, H.A., & Marshall, D. (2004). "Enhancing interaction with the driving ecology through haptic interfaces." *IEEE International Conference on System, Man and Cybernetics, 1*, The Hague, Netherlands, 841-846.

Lee, Y., Lee, J. & Boyle, L. (2009). "The interaction of cognitive load and attention-directing cues in driving." *Human Factors*, *51*, 271-280.

Martens, M., & Van Winsum, W. (2001). "Effects of speech versus tactile driver support messages on driving behaviour and workload." *Proceedings of the 17th international technical conference on the enhanced safety of vehicles,* Amsterdam, the Netherlands.

Moore, D.S., & McCabe, G.P. (2006). *Introduction to the practice of statistics*. New York: W.H. Freeman and Company.

Najm, W.J., Koopmann, J.A., & Smith, D.L. (2001). "Analysis of crossing path crash countermeasure systems." *Proceedings of the 17th international technical conference on the enhanced safety of vehicles,* Amsterdam, the Netherlands.

National Highway Transportation Safety Administration (2003). *Traffic Safety Facts 2002: A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System*. Washington, D.C.: NHTSA. Retrieved October 21, 2003, from http://www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/TSFAnn/TSF2002EE.pdf.

Patterson, R.D. (1982). *Guidelines for auditory warning systems on civil aircraft.* (CAA Paper 82017). London: Civil Aviation Authority.

Preston, H., & Storm, R. (2003). *Review of Minnesota's rural crash data*. Eagan, MN: CH2M HILL.

Preston, H., Storm, R., Donath, M., & Shankwitz, C. (2004). *Review of Minnesota's rural crash data: Methodology for identifying intersections for intersection decision support (IDS).* St. Paul, MN: Minnesota Department of Transportation.

Rakauskas, M., Manser, M., & Graving, J. (2009). *CICAS HF4.2 Validation Study: On-Road Evaluation of the Stop Sign Assist Decision Support Sign*. St. Paul, MN: Minnesota Department of Transportation, Research Services Section.

Sanders, M.S., & McCormick, E.J. (1993). *Human factors in engineering and design*, 7th ed. New York: McGraw-Hill, Inc.

Scott, J.J., & Gray, R. (2007). "Comparison of driver brake reaction times to multimodal rear-end collision warnings." *Proceedings of the Fourth International Driving Symposium on*

Human Factors in Driver Assessment, Training and Vehicle Design, Stevenson, WA, 285-291.
Scott, J.J., & Gray, R. (2008). "A comparison of tactile, visual, and auditory warnings for rear-end collision prevention in simulated driving." *Human Factors*, *50*(2), 264-275.
State of Minnesota Department of Public Safety (2008). *Minnesota driver's manual*. Retrieved August 20, 2009, from http://www.dps.state.mn.us/dvs/DLTraining/DLManual/DLManual.htm.
Tarek, S., Brown, G., & Navin, F. (1994). "Simulation of Traffic Conflicts at Unsignalized Intersections with TSC-Sim." *Accident Analysis and Prevention*, *26*(5), 593-607.
Van der Laan, J.D., Heino, A., & De Waard, D. (1997). "A simple procedure for the assessment of acceptance of advanced transport telematics." *Transportation Research Part C, 5*(1), 1-10.
Van Erp, J.B.F., Eriksson, L., Levin, B., Carlander, O., Veltman, J.E., & Vos, W.K. (2007). "Tactile cueing effects on performance in simulated aerial combat with high acceleration." *Aviation, Space and Environmental Medicine, 78*, 1128–1134.
Van Erp, J.B.F., Groen, E.L., Bos, J.E., & Van Veen, H.A.H.C. (2006). "A tactile cockpit instrument supports the control of self-motion during spatial disorientation." *Human Factors, 48*(2), 219–228.
Van Erp, J.B.F., & Van Veen, H.A.H.C. (2004). "Vibrotactile in-vehicle navigation system." *Transportation Research Part F: Traffic Psychology and Behaviour*, *7*(4-5), 247-256.
Van Erp, J.B.F., & Van Veen, H.A.H.C. (2006). "Touch down: The effect of artificial touch cues on orientation in microgravity." *NeuroScience Letters, 404*, 78–82.
Van Erp, J.B.F., Van Veen, H.A.H.C., Jansen, C., & Dobbins, T. (2005). "Waypoint navigation with a vibrotactile waist belt." *Transactions on Applied Perception, 2*(2), 106–117.
Walker, M., Takayama, L., & Landay, J.A. (2002). "High-Fidelity or Low-Fidelity, Paper or Computer? Choosing Attributes When Testing Web Prototypes." *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting,* Santa Monica, CA, 661-665.
Wickens, C.D., Helleberg, J., & Xu, X. (2002). "Pilot maneuver choice and workload in free flight." *Human Factors*, *44*(2), 171-188.
Wickens, C.D., Lee, J.D., Liu, Y., & Becker, S.E.G. (2004). *An Introduction to human factors engineering*, 2nd ed. Upper Saddle River, N.J.: Pearson Prentice Hall.
Zsambok, C.E., & Klein, G. (Eds.). (1997). *Naturalistic Decision Making*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Appendix A Pilot Study Consent Form

Consent Form

Intersection Navigation

You are invited to be in a research study of navigating intersections. You were selected as a possible participant because you are old enough to know how to drive. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

This study is being conducted by:
Daniel Drew
University of Minnesota department of Mechanical Engineering

Background Information

The purpose of this study is to test intersection navigation aids. This is an assessment of equipment, NOT of you or your abilities.

Procedures:

If you agree to be in this study, we would ask you to do the following things:
-Drive through several scenarios in the driving simulator.
-Answer questionnaires about your experience in the simulator.
-Give feedback about the navigation aids.

The entire study should last about 60 minutes.

Risks and Benefits of being in the Study

The study has the risk of simulator sickness, the symptoms of which may include dizziness, nausea, and similar forms of discomfort. It is your right to stop at any time, for any reason.

The benefit to participation is being able to participate in the research and development of intersection navigation aids.

Compensation:

You will NOT receive payment. Your donated time is appreciated.

Confidentiality:

The records of this study will be kept private. In any sort of report we might publish, we will not include any information that will make it possible to identify you or any other participants. Research records will be stored securely and only researchers will have access to the records.

Voluntary Nature of the Study:

Participation in this study is voluntary. Your decision whether or not to participate will not affect your current or future relations with the University of Minnesota. If you decide to participate, you are free to not answer any question or withdraw at any time with out affecting those relationships.

Contacts and Questions:

You may ask any questions you have now.
If you have questions later, **you are encouraged** to contact Daniel at:
Office: ME 352E
Phone: 612-623-8237
Email: drewx039@umn.edu

You may also contact Daniel's advisor:
Caroline Hayes
Phone: 612-626-8391
Email: hayes@me.umn.edu

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher, **you are encouraged** to contact the Research Subjects' Advocate Line, D528 Mayo, 420 Delaware St. Southeast, Minneapolis, Minnesota 55455; (612) 625-1650.

You will be given a copy of this information to keep for your records.

Statement of Consent:

I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature:______________________________________ Date:________________

Signature of Investigator:__________________________ Date:________________

IRB Code # 0702P02411
Version Date: 4-16-07

Appendix B Pilot Study Participant Instructions

STUDY SUMMARY

The purpose of this study is to investigate driver behavior while crossing at rural intersections. Because rural intersections experience a high number of crashes, this project has developed several new systems to help drivers make crossing decisions at rural intersections.

During this study you will be exposed to these new systems. These "smart" systems monitor the crossing traffic at the intersection to detect safe gaps. One of these systems is a sign whose message may change to display different types of information depending on the traffic conditions. Another system is a set of vibration pads in the seat. You should take note of these systems and use the information they provide if you think it is useful.

You will be asked to drive across a simulated intersection several times. You will drive on a two-lane road that crosses a four-lane divided highway. Once you have crossed the intersection, the drive will end and the simulator will be prepared for the next drive. Your goal is to cross the intersection safely and use the information provided by these systems if you think they are helpful.

You will now have a chance to practice driving in the simulator. You will complete a practice drive before we begin the study to help familiarize you with the vehicle and the simulator. You will also be asked to fill out several questionnaires throughout the study. At the end you will have the chance to give your opinions and suggestions on the systems.

If you have any questions, please feel free to ask at any time during the study.

PRACTICE DRIVE INSTRUCTIONS

The practice drive will help get you familiar with the simulator and the road you will be driving during the study. The practice drive will last for about 5 minutes. During this session, please drive as you normally would in the real world.

Please follow the experimenter's instructions to the best of your ability.

If you have any questions during the drive, the experimenter can hear you if you speak in a normal voice. If you have questions, please ask them during the practice drive.

Once the practice drive is finished you will be given a short break before beginning the experimental drives.

Please let the experimenter know immediately if you begin to feel unwell (i.e., dizzy, lightheaded, "strange") while driving in the simulator.

EXPERIMENTAL DRIVE INSTRUCTIONS

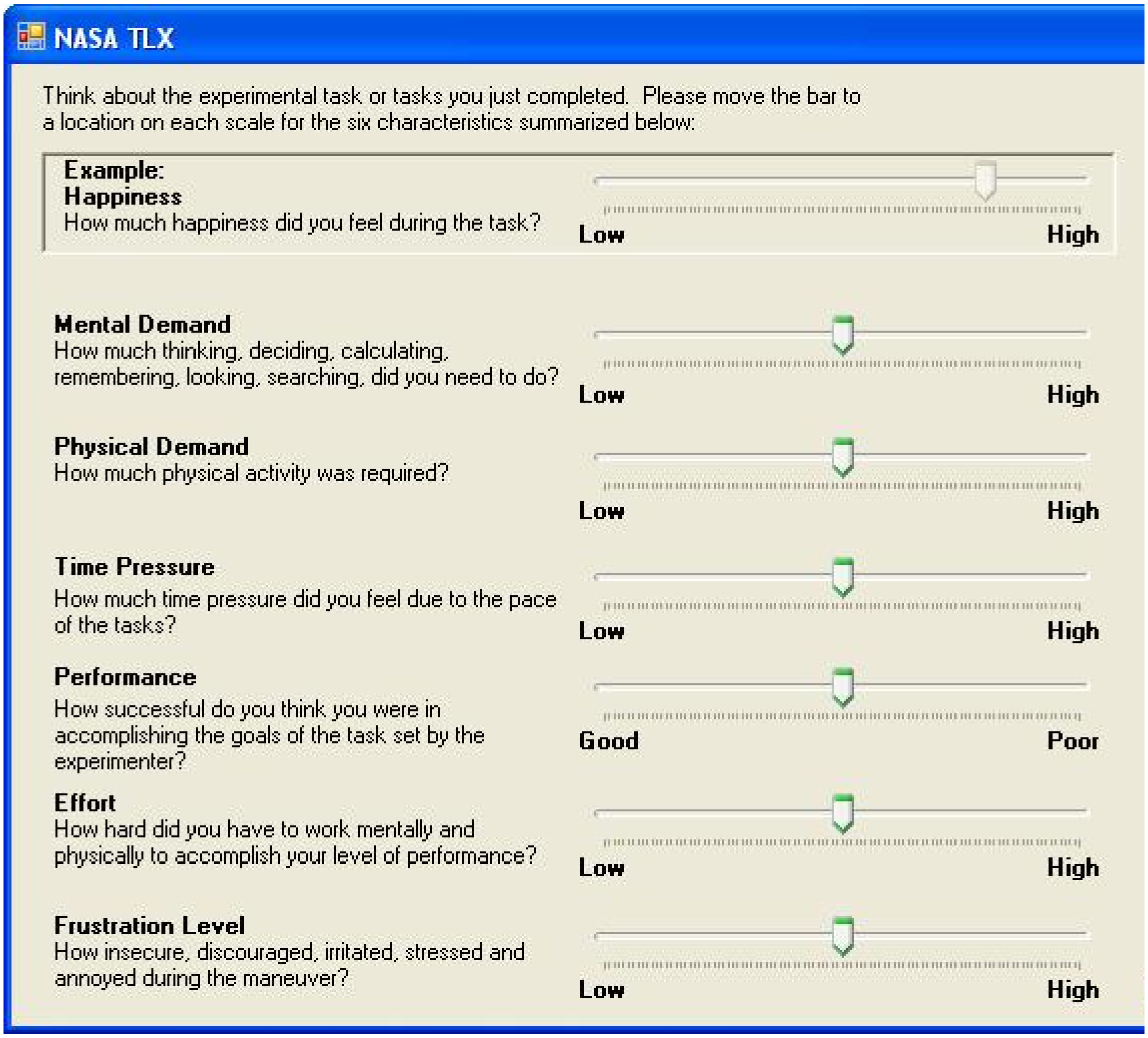
During this session you will complete two drives that are each approximately 5 minutes long. During these drives you will receive instructions over the vehicle's sound system. **Please follow all instructions that you receive, as well as any additional instructions provided by the experimenter.** If you have any questions during the drive, please ask.

Driving Tasks

In each drive, you will drive on a two-lane road that approaches a four-lane divided highway. You will then be required to cross a highway intersection. Once you have crossed the intersection, you will exit the simulator to complete a short questionnaire.

During most of these drives you will encounter new systems that are not familiar to you. These systems monitor the crossing traffic at the intersection to detect safe gaps. Your goal is to cross the intersection as you would normally if you encountered these systems in the real world. Examine these systems to see if you understand the information they provide and use the information if you think it is useful.

Appendix C NASA TLX Questionnaire



NASA TLX

Think about the experimental task or tasks you just completed. Please move the bar to a location on each scale for the six characteristics summarized below:

Example:
Happiness
How much happiness did you feel during the task?
Low — High

Mental Demand
How much thinking, deciding, calculating, remembering, looking, searching, did you need to do?
Low — High

Physical Demand
How much physical activity was required?
Low — High

Time Pressure
How much time pressure did you feel due to the pace of the tasks?
Low — High

Performance
How successful do you think you were in accomplishing the goals of the task set by the experimenter?
Good — Poor

Effort
How hard did you have to work mentally and physically to accomplish your level of performance?
Low — High

Frustration Level
How insecure, discouraged, irritated, stressed and annoyed during the maneuver?
Low — High

Appendix D Pilot Study Post-Condition Questionnaire

Page 1

Please indicate how strongly you agree or disagree with the following statements.
Answer these questions in relation to the system you just used while driving.

Example:
I feel happy today

○ Strongly Disagree ○ Disagree ○ Neutral (•) Agree ○ Strongly Agree

1. I felt confident using this system.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

2. I felt it was confusing to use this system.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

3. Using this system made me feel safer.

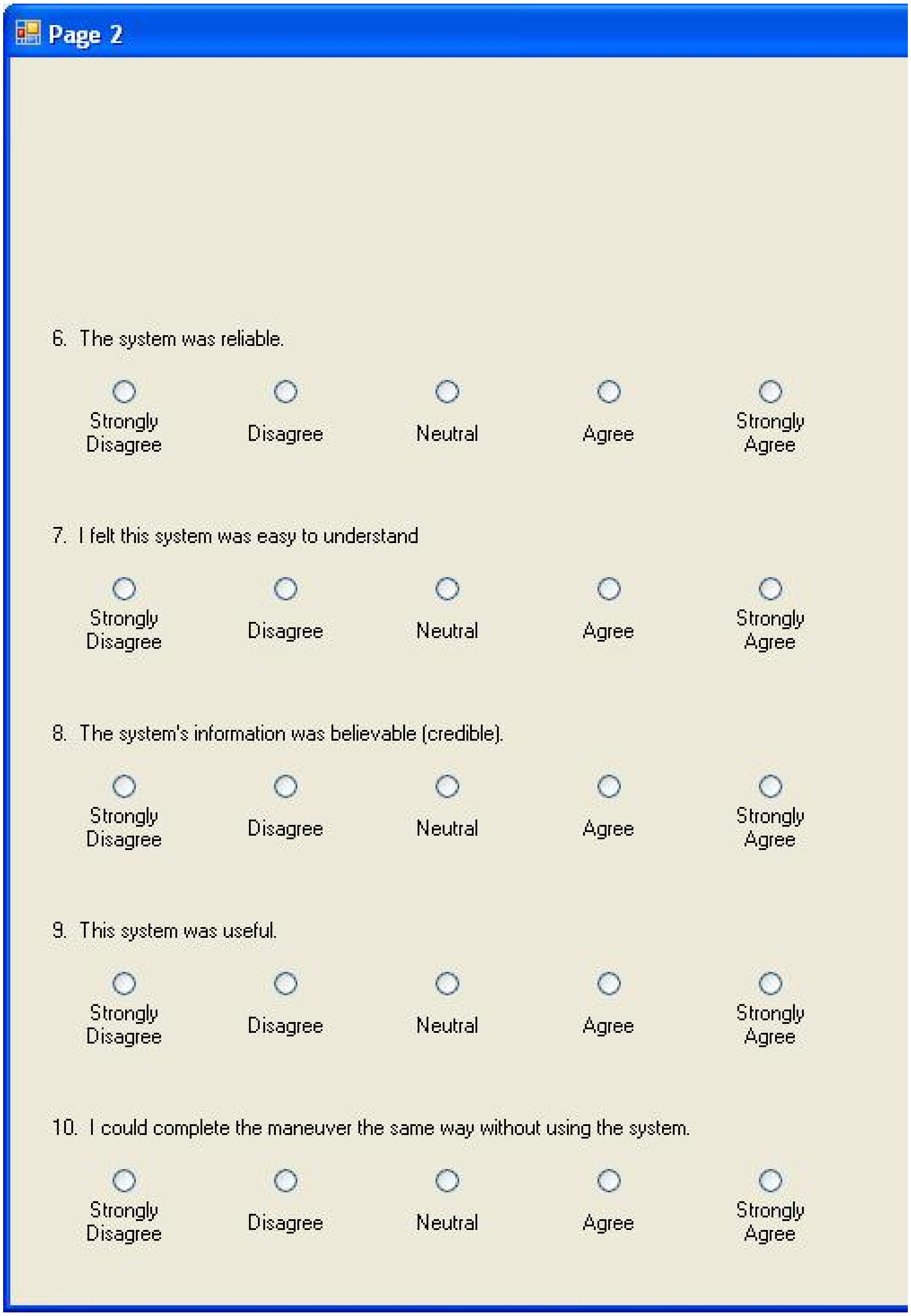
○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

4. I trusted the information provided by this system.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

5. I like this system.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree



Page 2

6. The system was reliable.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

7. I felt this system was easy to understand

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

8. The system's information was believable (credible).

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

9. This system was useful.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

10. I could complete the maneuver the same way without using the system.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

Appendix E Interview Questions

Interview questions

1. What do you see as the strengths and weaknesses of these systems?

2. Do the systems communicate the information you need?

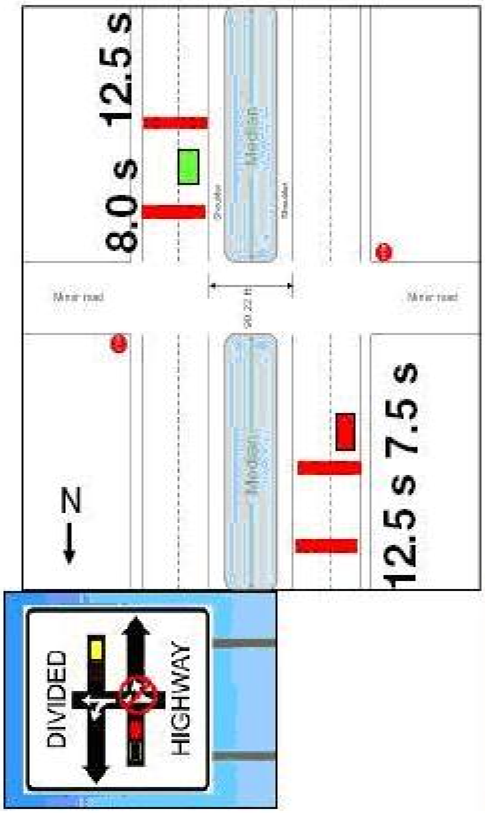
3. How could these systems be improved?

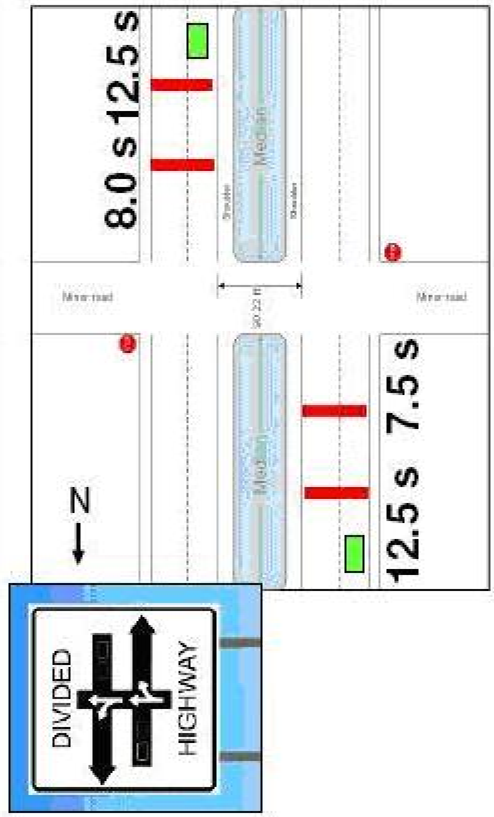
4. Which system do you think is best?

5. Do you have any other comments or feedback?

Appendix F Visual Aids for Explanation of Decision Support Systems

First page image reproduced by permission of HumanFIRST Program


DIVIDED
HIGHWAY
N
12.5 s
7.5 s
8.0 s
12.5 s
Median
Minor road


DIVIDED
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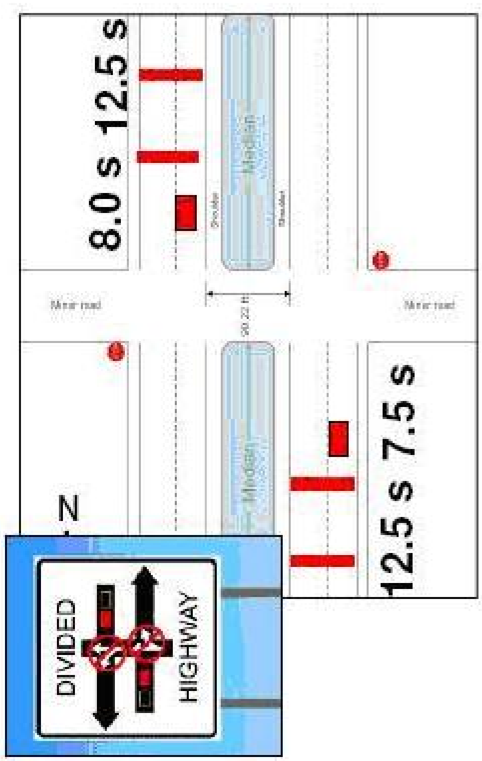
DIVIDED
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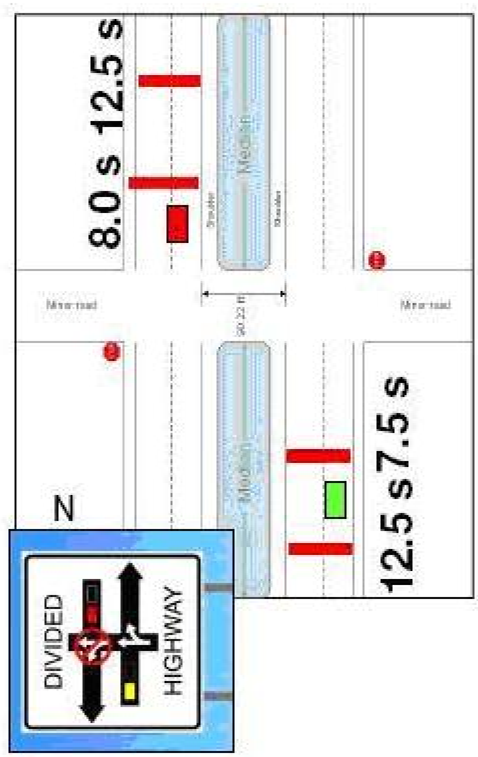
7.5 s
8.0 s
12.5 s
Median
Minor road


DIVIDED
HIGHWAY
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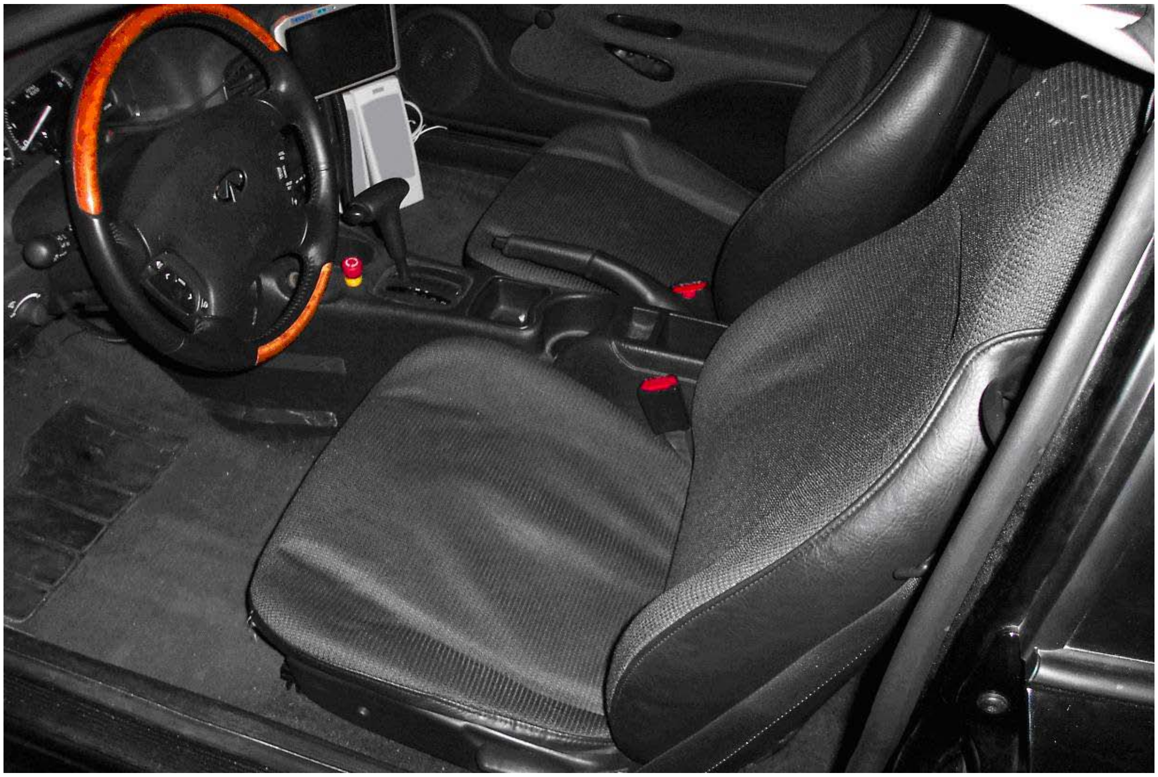
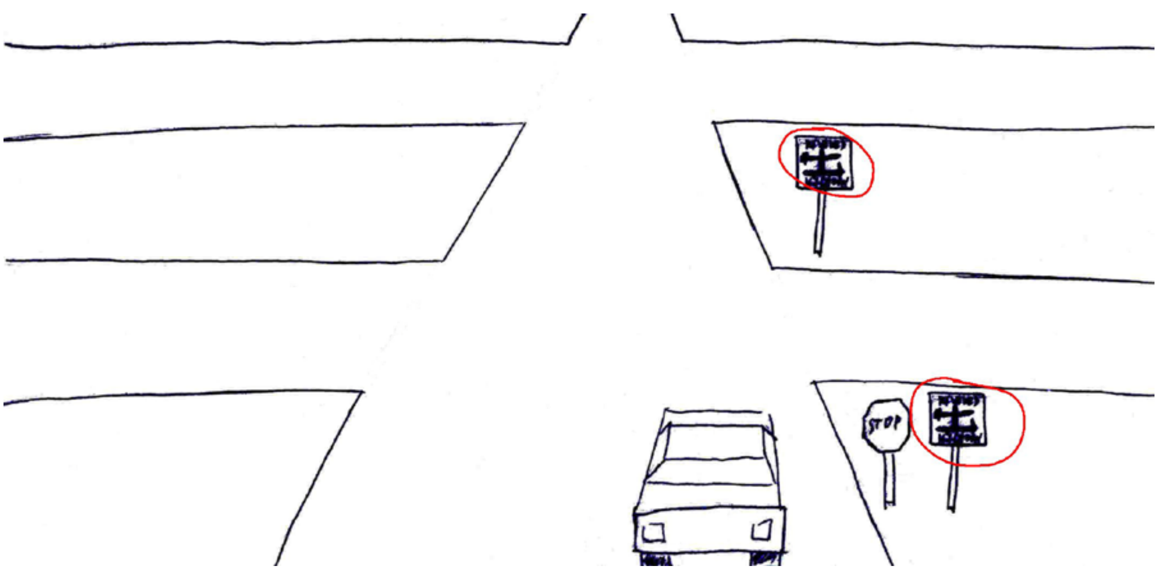
12.5 s
7.5 s
8.0 s
12.5 s
Median
Minor road




STOP

Appendix G Pilot Study Data

*asterisk denotes significant result ($p < 0.05$)

Driver performance data

For the seat condition, participant 3 waited for all traffic to pass in the SB lanes, so there was no data for accepted SB gap or SB safety margin.

	accepted SB gap			accepted NB gap		
	base	icon	seat	base	icon	seat
Participant 1	2.935	4.936	5.436	10.275	3.280	2.991
Participant 2	5.936	4.911	5.411	9.279	9.279	8.966
Participant 3	7.437	7.912	-	9.253	9.279	8.965
Participant 4	4.935	4.935	4.936	9.278	9.279	8.991
mean	5.311	5.674	5.261	9.521	7.779	7.478
std dev	1.888	1.493	0.282	0.502	2.999	2.991

	accepted SB gap			accepted NB gap		
	icon - base	icon - seat	seat - base	icon - base	icon - seat	seat - base
Participant 1	2.001	-0.501	2.502	-6.994	0.289	-7.284
Participant 2	-1.025	-0.500	-0.525	0.000	0.313	-0.313
Participant 3	0.476	-	-	0.025	0.313	-0.288
Participant 4	0.000	0.000	0.000	0.000	0.288	-0.287
mean	0.363	-0.334	0.659	-1.742	0.301	-2.043
std dev	1.259	0.289	1.617	3.501	0.014	3.494
n	4.000	3.000	3.000	4.000	4.000	4.000
confidence interval lower bound	-1.640	-1.051	-3.359	-7.313	0.278	-7.601
confidence interval upper bound	2.366	0.384	4.676	3.829	0.324	3.516
t	0.576	-2.001	0.706	-0.995	41.990	-1.170
p (two-sided)	0.605	0.183	0.553	0.393	<0.001*	0.327

	SB safety margin			NB safety margin		
	base	icon	seat	base	icon	seat
Participant 1	0.960	2.236	2.437	7.874	2.031	1.491
Participant 2	3.262	2.262	2.912	6.703	6.929	6.266
Participant 3	4.138	4.088	-	7.703	7.279	5.516
Participant 4	2.236	1.886	2.262	6.403	6.653	6.416
mean	2.649	2.618	2.537	7.171	5.723	4.922
std dev	1.368	0.995	0.336	0.727	2.475	2.321

	SB safety margin			NB safety margin		
	icon - base	icon - seat	seat - base	icon - base	icon - seat	seat - base
Participant 1	1.276	-0.201	1.477	-5.844	0.540	-6.383
Participant 2	-1.000	-0.650	-0.349	0.226	0.663	-0.437
Participant 3	-0.049	-	-	-0.424	1.763	-2.187
Participant 4	-0.351	-0.376	0.026	0.250	0.237	0.013
mean	-0.031	-0.409	0.384	-1.448	0.801	-2.249
std dev	0.958	0.227	0.965	2.947	0.666	2.915
n	4.000	3.000	3.000	4.000	4.000	4.000
confidence interval lower bound	-1.554	-0.972	-2.012	-6.137	-0.259	-6.887
confidence interval upper bound	1.493	0.154	2.781	3.241	1.860	2.390
t	-0.064	-3.127	0.690	-0.983	2.405	-1.543
p (two-sided)	0.953	0.089	0.561	0.398	0.096	0.221

	wait time			movement time		
	base	icon	seat	base	icon	seat
Participant 1	34.602	100.750	106.023	17.703	16.848	16.424
Participant 2	118.720	118.632	116.622	29.797	28.024	30.258
Participant 3	120.396	114.861	126.839	27.946	32.131	21.895
Participant 4	139.492	130.516	132.971	19.052	20.851	22.348
mean	103.302	116.190	120.613	23.625	24.463	22.731
std dev	46.759	12.266	11.836	6.130	6.892	5.695

	wait time			movement time		
	icon - base	icon - seat	seat - base	icon - base	icon - seat	seat - base
Participant 1	66.148	-5.272	71.421	-0.855	0.424	-1.280
Participant 2	-0.088	2.010	-2.098	-1.774	-2.235	0.461
Participant 3	-5.535	-11.978	6.443	4.185	10.236	-6.051
Participant 4	-8.976	-2.456	-6.521	1.798	-1.497	3.295
mean	12.887	-4.424	17.311	0.839	1.732	-0.894
std dev	35.695	5.861	36.472	2.697	5.779	3.921
n	4.000	4.000	4.000	4.000	4.000	4.000
confidence interval lower bound	-43.904	-13.748	-40.716	-3.452	-7.462	-7.132
confidence interval upper bound	69.678	4.901	75.338	5.129	10.927	5.345
t	0.722	-1.510	0.949	0.622	0.600	-0.456
p (two-sided)	0.522	0.228	0.413	0.578	0.591	0.680

*asterisk denotes significant result (p < 0.05)

NASA TLX items (data for participant 3 could not be collected due to computer error)

	mental demand			physical demand		
	base	icon	seat	base	icon	seat
Participant 1	54.500	35.500	58.000	39.500	56.500	40.500
Participant 2	26.500	33.000	22.500	5.500	4.500	6.500
Participant 4	31.500	27.500	30.500	18.500	18.500	19.000
mean	37.500	32.000	37.000	21.167	26.500	22.000
std dev	14.933	4.093	18.621	17.156	26.907	17.197

	mental demand			physical demand		
	icon - base	icon - seat	seat - base	icon - base	icon - seat	seat - base
Participant 1	-19.000	-22.500	3.500	17.000	16.000	1.000
Participant 2	6.500	10.500	-4.000	-1.000	-2.000	1.000
Participant 4	-4.000	-3.000	-1.000	0.000	-0.500	0.500
mean	-5.500	-5.000	-0.500	5.333	4.500	0.833
std dev	12.816	16.591	3.775	10.116	9.987	0.289
confidence interval lower bound	-37.339	-46.217	-9.878	-19.798	-20.312	0.116
confidence interval upper bound	26.339	36.217	8.878	30.465	29.312	1.551
t	-0.743	-0.522	-0.229	0.913	0.780	5.000
p (two-sided)	0.535	0.654	0.840	0.458	0.517	0.038*

	time pressure			performance		
	base	icon	seat	base	icon	seat
Participant 1	49.500	28.000	55.500	45.000	40.500	38.000
Participant 2	7.500	6.000	7.000	18.500	16.500	12.500
Participant 4	40.500	29.500	36.000	6.500	16.500	12.000
mean	32.500	21.167	32.833	23.333	24.500	20.833
std dev	22.113	13.156	24.405	19.700	13.856	14.869

	time pressure			performance		
	icon - base	icon - seat	seat - base	icon - base	icon - seat	seat - base
Participant 1	-21.500	-27.500	6.000	-4.500	2.500	-7.000
Participant 2	-1.500	-1.000	-0.500	-2.000	4.000	-6.000
Participant 4	-11.000	-6.500	-4.500	10.000	4.500	5.500
mean	-11.333	-11.667	0.333	1.167	3.667	-2.500
std dev	10.004	13.985	5.299	7.751	1.041	6.946
confidence interval lower bound	-36.187	-46.410	-12.832	-18.090	1.081	-19.757
confidence interval upper bound	13.520	23.077	13.499	20.424	6.252	14.757
t	-1.962	-1.445	0.109	0.261	6.102	-0.623
p (two-sided)	0.189	0.285	0.923	0.819	0.026*	0.597

	effort			frustration level		
	base	icon	seat	base	icon	seat
Participant 1	49.000	42.000	52.500	43.000	49.000	43.000
Participant 2	19.000	19.500	18.500	2.000	6.000	7.000
Participant 4	32.500	35.000	33.500	50.000	50.000	50.000
mean	33.500	32.167	34.833	31.667	35.000	33.333
std dev	15.025	11.514	17.039	25.929	25.120	23.072

	effort			frustration level		
	icon - base	icon - seat	seat - base	icon - base	icon - seat	seat - base
Participant 1	-7.000	-10.500	3.500	6.000	6.000	0.000
Participant 2	0.500	1.000	-0.500	4.000	-1.000	5.000
Participant 4	2.500	1.500	1.000	0.000	0.000	0.000
mean	-1.333	-2.667	1.333	3.333	1.667	1.667
std dev	5.008	6.788	2.021	3.055	3.786	2.887
confidence interval lower bound	-13.776	-19.532	-3.687	-4.256	-7.739	-5.505
confidence interval upper bound	11.109	14.198	6.354	10.923	11.072	8.838
t	-0.461	-0.680	1.143	1.890	0.762	1.000
p (two-sided)	0.690	0.567	0.372	0.199	0.525	0.423

Appendix H Participant Interview Feedback on Pilot Study Decision Support Systems

Below are the results of the interview feedback. Statements have been paraphrased. The meanings of the DSSs were explained during the interviews.

For the Icon Sign

Participant 1

- I never saw the "yellow" state for the near side sign.
- I didn't know the legality issues related to the sign. I wondered about this at first.
- I wondered if there would be a green condition.
- For the near side traffic, the Icon Sign is on right side while traffic is coming from the left, so I can't watch both at once. I don't want to miss it if it turns yellow, but I want to watch traffic.
- The median sign is more useful since it is in your field of view while you are watching the approaching traffic.
- The "circle with slash" symbol is useful.
- The Icon sign is easier to understand, but the vibration is a good form of feedback.

Participant 2

- The sign was better. The colors were good, but the placement was poor.
- It would be good to have the first sign on the left.
- The signs were not especially useful, particularly when traffic was coming from the left, since you can't see both the sign and the traffic. I used the yellow mark as a confirmatory.
- In the median, the sign was in my peripheral vision.
- The sign was better

Participant 3

- The signs are applicable to all vehicles (no special setup required).

- The signs communicate the information needed.
- The signs are useful. I tended to follow the sign's suggestions even if I saw gaps available.
- For the second set of lanes, the sign was easier to see.
- The nearer sign was too close. I just watched the far sign.

Participant 4

- The sign was self explanatory, but on the wrong side. I have to blindly follow it. It should be in peripheral vision.
- The Icon Sign could be improved by moving the sign to other side.
- The Icon Sign could be improved with notes on the sign to show what "ok" & "not ok" conditions look like (i.e. a key).
- Green would be a more universal color to use (though the circle with a slash is an obvious symbol, too).
- I preferred the sign.
- The signs aren't bad, but I am hesitant to trust them if visibility is good enough.

For the Vibrotactile Seat

Participant 1

- I didn't know there was a right/left at first.
- I couldn't tell if the vibration meant "go" or "don't go".
- I don't want to have to inch forward to know whether to go.
- It's good that the seat's feedback was definite.
- The Vibrotactile Seat could be improved if it could help the driver make a decision instead of trying to correct the driver's decision.

- The Icon sign is easier to understand, but the vibration is a good form of feedback.

Participant 2

- If radar is installed in the car for the real-world counterpart of the Vibrotactile Seat, it might not work depending on the angle of the car.
- Once I figured out the vibration, I found it useful as a confirmatory.
- I thought the vibration meant "go", or "edge up further".

Participant 3

- The vibration does not communicate the information needed.
- The vibration would be better if always runs. It would be more informative (though then it would run constantly, which would not be as effective).
- The vibration is not intuitive. It doesn't make sense.

Participant 4

- For the seat, you've already made up your mind when it vibrates. This could be too late.
- The seat is too late to communicate needed information.
- The Vibrotactile Seat could be improved with notification of what the seat means.

Appendix I Simulator Sickness Screening Questionnaire

Screening Questionnaire

This questionnaire will be administered during the recruitment process to determine eligibility for participation.

1. What is your age?
EXCLUDE IF NOT 18 OR OLDER

2. Have you had a driver's license for at least 1 year?
EXCLUDE IF NO

3. Yes or no, do you have 20/40 vision, either corrected or uncorrected? (i.e. persons that use corrective lenses which improve their vision to 20/40 may participate)
EXCLUDE IF NO

4. Yes or no, do you have any health problems that affect your driving?
EXCLUDE IF YES

5. Yes or no, do you experience inner ear problems, dizziness, vertigo, or balance problems?
EXCLUDE IF YES

6. Yes or no, do you have a history of motion sickness? (e.g., back seat of car, boats, amusement park rides, etc)
EXCLUDE IF YES

7. Yes or no, do you have a history of claustrophobia?
EXCLUDE IF YES

8. Yes or no, are you suffering from any lingering effects of stroke, tumor, head trauma, or infection?
EXCLUDE IF YES

9. Yes or no, do you or have you ever suffered from epileptic seizures?
EXCLUDE IF YES

10. Yes or no, do you have a history of migraines?
EXCLUDE IF YES

Appendix J Counterbalance

Participant	1st condition	2nd condition	3rd condition	4th condition
1	No DSS	Icon Sign	Side Mirror	Vibrotactile Seat
2	No DSS	Icon Sign	Vibrotactile Seat	Side Mirror
3	No DSS	Side Mirror	Icon Sign	Vibrotactile Seat
4	No DSS	Side Mirror	Vibrotactile Seat	Icon Sign
5	No DSS	Vibrotactile Seat	Icon Sign	Side Mirror
6	No DSS	Vibrotactile Seat	Side Mirror	Icon Sign
7	Icon Sign	No DSS	Side Mirror	Vibrotactile Seat
8	Icon Sign	No DSS	Vibrotactile Seat	Side Mirror
9	Icon Sign	Side Mirror	No DSS	Vibrotactile Seat
10	Icon Sign	Side Mirror	Vibrotactile Seat	No DSS
11	Icon Sign	Vibrotactile Seat	No DSS	Side Mirror
12	Icon Sign	Vibrotactile Seat	Side Mirror	No DSS
13	Side Mirror	No DSS	Icon Sign	Vibrotactile Seat
14	Side Mirror	No DSS	Vibrotactile Seat	Icon Sign
15	Side Mirror	Icon Sign	No DSS	Vibrotactile Seat
16	Side Mirror	Icon Sign	Vibrotactile Seat	No DSS
17	Side Mirror	Vibrotactile Seat	No DSS	Icon Sign
18	Side Mirror	Vibrotactile Seat	Icon Sign	No DSS
19	Vibrotactile Seat	No DSS	Icon Sign	Side Mirror
20	Vibrotactile Seat	No DSS	Side Mirror	Icon Sign
21	Vibrotactile Seat	Icon Sign	No DSS	Side Mirror
22	Vibrotactile Seat	Icon Sign	Side Mirror	No DSS
23	Vibrotactile Seat	Side Mirror	No DSS	Icon Sign
24	Vibrotactile Seat	Side Mirror	Icon Sign	No DSS

Appendix K Experimenter Instructions and Participant Verbal Instructions

Procedures

Introduction

Welcome participant; check that they are the person scheduled in that time slot; check their driver's license; ensure they have their glasses needed for distance and/or reading

Informed Consent

"The first thing we will do today is look at the informed consent form. All University of Minnesota studies have to be approved by a research ethics board to ensure that we are treating participants appropriately. Consent forms are required by the ethics board. I will go over the form with you, ask you to read the form and if you agree to continue with participation in this study, you can sign and date the form on the second page."

"First, I would like to point out the **Background and Procedures** sections. Today you will be driving in the simulator and interacting with new information systems. You will be answering questionnaires about these systems while in the vehicle. Once we are ready to begin, I will explain the study in more detail. You will be asked to provide us with some basic demographic information about yourself. We will also test your vision using a standard eye chart. We will then provide you with an introduction to the study. At that point, you will complete a practice drive in the simulator. Once you are comfortable with how the simulator operates, we'll begin the experiment. It should take us about 2 hours to complete all the study tasks."

"Second, I would like to talk about the **Risks and Benefits of being in this study and Compensation.** There is a small risk that you may experience motion sickness while in the simulator. A small percentage of individuals experience motion sickness, even if they have never suffered from motion sickness before. If you do begin to feel uncomfortable while in the simulator, please do let me know and we can stop the study.

You will receive $50 for your participation today. Please keep in mind that this study is voluntary and you can withdraw at any time or for any reason without penalty."

"Third, please note that all records associated with this study are confidential. Your name will never be associated with the data collected during this study."

"I will now ask you to **Read the Consent Form** and sign and date it on the second page if you are willing to continue with the study today. If you have any questions about the consent form, please ask me. Also, I can provide a second copy for you to take with you if you wish."

"The ethics board also asks us to make sure you understand the consent form by asking you about it, so I need to ask you a few questions."

List of questions and examples of valid answers:

Q: Can you describe what you are to do during this study?
A: Drive through an intersection and use the provided decision support systems if I find them useful.

Q: Can you describe your understanding of the risks?

A: Simulator sickness, nausea or dizziness.

Q: Do you know what to do if you feel dizzy, nauseous, or feel strange?
A: Stop the vehicle and let the experimenter know I wish to quit the study.

Q: Can you describe your right to withdraw?
A: I may withdraw at any time and for any reason without penalty.

If their answers do not cover all the key points, explain the full answer to them.

Demographic Questionnaire
Have participant complete computerized demographic questionnaire.

Vision Test
Check participant's vision using test machine

BREAK (if needed): The first part of the study will take about **one hour** so if you need to get some water or use the restroom, you should do so now.

Study Introduction
Have participant read study introduction and ask them if they have any questions. Answer any questions you can, without biasing the study goals. They may ask detailed questions about the smart signs, simply stick to the scope the introduction.

Practice Drives
"We will now move to the simulator and you will complete the practice drives."
"Please get into the vehicle and adjust the seat so that you can comfortably reach all the controls." *[help them adjust seat, etc, if necessary]*
"For the practice session, you will be starting a short distance from the intersection. Your task is to drive the vehicle to the intersection, stop at the stop sign, and then cross over the intersection when you feel it is safe to do so."
"The goal of these drives is to help you familiarize yourself with stopping at the stop sign so that:

1. You can see the approaching traffic from the left while at the stop sign
2. You are stopped an appropriate distance from the intersection

During each drive I will provide instructions on how to improve your ability to meet these two task goals."
"Please keep in mind that the simulator will not feel like a real car. It may take you a few practice drives to get familiar with how the car feels and works and that is ok. Your goal is to get familiar with how this vehicle operates and with crossing the intersection."
"I will be at the computer station behind the curtain. I can see you on the video monitor and I will keep an eye on you. You will be able to hear me over speakers in the vehicle and I can hear you if you speak in a normal voice. Please let me know if the volume is sufficient while I am talking to you."
(Make sure:

1. *The lights are on so the dashboard display is visible*
2. *To show them how to turn on the car using the key*
3. *To remind them the car will need to be in park to start the vehicle*

4. *To remind them the vehicle will need to be started at the beginning of each new drive)*

Also: you can talk them through stopping the car once they've crossed the intersection over the headset.

Run at least 2 practice trials per participant (more if they need it).

Experimental Drives
"Ok, now that you are familiar with the vehicle, we will begin the experiment. Just like in the practice drive, you will drive up to the stop sign and cross when it is safe to do so."

"However, during the experimental drives a smart system may be present. This means the information given by the system changes in real time depending on the current traffic conditions near the intersection. The system presents information that helps you, the driver, make decisions about when to cross or turn at the intersection based on current traffic conditions. Your goal is to cross the intersection as you would normally if you encountered these systems in the real world. Take note of the systems to see if you understand the information they provide and use the information if you think it is useful."

"You will complete two drives in a row and then answer some questionnaires about the drives you just completed. Please make sure to read all the instructions on the questionnaires carefully. I will be here to help you with the questionnaires while you are answering them."

[walk participant through questionnaires for first condition]

"You will complete four sets of two drives each, for a total of eight drives. We will take a break after the first four drives."

Final Questionnaire
[participant exits vehicle after final set of trials and finishes the questionnaires]

Reimbursement
[If participant had a positive experience and is interested in participating in future sim studies, take their name, age and phone number/email.]
"We ask that if you know any other people scheduled to participate in this study that you do not reveal to them any specific details about what you were required to do."

Appendix L Consent Form

CONSENT FORM

Driver-Vehicle Interfaces for Intersection Collision Avoidance

You are invited to be in a research study to examine the understandability of new systems designed to help with navigating intersections. You were selected as a possible participant because you responded to our recruitment inquiries and were found to be a suitable participant for this study. We ask that you read this form carefully and ask any questions you may have before agreeing to be in the study.

This study is being conducted by Daniel Drew, a Mechanical Engineering graduate student working for the HumanFIRST Program at the University of Minnesota.

Background Information:
The purpose of this study is to investigate how people drive at intersections in rural environments and how new systems may improve safety at these intersections.

Procedures:
If you agree to be in this study, we will ask you to do the following things: (1) be trained in our driving simulator; and (2) perform a number of directed drives through an intersection in a simulated rural environment of Minnesota Highway 52 (TH52). Your vision will be checked using a standard eye chart. You will also be given some questionnaires to complete that ask you about your driving history, your experiences in the simulator, and your opinions of the systems being tested. The duration of the entire study will be about 2 hours.

Risks and Benefits of Being in the Study:
There are no direct benefits to you for participating in this study, other than the opportunity to experience a simulator and participate in research. A small percentage of individuals may experience motion sickness while driving in the simulator. If you begin to feel unwell, dizzy, or nauseous, notify us and we will stop the study. Note: you are free to withdraw from the study at any time if you do not wish to continue.

Compensation:
You will receive a payment of $50 for participation. If you terminate the study early, you will still receive full payment.

Confidentiality:
The records of this study will be kept private. You name will not be associated with any of the data collected today. In any sort of report we might publish, we will not include any information that will make it possible to identify you or other participants. Research records are stored securely in locked offices and only HumanFIRST personnel will have access to the data collected.

Voluntary Nature of the Study:
Participation in this study is voluntary. Your decision whether or not to participate will not affect your current or future relations with the University of Minnesota. If you decide to participate, you are free to not answer any question or withdraw at any time without affecting those relationships.

Contacts and Questions:
You may ask any questions you have now.
If you have questions later, **you are encouraged** to contact Daniel at:
Office: ME 388
Phone: 612-623-8237
Email: drewx039@umn.edu
Mailing Address:
Mechanical Engineering Room 1101
111 Church St. S.E.
Minneapolis, MN 55455

You may also contact Daniel's advisor:
Caroline Hayes
Phone: 612-626-8391
Email: hayes@me.umn.edu

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher, **you are encouraged** to contact the Research Subjects' Advocate Line:
D528 Mayo
420 Delaware St. S.E.
Minneapolis, Minnesota 55455
Phone: (612) 625-1650.

You will be offered a copy of this information to keep for your records.

Statement of Consent: I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature:_______________________________________ Date: _________________

Signature of Investigator:__________________________ Date: _________________

Appendix M Participant Reimbursement Form

PARTICIPANT REIMBURSEMENT FORM

Principle Investigator: _D. Drew____
Study Name: Driver-Vehicle Interfaces for Intersection Collision Avoidance (Human Subjects Code Number: 0812P56043)
Reimbursement amount for each participant: _$50____

My signature below indicates that:

- I have received $____ for my participation in the above cited study conducted by the HumanFIRST program at the University of Minnesota.
- I feel that I have recovered from the study and agree that I am fit to be released under my own responsibility.

Signature: ______________________________ Date: ______________

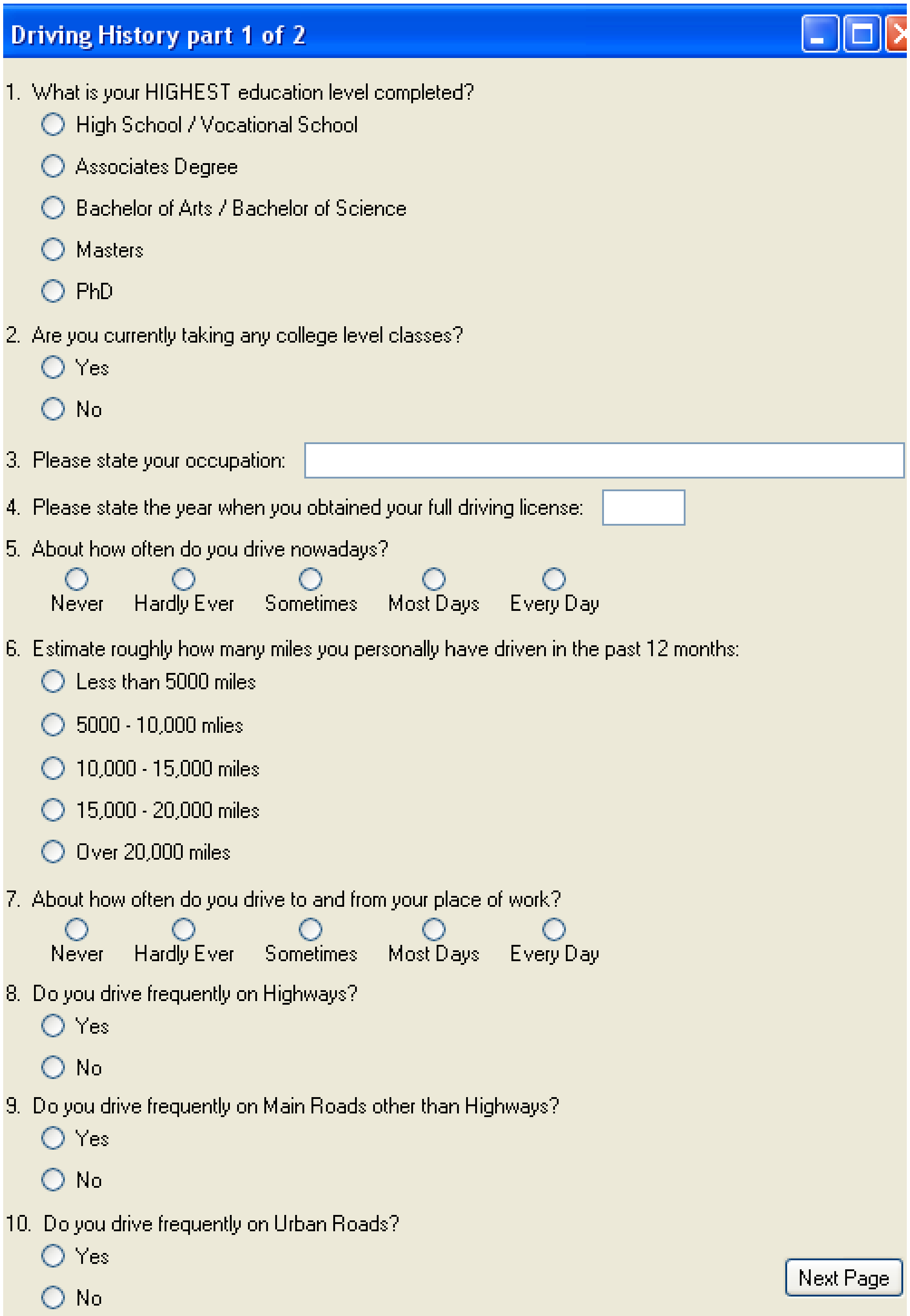
Print Name: ______________________________

Street Address: ____

City: ____________________ State: __________ Zip: ______________

Phone:(___)____-__________

Appendix N Driving History and Driver Demographic Questionnaire



Driving History part 1 of 2

1. What is your HIGHEST education level completed?
   - ◯ High School / Vocational School
   - ◯ Associates Degree
   - ◯ Bachelor of Arts / Bachelor of Science
   - ◯ Masters
   - ◯ PhD
2. Are you currently taking any college level classes?
   - ◯ Yes
   - ◯ No
3. Please state your occupation: [ ]
4. Please state the year when you obtained your full driving license: [ ]
5. About how often do you drive nowadays?

   ◯ Never ◯ Hardly Ever ◯ Sometimes ◯ Most Days ◯ Every Day
6. Estimate roughly how many miles you personally have driven in the past 12 months:
   - ◯ Less than 5000 miles
   - ◯ 5000 - 10,000 mlies
   - ◯ 10,000 - 15,000 miles
   - ◯ 15,000 - 20,000 miles
   - ◯ Over 20,000 miles
7. About how often do you drive to and from your place of work?

   ◯ Never ◯ Hardly Ever ◯ Sometimes ◯ Most Days ◯ Every Day
8. Do you drive frequently on Highways?
   - ◯ Yes
   - ◯ No
9. Do you drive frequently on Main Roads other than Highways?
   - ◯ Yes
   - ◯ No
10. Do you drive frequently on Urban Roads?
    - ◯ Yes
    - ◯ No

[Next Page]

Driving History part 2 of 2

Previous Page

11. Do you drive frequently on Country Roads?
   - ◯ Yes
   - ◯ No

12. During the last three years, how many MINOR road accidents have you been involved in where you were at fault?
   (A minor accident is one in which no-one required medical treatment, AND costs of damage to vehicles and property were less than $1000).

   Number of minor accidents [ ] (if none, write 0)

13. During the last three years, how many MAJOR road accidents have you been involved in where you were at fault?
   (A major accident is one in which EITHER someone required medical treatment, OR costs of damage to vehicles and property were greater than $1000, or both).

   Number of major accidents [ ] (if none, write 0)

14. During the last three years, have you ever been convicted for:

   a. Speeding
   - ◯ Yes
   - ◯ No

   b. Careless or dangerous driving
   - ◯ Yes
   - ◯ No

   c. Driving under the influence of alcohol/drugs
   - ◯ Yes
   - ◯ No

15. What type of vehicle do you drive most often?
   - ◯ Motorcycle
   - ◯ Passenger Car
   - ◯ Pick-Up Truck
   - ◯ Sport utility vehicle
   - ◯ Van or Minivan
   - ◯ Other, briefly describe: [ ]

Next Survey

Appendix O Study Summary

First page image reproduced by permission of HumanFIRST Program.

STUDY SUMMARY

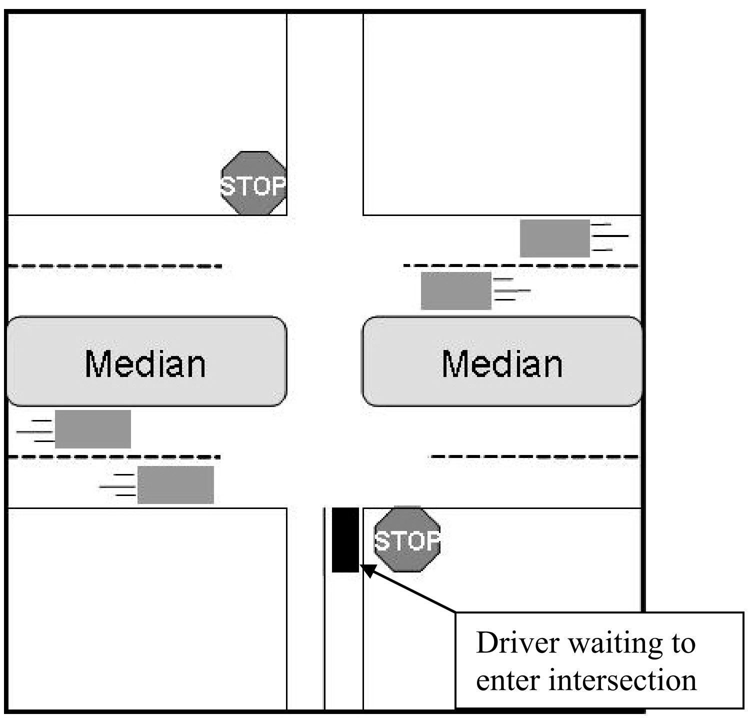
The purpose of this study is to investigate driver behavior while crossing rural intersections. This project has developed several new systems to help drivers make crossing decisions at rural intersections.

During this study you will be able to experience these systems. These "smart" systems monitor the approaching traffic at the intersection and can communicate different messages in real time based on the current traffic conditions. These systems are meant to present information that helps you, the driver, make decisions about when to cross or turn at the intersection. Your goal is to drive as you would normally if you encountered these systems in the real world.

One of these systems is a sign whose display can change. Another system is a display that replaces the side view mirrors. Another system is a set of vibration pads in the seat. You should take note of these systems and use the information they provide if you think it is useful.

You will be asked to drive across a simulated rural intersection several times. The diagram below shows a typical rural intersection where a smaller road crosses a larger, multi-lane road with fast-moving traffic. Your goal is to cross the intersection safely, and you may use the information provided by the systems if you wish.

If you have any questions, please feel free to ask at any time during the study.



Please let the researcher know when you have finished reading this page.

Appendix P Post-Driving Maneuver Questionnaire

POST CONDITION QUESTIONNAIRE

Answer the following questions in regards to the most recent set of times you crossed the intersection by placing a mark (**X**) in the appropriate box.

1. Did you feel you had enough time before making your maneuver (turn or cross) through the intersection?

   Not enough time ☐—☐—☐—☐—☐ *More than enough time*

2. Did you feel you had enough time to make your maneuver (turn or cross) through the intersection?

   Not enough time ☐—☐—☐—☐—☐ *More than enough time*

3. How safe was the gap in traffic that you chose while driving through the intersection?

   Not safe ☐—☐—☐—☐—☐ *Extremely safe*

4. How frustrating was your entire experience at the intersection?

   Not frustrating ☐—☐—☐—☐—☐ *Extremely frustrating*

5. How much mental effort was needed to drive through the intersection?

   Small amount of effort ☐—☐—☐—☐—☐ *Large amount of effort*

6. How much physical effort was needed to drive through the intersection?

   Small amount of effort ☐—☐—☐—☐—☐ *Large amount of effort*

7. How would you rate your overall performance while driving through the intersection?

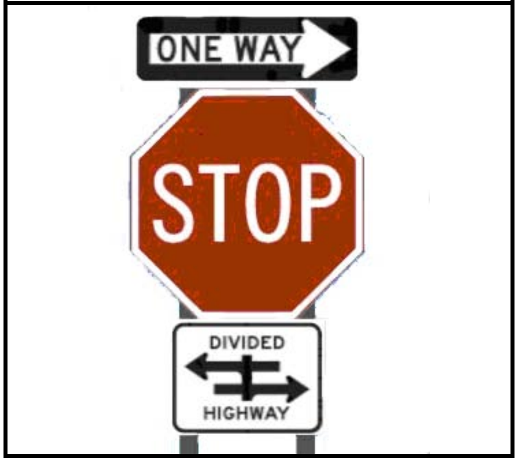
   Worse than normal ☐—☐—☐—☐—☐ *Better than normal*

Appendix Q Post-Condition Questionnaire—Stop Sign

Stop sign images reproduced by permission of HumanFIRST Program

You just observed this system at the intersection.

Stop Sign



Please answer the question on this page and the questions on the following pages based on your experience driving through the intersection with this system present.

Please describe in your own words what you think this system's function is and what information it provides to the driver (you).

Continued on Next Page

Please indicate how strongly you agree or disagree with the following statements.
Answer these questions in relation to the system you just observed at the intersection while driving.

1. I felt confident using this system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

2. I felt it was confusing to use this system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

3. Using this system made me feel safer.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

4. I trusted the information provided by the system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

5. I like this system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

6. The system was reliable.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

7. I felt this system was easy to understand.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

8. The system's information was believable (credible).

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

9. This system was useful.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

10. I could complete the maneuver the same way without using the system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

Continued on Next Page

11. Did you use the information from this system to help you make your crossing decisions?

☐Yes ☐No

If "yes", please explain what information you used or how you used the information to make your decision of when to cross?

If **"no"**, please explain why you did not use the information presented on the system.

Only move onto the next questionnaire once you have completed this section.

System Description

You just observed this system at the intersection.

This sign is the standard stop sign found at this type of intersection. It does not provide any information about the traffic at the intersection. It simply tells the driver that they must stop at the intersection before crossing. The crossing decision rests entirely upon the driver.

Sign	What the Sign Means
	**Stop at the intersection.**

Please rate your opinion of the system shown using all the items listed below. Please refer to the System Description page if you need a reminder of how each system works and the types of messages it presents. Remember that, although multiple pictures may be shown, each set of pictures represents only ONE system capable of displaying several messages.

Example: If you thought the system was very easy to use but required a lot of effort you might respond as follows:

Easy	☒	☐	☐	☐	☐	Difficult
Simple	☐	☐	☐	☒	☐	Confusing

Useful	☐	☐	☐	☐	☐	Useless
Pleasant	☐	☐	☐	☐	☐	Unpleasant
Bad	☐	☐	☐	☐	☐	Good
Nice	☐	☐	☐	☐	☐	Annoying
Effective	☐	☐	☐	☐	☐	Superfluous
Irritating	☐	☐	☐	☐	☐	Likeable
Assisting	☐	☐	☐	☐	☐	Worthless
Undesirable	☐	☐	☐	☐	☐	Desirable
Raising Alertness	☐	☐	☐	☐	☐	Sleep-inducing

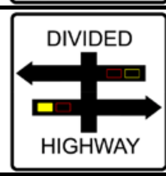
Appendix R Post-Condition Questionnaire—Icon Sign

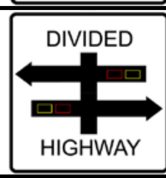
Icon sign images reproduced by permission of HumanFIRST Program

You just observed this system at the intersection.

Remember that, although multiple pictures are shown, this set of pictures represents only ONE sign that is capable of displaying several messages

Sign with Different Messages





Please answer the question on this page and the questions on the following pages based on your experience driving through the intersection with this system present.

Please describe in your own words what you think this system's function is and what information it provides to the driver (you).

____

____

____

Continued on Next Page

Please indicate how strongly you agree or disagree with the following statements.
Answer these questions in relation to the system you just observed at the intersection while driving.

1. I felt confident using this system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

2. I felt it was confusing to use this system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

3. Using this system made me feel safer.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

4. I trusted the information provided by the system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

5. I like this system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

6. The system was reliable.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

7. I felt this system was easy to understand.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

8. The system's information was believable (credible).

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

9. This system was useful.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

10. I could complete the maneuver the same way without using the system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

Continued on Next Page

11. Did you use the information from this system to help you make your crossing decisions?

☐Yes ☐No

If "yes", please explain what information you used or how you used the information to make your decision of when to cross?

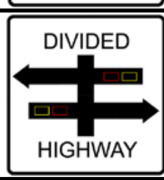
If **"no"**, please explain why you did not use the information presented on the system.

Only move onto the next questionnaire once you have completed this section.

System Description

You just observed this system at the intersection.

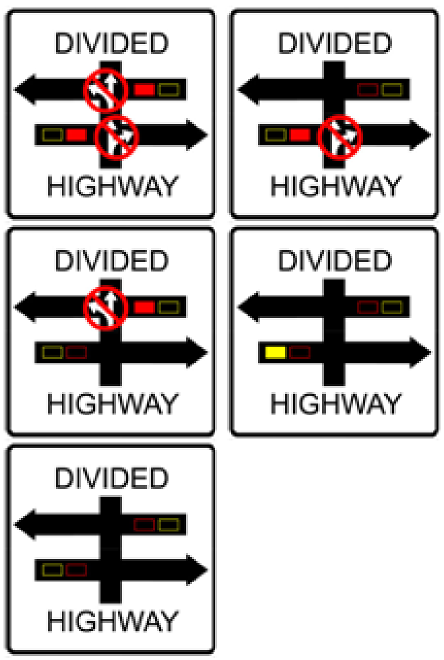
This sign shows an overview of the highway and the direction of travel of vehicles on the highway. This sign uses icons to indicate when traffic is detected near the intersection in each set of lanes (near and far lanes). When traffic is detected too close to the intersection in a set of lanes, a red block (indicating a vehicle) is lit up. At the same time, an icon indicates that it is unsafe to enter the intersection and which maneuvers might be dangerous. When a vehicle is detected approaching the intersection, but is not considered too close a yellow icon lights up (indicating the presence of a vehicle). This icon is yellow to indicate that it may be OK to cross, but that the driver should still proceed cautiously. If no vehicles are detected near the intersection, none of the icons are lit up. In this case, it may be ok to enter the intersection to cross over or turn right/left.

Sign with Different Messages	What Each Message Means
	**Do not enter the intersection; a vehicle is detected too close to the intersection in the near lanes (approaching from the left).**
	**Do not enter the intersection; vehicles are detected too close to the intersection in both the near (approaching from left) and far lanes (approaching from right).**
	**You may turn right; no vehicles detected approaching from the left in the near lanes. Vehicles are detected approaching from the right and are too close to the intersection; do not cross or turn left into the far lanes.**
	**A vehicle is detected approaching from the left in the near lanes. You may be able to cross or turn, but proceed with caution.**
	**No vehicles are detected approaching in the near (from the left) or far lanes (from the right). You may be able to cross or turn.**

Please rate your opinion of the system shown using all the items listed below. Please refer to the System Description page if you need a reminder of how each system works and the types of messages it presents. Remember that, although multiple pictures may be shown, each set of pictures represents only ONE system capable of displaying several messages.

Example: If you thought the system was very easy to use but required a lot of effort you might respond as follows:

Easy	☒ ☐ ☐ ☐ ☐	Difficult
Simple	☐ ☐ ☐ ☒ ☐	Confusing



Useful	☐ ☐ ☐ ☐ ☐	Useless
Pleasant	☐ ☐ ☐ ☐ ☐	Unpleasant
Bad	☐ ☐ ☐ ☐ ☐	Good
Nice	☐ ☐ ☐ ☐ ☐	Annoying
Effective	☐ ☐ ☐ ☐ ☐	Superfluous
Irritating	☐ ☐ ☐ ☐ ☐	Likeable
Assisting	☐ ☐ ☐ ☐ ☐	Worthless
Undesirable	☐ ☐ ☐ ☐ ☐	Desirable
Raising Alertness	☐ ☐ ☐ ☐ ☐	Sleep-inducing

Appendix S Post-Condition Questionnaire—Side Mirror Displays

You just observed this system at the intersection.

Remember that, although multiple pictures are shown, each column of pictures represents only ONE display that can change appearance.

Display with car icon and fill bar	
Left Display	Right Display
	
	

Please answer the question on this page and the questions on the following pages based on your experience driving through the intersection with this system present.

Please describe in your own words what you think this system's function is and what information it provides to the driver (you).

____

____

____

Continued on Next Page

Please indicate how strongly you agree or disagree with the following statements.
Answer these questions in relation to the system you just observed at the intersection while driving.

1. I felt confident using this system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

2. I felt it was confusing to use this system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

3. Using this system made me feel safer.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

4. I trusted the information provided by the system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

5. I like this system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

6. The system was reliable.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

7. I felt this system was easy to understand.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

8. The system's information was believable (credible).

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

9. This system was useful.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

10. I could complete the maneuver the same way without using the system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

Continued on Next Page

11. Did you use the information from this system to help you make your crossing decisions?

☐Yes ☐No

If "yes", please explain what information you used or how you used the information to make your decision of when to cross?

If **"no"**, please explain why you did not use the information presented on the system.

Only move onto the next questionnaire once you have completed this section.

System Description

You just observed this system at the intersection.

This display occupies the left and right side view mirrors of the vehicle. The left display presents information about traffic coming from the left (i.e. traffic in the near lanes) and the right display presents information about traffic coming from the right (i.e. traffic in the far lanes). A car icon appears on the display when traffic is close to the intersection. A fill bar also appears at this time, and the length of the bar corresponds to how close the traffic is to the intersection. As traffic approaches, the bar decreases in length.

Display with car icon and fill bar	What each image means
	Icon indicates traffic is approaching from the left. Bar indicates how close traffic is to the intersection.
	Icon indicates traffic is approaching from the left. Bar indicates how close traffic is to the intersection.
	Icon indicates traffic is approaching from the right. Bar indicates how close traffic is to the intersection.
	Icon indicates traffic is approaching from the right. Bar indicates how close traffic is to the intersection.

Please rate your opinion of the system shown using all the items listed below. Please refer to the System Description page if you need a reminder of how each system works and the types of messages it presents. Remember that, although multiple pictures may be shown, each set of pictures represents only ONE system capable of displaying several messages.

Example: If you thought the system was very easy to use but required a lot of effort you might respond as follows:

Easy	☒	☐	☐	☐	☐	Difficult
Simple	☐	☐	☐	☒	☐	Confusing

Useful	☐	☐	☐	☐	☐	Useless
Pleasant	☐	☐	☐	☐	☐	Unpleasant
Bad	☐	☐	☐	☐	☐	Good
Nice	☐	☐	☐	☐	☐	Annoying
Effective	☐	☐	☐	☐	☐	Superfluous
Irritating	☐	☐	☐	☐	☐	Likeable
Assisting	☐	☐	☐	☐	☐	Worthless
Undesirable	☐	☐	☐	☐	☐	Desirable
Raising Alertness	☐	☐	☐	☐	☐	Sleep-inducing

Appendix T Post-Condition Questionnaire—Vibrotactile Seat

You just observed this system at the intersection.

Seat with vibrational capability

Please answer the question on this page and the questions on the following pages based on your experience driving through the intersection with this system present.

Please describe in your own words what you think this system's function is and what information it provides to the driver (you).

____

____

____

Continued on Next Page

Please indicate how strongly you agree or disagree with the following statements.
Answer these questions in relation to the system you just observed at the intersection while driving.

1. I felt confident using this system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

2. I felt it was confusing to use this system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

3. Using this system made me feel safer.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

4. I trusted the information provided by the system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

5. I like this system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

6. The system was reliable.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

7. I felt this system was easy to understand.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

8. The system's information was believable (credible).

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

9. This system was useful.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

10. I could complete the maneuver the same way without using the system.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

Continued on Next Page

11. Did you use the information from this system to help you make your crossing decisions?

☐Yes ☐No

If "yes", please explain what information you used or how you used the information to make your decision of when to cross?

If **"no"**, please explain why you did not use the information presented on the system.

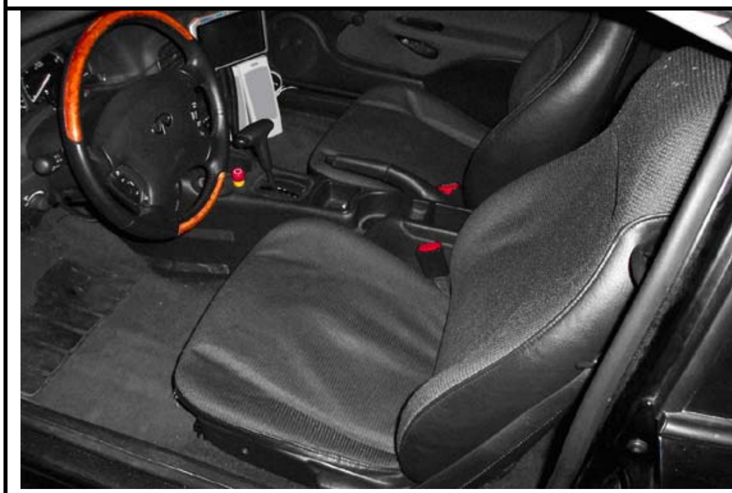
Only move onto the next questionnaire once you have completed this section.

System Description

You just observed this system at the intersection.

This seat has two vibrational pads, located under the driver's legs. The pads vibrate to indicate the presence of traffic approaching in each set of lanes (near and far lanes). When traffic is detected close to the intersection in a set of lanes, a pad vibrates to indicate from which direction the traffic is approaching, indicating that the driver should take this into consideration when deciding whether to proceed.

Seat with vibrational capability



Please rate your opinion of the system shown using all the items listed below. Please refer to the System Description page if you need a reminder of how each system works and the types of messages it presents. Remember that, although multiple pictures may be shown, each set of pictures represents only ONE system capable of displaying several messages.

Example: If you thought the system was very easy to use but required a lot of effort you might respond as follows:

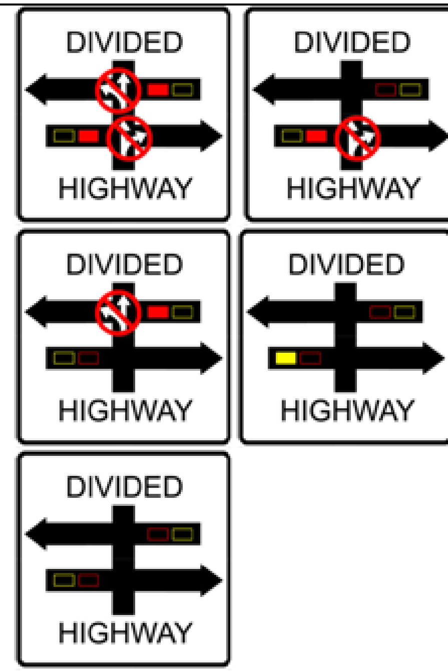
Easy	☒	☐	☐	☐	☐	Difficult
Simple	☐	☐	☐	☒	☐	Confusing

Useful	☐	☐	☐	☐	☐	Useless
Pleasant	☐	☐	☐	☐	☐	Unpleasant
Bad	☐	☐	☐	☐	☐	Good
Nice	☐	☐	☐	☐	☐	Annoying
Effective	☐	☐	☐	☐	☐	Superfluous
Irritating	☐	☐	☐	☐	☐	Likeable
Assisting	☐	☐	☐	☐	☐	Worthless
Undesirable	☐	☐	☐	☐	☐	Desirable
Raising inducing Alertness	☐	☐	☐	☐	☐	Sleep-

Appendix U Ranking Questionnaire

Icon Sign images reproduced by permission of HumanFIRST Program

Please rank the systems from 1 to 3. A rank of **“1”** indicates the system is **most preferred** based on both your personal preference for it <u>and</u> on your assessment of how helpful you feel that system is for making crossing decisions. A rank of **“3”** indicates the system is **least preferred** based on your personal preference <u>and</u> your assessment of how helpful the system is for making crossing decisions. Please refer to the System Description pages that describe the meanings of the systems if you need a reminder of how each system works and the types of messages it presents. Remember that, although multiple pictures are shown, each set of pictures represents only ONE system that is capable of displaying several messages.

 System 1	 System 2	 System 3
Rank___	Rank___	Rank___

Appendix V Responses to Open-Ended Comprehension Question

List of answers to the question: "Please describe in your own words what you think this system's function is and what information it provides to the driver (you)."
Icon Sign <u>Comprehend:</u> 1. It tells you whether or not it is safe to driver through the intersection. 2. It lets the driver know when the safest time to cross is 3. Shows where cars are. 4. Lets the driver know when it is clear to cross. 5. The sign indicates that traffic is coming and when it is safe to cross. With a green square being safe and red indicating you should wait. 6. This system tells the driver when it is safe to cross or turn at a divided highway. It does so by flashing signs for each lane that tell whether or not one can turn or go straight through the given lane. 7. to let the driver know if it is ok to proceed in a turn, drive to the middle of intersection, or drive from middle all the way across when there is enough time to safely pass 8. This sign uses an active sign to indicate the flow of traffic in each divided lane. 9. when to cross the intersection and when not to 10. To tell you the different functions available to you. And which directions not to go at a particular time 11. Distance of approaching cars. Safe / unsafe to cross. 12. Same purpose as the stop sign. Showed driver when they could and couldn't go. 13. Indicates when safe to go through or turn & traffic. 14. It seems like it tells you when it's not okay to turn a certain way at the time. 15. Once you reach the intersection, there is an easy to read sign, one that is greyed out (when which is for the 2nd set of the intersection) and one is in black with a red X around it. Once the red X goes away and you see yellow, you may cross the intersection and do the same at the 2nd set of intersection. <u>Not Comprehend</u> 1. The sign tells you that the highway is divided and not to turn into oncoming traffic 2. The signs provide information to the driver on which way he could turn and that it informs him/her that there's cars coming from both directions. 3. So far no information that was useful 4. It lets driver know they can proceed across divided highway or merge left with traffic going that direction or turn and merge right at next portion of divided highway. 5. indicates right or left turn possible in addition to straight 6. I think the "symbols" inside the bars show which direction you can go as well as the flow of traffic. 7. if you may cross all of the divided highway, just turn right or just turn left or cross with no restriction other than traffic 8. Don't Know!!

9. This looks like good information to have, though I did not even see the sign until I was mostly through the intersection.

Mirror Display

Comprehend

1. Tells you with the bar how far away the car is / how fast it is approaching
2. Its function os to let the driver know how far away a car is and ho fast its approaching
3. I think this system tells the driver how far away traffic is on either side. It tells the driver how big of a gap they have to cross.
4. To show car distance. Honestly I didn't use them.
5. Warns of coming traffic. Full bar at the bottom indicates a car is close, not full indicates cars are further away.
6. The system functions so as to let the driver know how close an oncoming car is, and thus how much time they have to cross. This is signified through a bar that moves right and decreases in quantity as the car approaches (from the left).
7. This one was really helpful in that it guided you with when the cars exactly pass.
8. to let you know the gap distance of the nearest vehicle w/ the "progress" bar below the car in the side mirror. No bar = big gap
9. Length of how far car is away / How close oncoming vehicle is
10. This system uses a display, monted in the position of the typical side-view mirrors, to indicate via bar graph how much clearance is present on that side of the vehicle.
11. I think it has something to do with gauging the distance of an approaching vehicle. Long bar = longer distance
12. Show distance of approaching cars
13. I liked using the system in addition to visual cues. I wouldn't rely on just using the system, but it helped choose when to go.
14. How much space or time I had to approach the intersection as well as cross the intersection.
15. Distracting - ? To tell me how fast (close) the car is from L & R to where the intersection is.
16. to allow you to proceed when safe / tells you how far car is away
17. The left display was indicative of traffic on the left. When the bar was full, I think you would have to wait as traffic was too close. The right display had the same information for the oncoming traffic to the right.
18. It was telling where the car was and the bar went down as they got closer to passing me.
19. The display on both (both mirrors) sides is trying to let you know the distance between your vehicle and the approaching vehicles. The right mirror is for traffic approaching from the right and the left is from the left etc.
20. When you come to an intersection, the display on one rearview mirror has a bar at the bottom showing you how much time you would have to cross the intersection.

The more colored the bar is, the less time you would have to cross the intersection, once there is no color you are safe to cross.

Not Comprehend
1. To alert drivers as cars go thru the intersection.
2. confusing annoying
3. supposed to alert you to an coming traffic. Did not pay attention to the icon trusted myself
4. The amount of room either to approach stop sign or between each car approaching.

Vibrotactile Seat
Comprehend
1. The strength of vibration indicates how close a car is to the intersection
2. I think its used to alert the driver that there is a car coming and based on the intensity of the vibration, whether it is safe to go!
3. The seat vibrates when traffic is approaching. The side that vibrates tells you which side traffic is coming from and the intensity tells you how close the cars are.
4. To indicate what side a car is coming from. It provided me with that info.
5. I thought it was vibrating to warn of oncoming traffic.
6. This system vibrates the seat to alert the driver that there is oncoming traffic and it is unsafe to cross - the left side vibrates when there is traffic approaching from the left, and the right side vibrates when there is traffic approaching from the right.
7. More vibration as cars are coming / how close cars are
8. This system uses a vibrating device in the seat that "rumbles" when traffic at the intersection would make crossing hazardous.
9. Left underseat pad vibrated quickly when it was not safe to cross because of traffic coming from left at intersection and right vibrated rapidly when the right traffic was causing it to not be safe to cross or turn.
10. Vibrates when crossing traffic makes it unsafe to cross
11. It vibrates on the left side for oncoming traffic on the left, and right side for right traffic.
12. I think it vibrated when you were supposed to stop (or stay stopped). It was annoying to me because it took my mind off what I was already concentrating on.
13. It seemed like it vibrated when cars were coming then it stopped when I crossed. It could be letting you know when cars are coming, but I didn't do anything different.
14. The seat vibrates on the left if a car is coming on your left and vibrates on the right seat if its coming on your right, vibrates both sides if cars are coming from both ways.

Not Comprehend
1. Alert driver of upcoming intersection
2. I'm guessing its there to warn us when we slow down or just vibration to wake you up a little.
3. Vibrations to alert the driver of traffic or crossings remain on until the intersection

is crossed
4. The system would definitely wake you up if you were sleepy
5. I didn't like it, very distracting but it provides which direction to turn the wheel.
6. Notify of a stop coming up / cross over of another road.
7. To alert me that I need to be aware of conditions / prepares to me to be more mentally alert
8. Lets the driver know he is close to the intersection but irritating but could see how it might keep some people more alert.
9. I am not sure what the vibration means. Perhaps it is safe to proceed. I ignored it because I was unsure of its purpose.
10. To let the driver know when there is enough space to safely cross the intersection.

Appendix W Self-Reported DSS Use

Icon Sign	
Used Information?	Explanation
yes	It allowed me to be much more confident in my judgment that it was safe to cross the intersection.
yes	During the second part of the hwy x-ing, I waited for the sign to say it was safe
no	I didn't need to turn so it didn't provide me with relevant information. Also it didn't tell me when to cross.
yes	I used it out of laziness.
yes	I used the indicator on the 2nd simulation to monitor traffic approaching the intersection.
no	I used it on the first drive. On the second, I was confident that I could cross at a point where the sign did not indicate to go.
yes	I waited until the system signified that it was safe to go straight through the first lane (i.e., I waited for the green box), and then I did the same for the second lane.
no	I didn't use the system because I concentrated on looking out for the cars which I think is a good way too.
yes	when the yellow light appeared it was more clear that there was more time - Note - convention may clear up confusion w/ sign, green instead of yellow Note - time is wasted looking at the sign and then to traffic if traffic is heavy - also 90% of drivers are minus common sense - would have to be taught to read signs display
no	I have more trust in my own judgment
yes	While I did take notice of the active sign's indications, I instinctually relied on sight to assure clearance for road crossings.
no	I was watching and judging traffic and accelerating as was looking no real time to look at sign
yes	I used the information to know not to turn left at 1st intersection and not to turn right at second intersection of divided highway.
no	It was difficult to understand. I didn't know if I should cross or not.
yes	When system said safe to cross I confirmed by sight; also when I thought safe checked system
no	I did not see the sign until I was almost through the intersection. I feel I would use it if I knew it was there beforehand.
yes	Let me know when it was and wasn't safe to go. When sign was red I stayed, once green I went.
no	I reverted to my normal driving behaviors and didn't really pay it much attention.
no	I was so focused on traffic that I paid no attention to the sign.
yes	Glancing at the sign just reminded me: 1) what type of highway it is - divided; which means I have to stop at the median and look for traffic from my right; and 2) that I have to yield at the median for upcoming traffic.
no	Did not notice
no	I did not really use the system because I know how much time I need to cross and when it is not safe. Although I think it would be good for other people.

no	To complicated, it is easier to look right, left, right to see with your own eyes what you are approaching. If no traffic was coming whatsoever, I would use it. If I knew for certain what it meant.
yes	Yes, I didn't think I even checked for cars, it is very reliable and is as easy to understand as "stop lights"
Mirror Display	
Used Information?	Explanation
yes	I looked at the info (red bar) and used it to make my decision. At first the system was confusing but after a trial I understood it. I didn't like it though. I wasn't sure how much of a red bar I needed to be safe. I think it made me feel less safe. It might become a desirable system after becoming accustomed to it.
no	Because I thought it was more useful to just look at the traffic to determine a safe time to go
yes	I looked at the gap in traffic and decided if I wanted to cross. If the red bar indicated that the gap wasn't very big I would wait to see if there was a car I couldn't see coming.
no	I'm used to driving without it so I just didn't need them.
yes	I used the system to help monitor cars thru the intersection, but found it distracting as it doesn't tell you when the next car is coming so you have to watch it and the actual traffic. Makes it more work w/ no real benefit.
yes	I did. It was especially helpful at the median where I have a harder time seeing the traffic from the right.
yes	I first made sure that I would cross each of the lanes without using the system; then I used the system to confirm that it was safe to cross.
yes	This was really helpful in crossing.
yes	The system was interesting but the bar indicating the distance was not as helpful as keeping my eyes on the road. Note - again - maybe a bar that turns green w/ no cars would be better?
no	I watched it but used my own judgment
yes	This system was especially useful when crossing the hill between divided traffic lanes, as it gave information about flow when a visual check is not possible.
no	The system was too confusing and made me take my eyes off the road
no	I wasn't exactly sure about its use or the information it was providing…therefore I needed to rely on my information that I could see and experience base to guess time I had to cross safely.
no	I really use just my eyes and sense of driving to cross intersections. I don’t look at other distractions. I can't do all that and focus.
yes	To confirm observations
yes	(blank)
no	When crossing an intersection, you hardly ever see the rearview mirrors anyways, so by having systems in place, they wouldn't be useful only confusing.
no	Distraction from real traffic patterns. I didn't know if it was "trust worthy"
no	I trusted my own vision more, although a little more familiarity would give me more confidence.

no	While I did look at the "bar" below the car on the system, I had already determined my own time to more and just glanced at it to see where the bar was.
no	trust myself
yes	Although it didn't really help me decide when I would cross, it was definitely useful information to have when you are looking at the cars.
yes	I watched the mirrors, once I finally noticed. I studied the line to see how accurate it was before I trusted it.
yes	Yes, I watched the screen to see when the bars were not filled in and therefore I knew there was enough time for me to cross.
Vibrotactile Seat	
Used Information?	Explanation
yes	I sort of used the info. I relied mostly on my judgment and used the system in a background sort of way.
no	I didn't use it b/c I didn't quite understand it
yes	If there was little or no vibration then I knew it was probably safe to cross.
yes	When a part of the car frame blocked my vision, it helped me spot a car.
no	System didn't give any indication of when it was safe to cross. Only made me aware of intersection.
no	I was not confident in its purpose.
yes	I used the system to confirm that the road was indeed clear, as I perceived it to be.
no	It's just a vibration nothing important
yes	I liked this system because it was not visually distracting and the a-rhythmic pattern kept me alert. Very neat. Would not want this in the city though.
no	It was somewhat useful as an indicator but I would still trust my own judgment over this
yes	I used this system as a complimentary input, along with visual traffic checks, to determine if passage would be safe.
no	the info was too confusing but it will wake you up at the intersection
yes	I used this information as well as visual info to determine it was safe to proceed when vibrations slowed from rapid pulsations
no	It was distracting didn't like it very much. Sorry
yes	confirm observation
yes	(blank)
yes	The vibrations stopped when there were no cars near the intersection and there was enough room for the cars to pass.
no	I took the vibration to indicate a stop or need to be careful (?) coming to a road that crossed with heavy traffic.
no	I think my vision and reflexes were predominant.
no	I don't feel I got a good "read" on when the vibrating actually stopped. I watched the traffic and felt confident of my own driving skills that I could get through the intersection. The vibration, I felt distracted my maneuvers.
no	was not necessary

no	I didn't really understand what it was doing until the end, but I can see cars coming without the system.
no	I can't validate using something if I don't know 100% for sure what the system is trying to communicate. To me that would be like driving blind and trusting your passenger to give you surroundings, senses, etc.
yes	Yes, I used the system by crossing once the vibration stopped or slowed.

Appendix X Ranking Questionnaire Results

A Ranking of 1 indicated most preferred, while 3 indicated least preferred	
Icon Sign	
Ranking	Explanation
1	This was by far my favorite. The red/yellow black rather than a gradient (red bar) is most helpful).
1	This was the most clear cut and easy to understand.
1	I didn't understand it at first but it tells you exactly when to turn and isn't annoying
2	
1	Made the most sense. Could be larger or brighter w/ a green light when clear.
1	Helpful and sensible. Seems most practical.
2	This system was straightforward, although a little too detailed. Nonetheless, somewhat helpful.
2	I felt that this is boring.
2	Complex but sign remains more in view of traffic so you can check traffic and sign visually.
2	Easy to figure out
3	This system provides a good deal of information, but could be confusing to some
1	most clear
2	Was somewhat helpful added with my own visual assessment. However, caused me to look away from traffic.
1	This one would definitely lessen accidents and give drivers more information.
1	(?) Added to information from the sign (?)
2	This was ok, but was another thing to look at when making a decision to cross
1	Least confusing. Very easy to understand. Relates to stoplight experience.
1	most familiar / easy
3	Confusing. Not enough time to digest
3	Too much reading for smooth driving. A person could get "fixated" on this when looking would actually be faster.
1	helpful
2	Too many things to look at, distracting.
2	I would only use this if no traffic was coming to make sure I knew the flow (direction of traffic)
1	This is very easy to use. Doesn't take much effort and seems the most reliable.
Mean = 1.63	
Side Mirror Displays	
Ranking	Explanation
2	Red bar annoying / too ambiguous to be helpful
2	This one could be useful at night but not so much during the day.
3	I didn't trust the information and it wasn't as clear as the other methods.
3	I feel like extra technology only clutters my head and puts me in a worst place to deal with stressful situations.
3	Didn't tell you anything you couldn't see. Didn't let you know about additional (?) cars.
2	helpful but could be distracting

3	I found this system to be distracting at best, and the information it provided was not reassuring.
1	This makes it easier because some cars are not as easy to see but with this it make it easier.
3	Looking from the mirror to traffic and back to the mirror is not easy to do quickly
1	easy to see and understand / simplified
2	This system provided helpful information about traffic flow, but could be a visual distraction
3	confusing
3	Was distracting to me visually. I would rather look myself.
2	It was also very helpful but the signs were way more informational.
2	Confusing at firs. Not where I would look for information.
3	this was helpful, but not as much as the others
3	most confusing / harder to understand
3	confusing / distracting
1	helpful. Easy to see
1	Pretty clear, visual. The meaning is the most universal.
3	distracting
1	It helps you understand how fast the cars are moving which many people misinterpret.
1	If I were to question how far the approaching vehicles were I would use this in conjunction to a head check. Never just by itself.
2	System was easy to understand, didn't seem as reliable.
Mean = 2.21	
	Vibrotactile Seat
Ranking	Explanation
3	Seat pad sort of annoying.
3	I didn't like this b/c it was hard to decipher what the vibrations meant.
2	Effective but irritating
1	
2	More annoying than helpful.
3	distracting and annoying
1	This system was simple, and alerted the driver (me in a very effective manner. It also felt rather pleasant.
3	I didn't see it useful as much as system one but its still good.
1	least visually distracting
3	Annoying to have the vibration
1	This system gives a clear signal about the nature of crossflowing traffic without removing sight from the road.
2	not specific enough
1	Was helpful added with my own visual assessment of whether it was safe to proceed.
3	Very distracting I can't do distractions
3	Very irritating. Somewhat distracting.
1	this was the easiest to use because it was least distracting and complimented my decisions

2	only 2nd because -> was better experience . Equally likeable.
2	helps awareness
2	Ok. Heightened alertness
2	Rather annoying however the vibration would help someone who might be a little tired.
2	annoying
3	It was more annoying than useful.
3	The vibration is irritating, and I lose all concentration on the task at hand (DRIVING)
3	I found this system to be somewhat useful but annoying as well. Could be useful for people driving at night to keep them awake.
Mean = 2.17	

Appendix Y Participant Booklet, Version 1 (used April 15 and 22)

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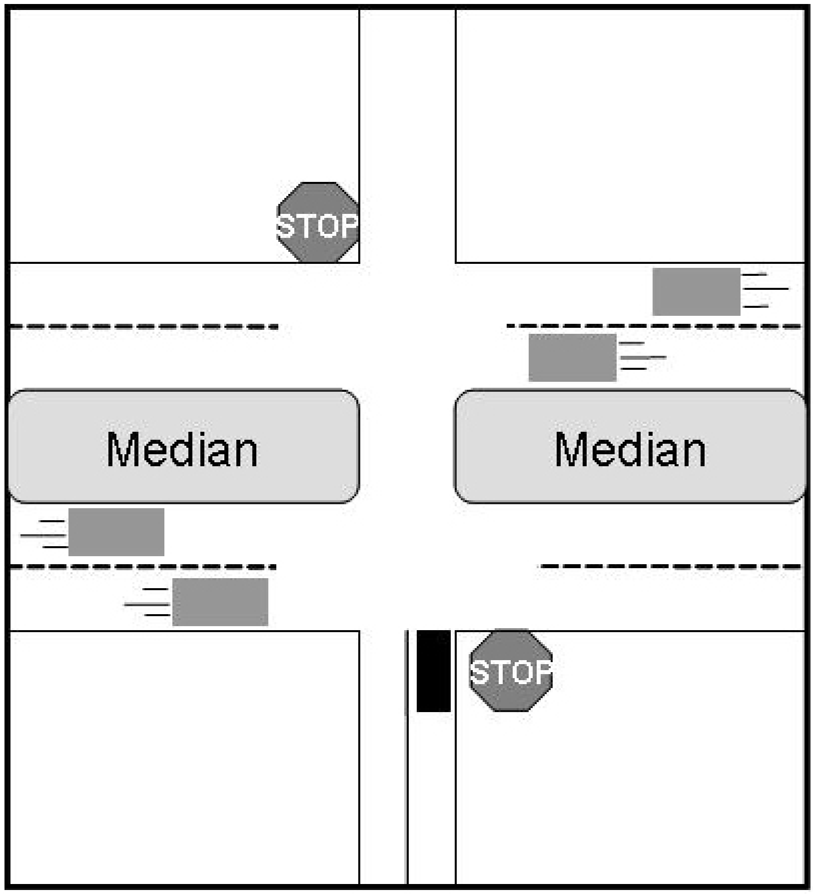
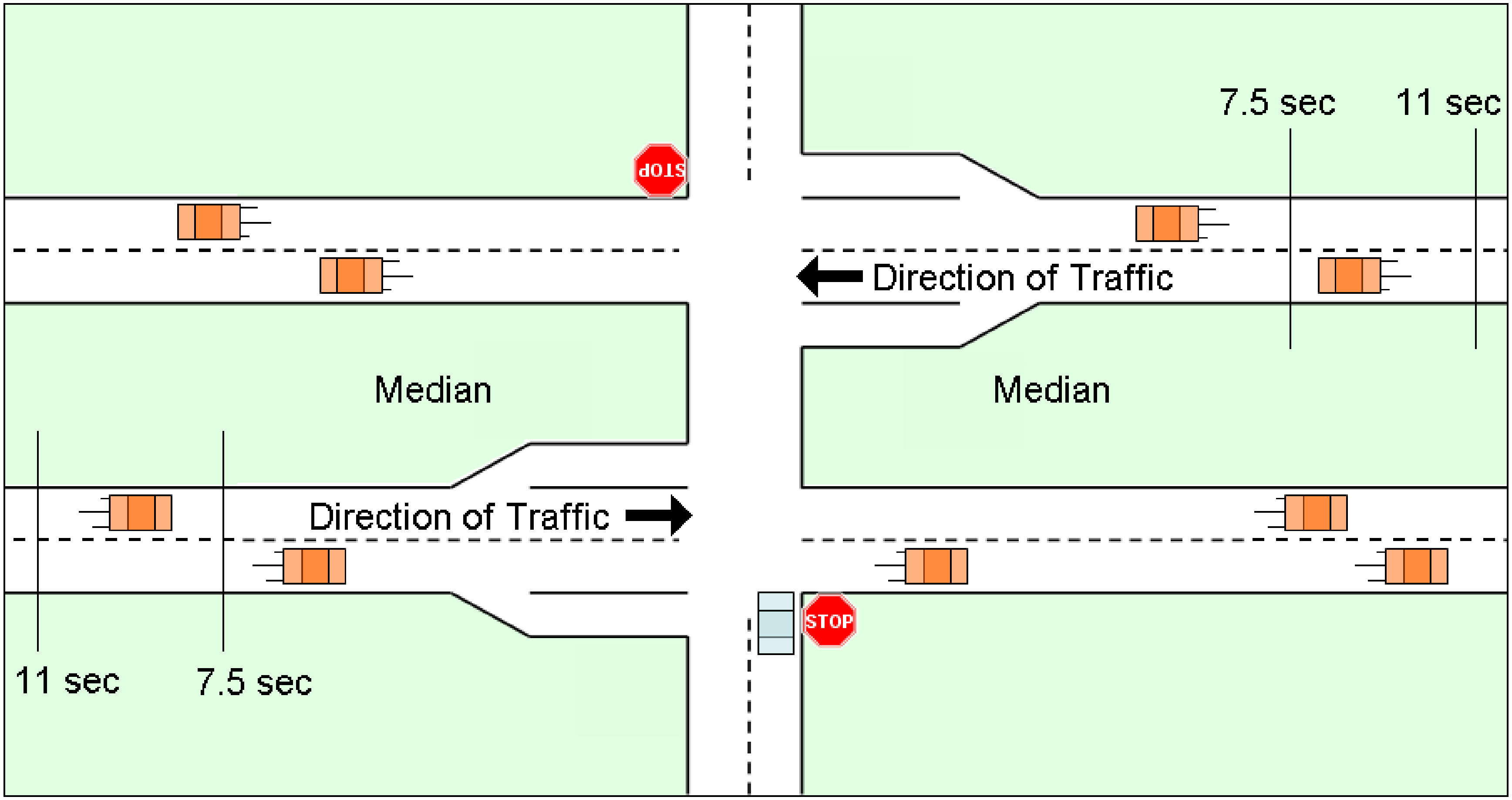


Thru-stop intersection: a high-speed highway crosses a minor road.

This particular highway is a divided highway, with two lanes of traffic on each side of the median.

Highway traffic does not stop.

Minor road traffic must wait at the stop sign for a gap in highway traffic.

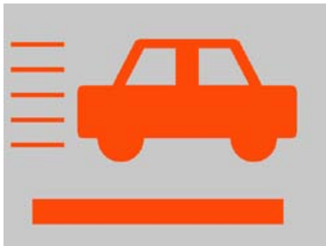


For the navigation systems we are discussing today, two values of time-to-arrival are considered to be of special importance:

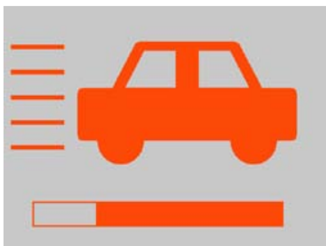
7.5 seconds

11 seconds

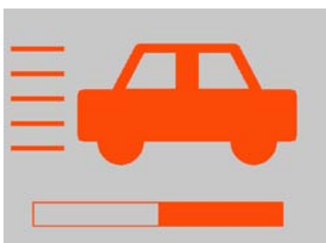
This display has a bar showing the time-to-arrival of traffic.
There could be two displays: one for traffic from the left and one for traffic from the right.



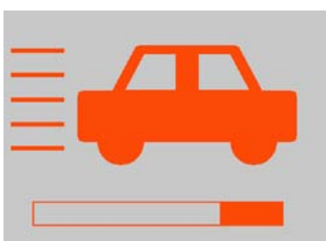
The bar is full. Traffic is 7.5 seconds away.



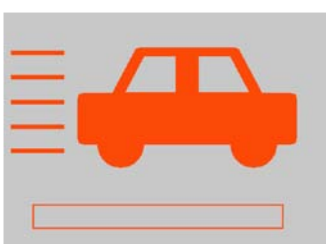
The bar is ¾ full.



The bar is ½ full.

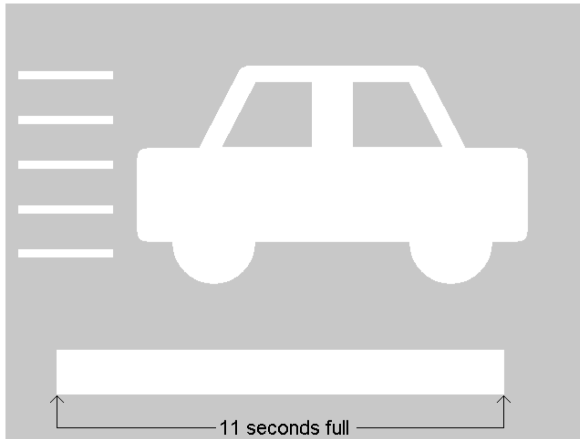


The bar is ¼ full.

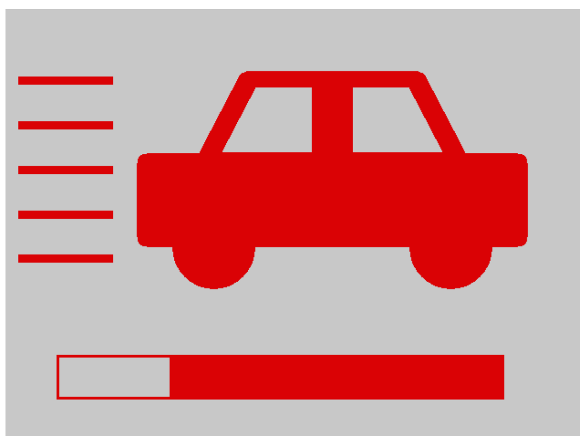


The bar is empty. The approaching vehicle is just now passing the intersection.

The nearest approaching vehicle is farther away than 7.5 s



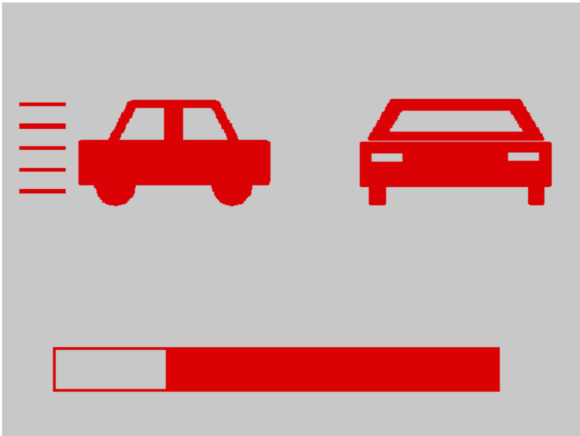
The bar is now full when the nearest vehicle is 11 seconds away.



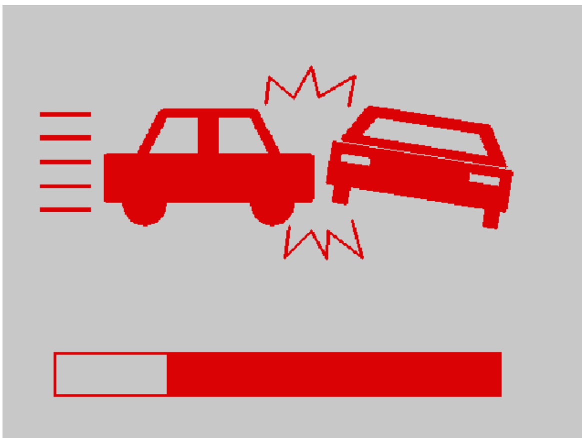
When the nearest vehicle is 7.5 seconds away, the display changes from yellow to red.

As another option, the picture could change once the nearest vehicle is 7.5 seconds away.

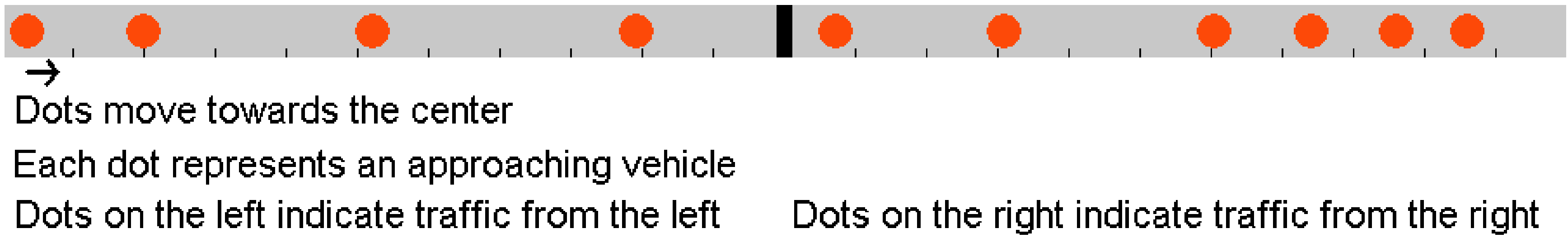
Two options:



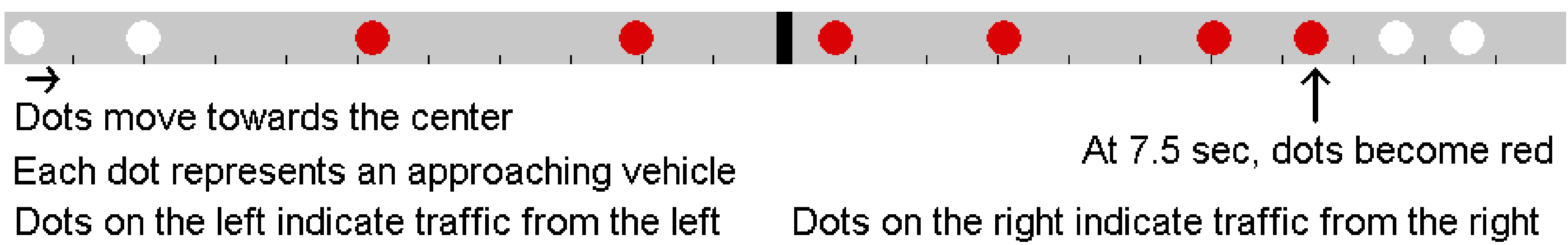
OR



A stream of lights could show multiple approaching vehicles.



The color coding option could be applied to this display as well.



The vehicle could have vibrational pads in the driver's seat.

The left pad vibrates if traffic from the left is within 7.5 seconds.

The right pad vibrates if traffic from the right is within 7.5 seconds.

Speech Message

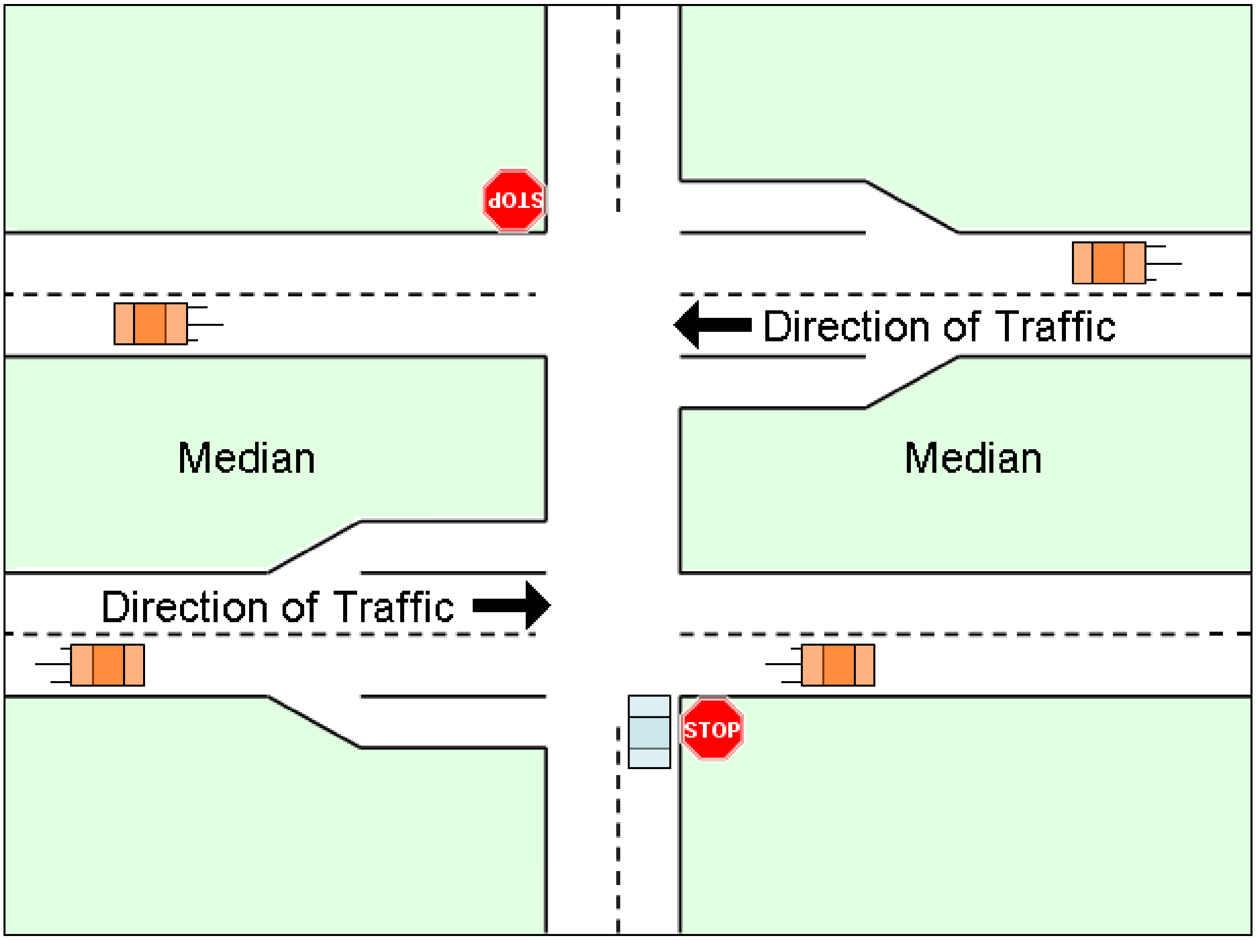
While waiting at the stop sign:

"Wait" spoken once per second if traffic from the left is within 7.5 seconds.

While waiting in the median:

"Wait" spoken once per second if traffic from the right is within 7.5 seconds.

Appendix Z Participant Booklet, Version 2 (used April 29)
Intersection drawings adapted by permission of HumanFIRST Program

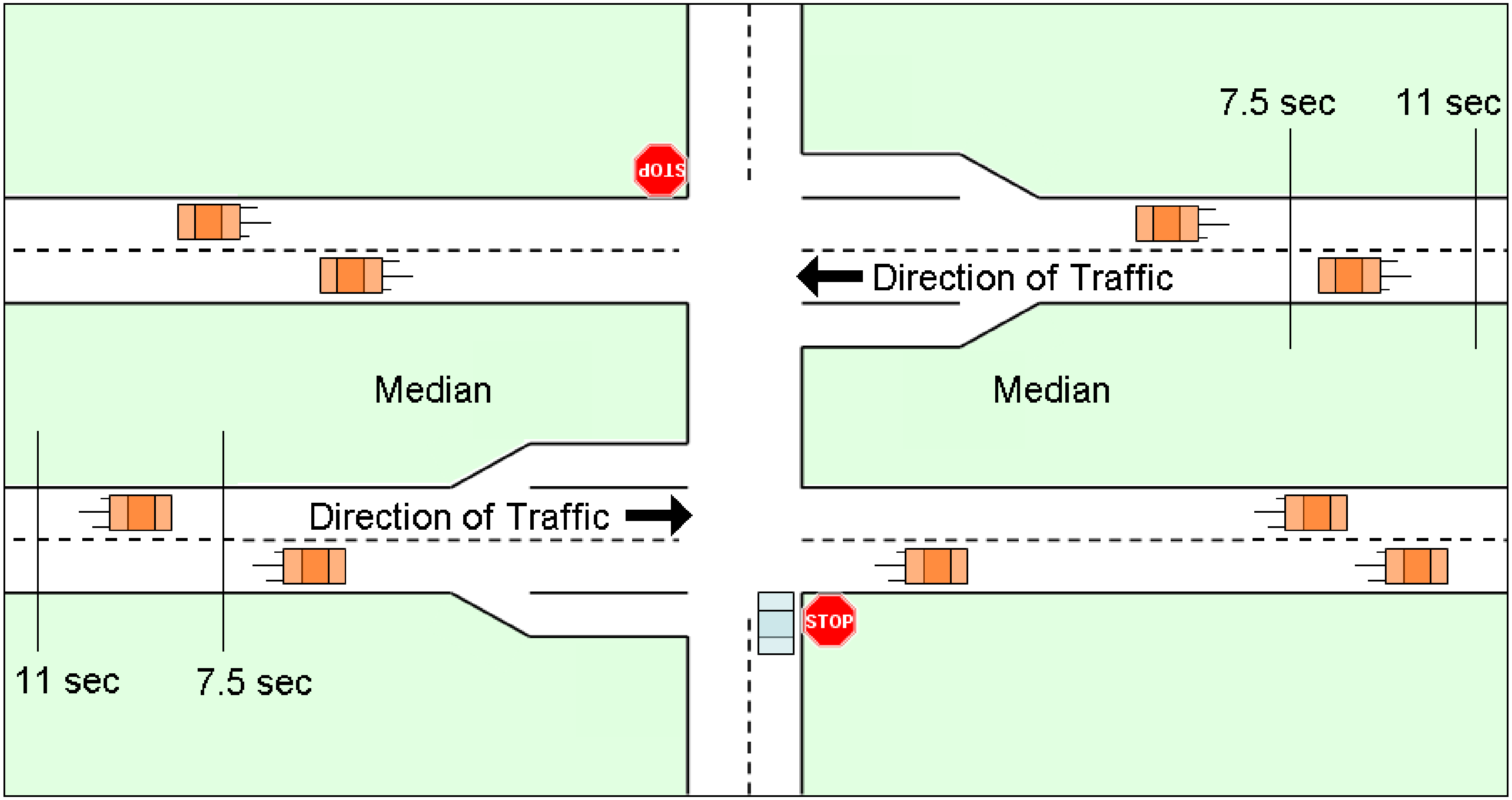


Thru-stop intersection: a high-speed highway crosses a minor road.

This particular highway is a divided highway, with two lanes of traffic on each side of the median.

Highway traffic does not stop.

Minor road traffic must wait at the stop sign for a gap in highway traffic.



For the navigation systems we are discussing today, two values of time-to-arrival are considered to be of special importance:

7.5 seconds

11 seconds

Speech Message

While waiting at the stop sign:

"Wait" spoken once per second if traffic from the left is within 7.5 seconds.

While waiting in the median:

"Wait" spoken once per second if traffic from the right is within 7.5 seconds.

Other points to consider:

Does the speech message need to be spoken as frequently?

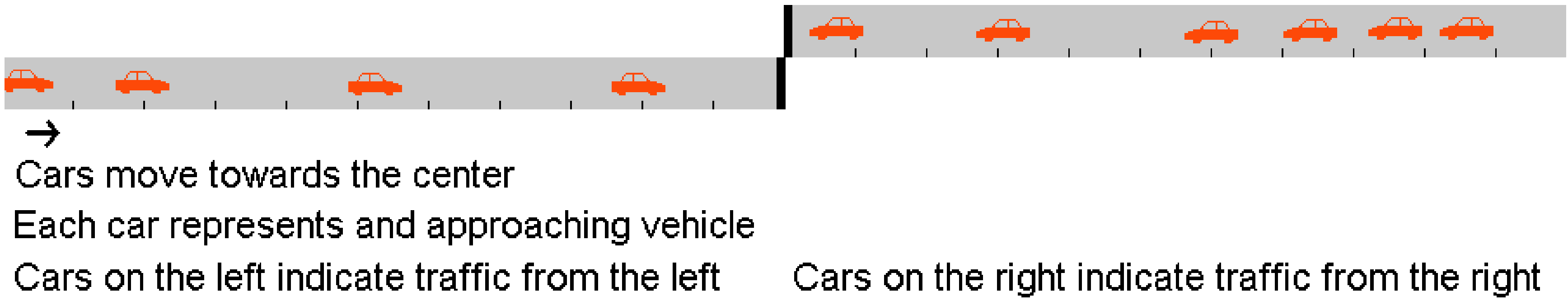
Could a tone, beep, or click be more effective than a spoken message?

The vehicle could have vibrational pads in the driver's seat.

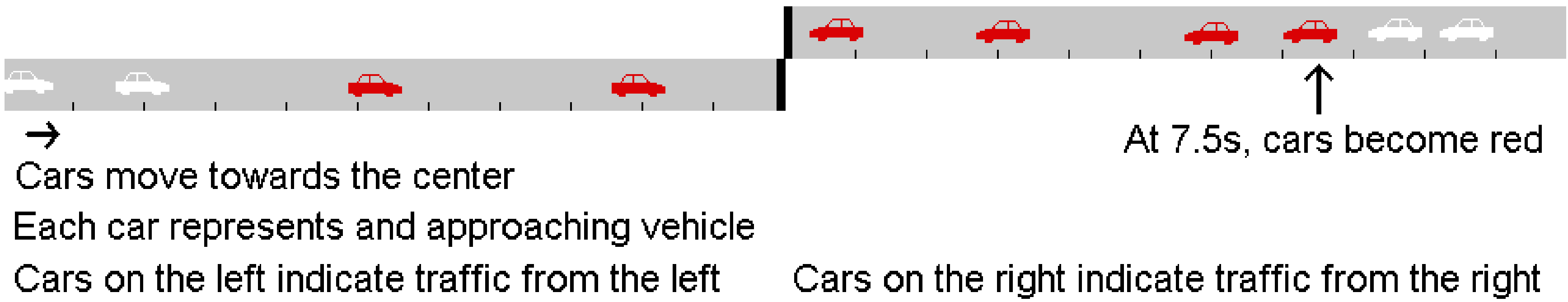
The left pad vibrates if traffic from the left is within 7.5 seconds.

The right pad vibrates if traffic from the right is within 7.5 seconds.

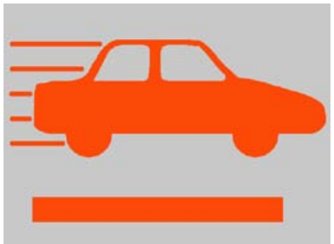
A stream of lights could show multiple approaching vehicles.



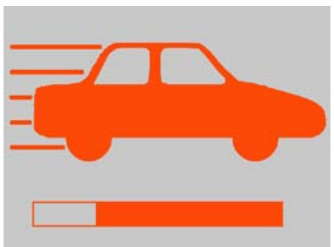
The approaching vehicles could also be color coded.



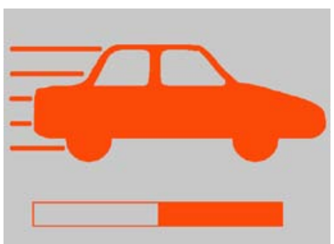
This display has a bar showing the time-to-arrival of traffic.
There could be two displays: one for traffic from the left and one for traffic from the right.



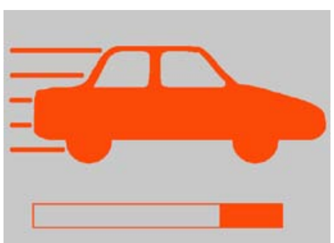
The bar is full. Traffic is 7.5 seconds away.



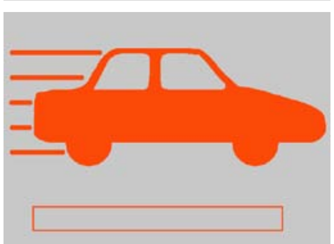
The bar is ¾ full.



The bar is ½ full.



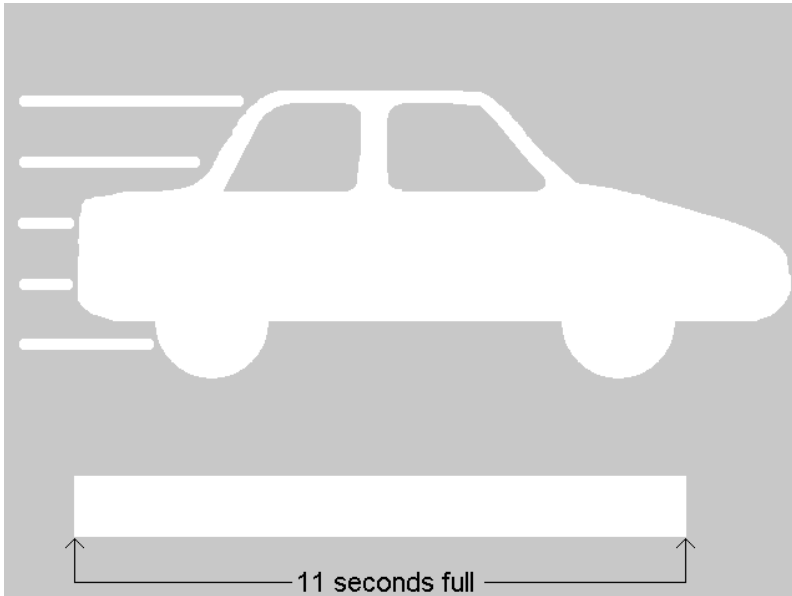
The bar is ¼ full.



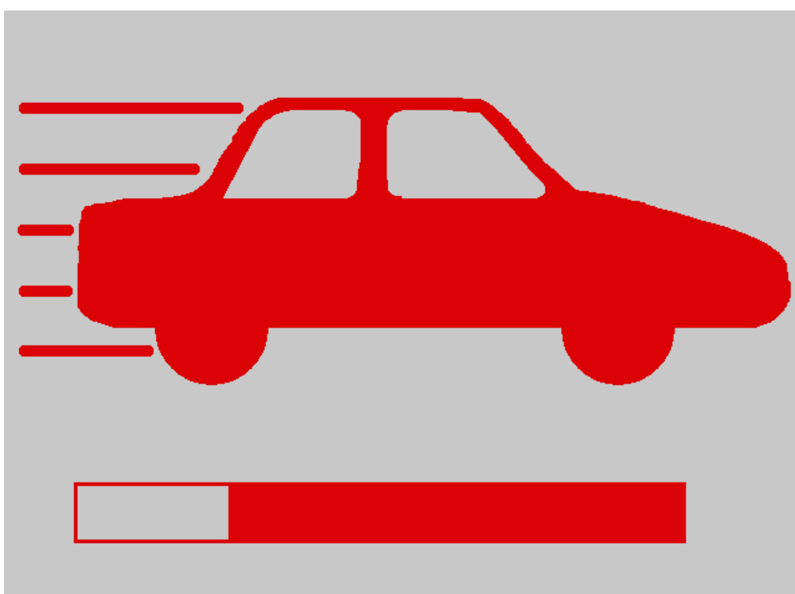
The bar is empty. The approaching vehicle is just now passing the intersection.

The nearest approaching vehicle is farther away than 7.5 s

Two changes:



The bar is now full when the nearest vehicle is 11 seconds away.

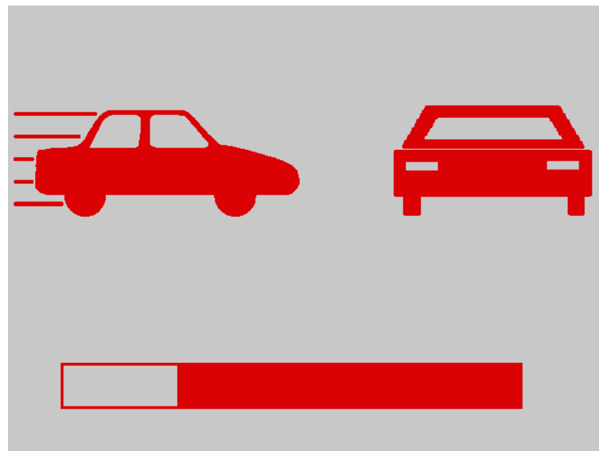


When the nearest vehicle is 7.5 seconds away, the display changes from yellow to red.

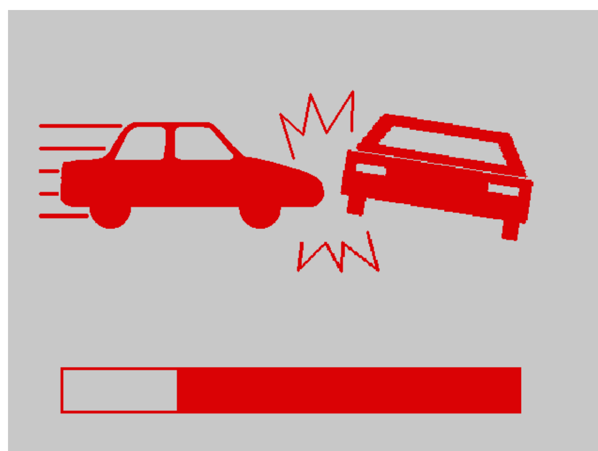
As another option, the picture could change once the nearest vehicle is 7.5 seconds away.

Two options:

OPTION 1:



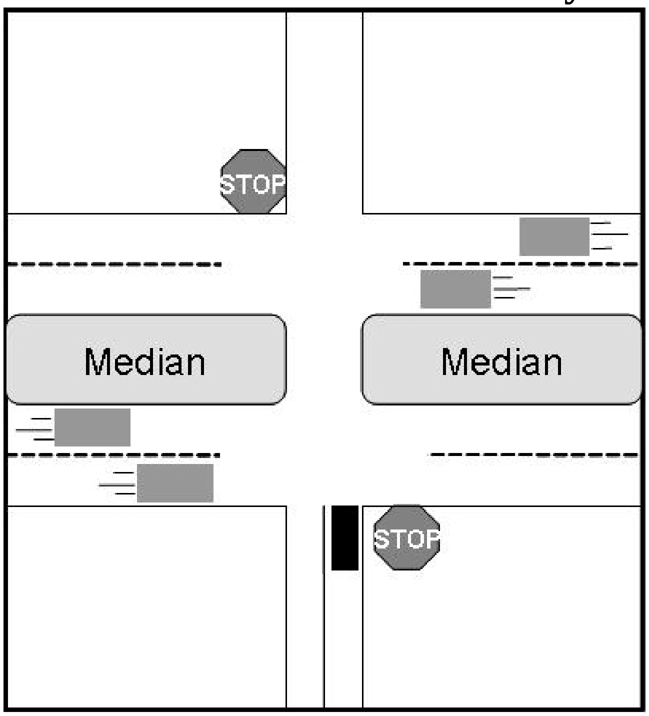
OPTION 2:



Appendix AA Recruitment Flyer
Intersection image reproduced by permission of HumanFIRST Program

Research Study – Participants Needed:

Feedback on Intersection Navigation Systems
University of Minnesota



Study Duration: Two (2) hours

Compensation: $30

Tasks: You will participate in a small group discussion (i.e. a focus group) and answer questionnaires

Requirements: You **must be licensed to drive**, and have **20/40 vision** or better (it is OK if you need corrective lenses to have 20/40).
For information, contact Daniel Drew at drewx039@umn.edu

Intersection Navigation Study drewx039@umn.edu	Intersection Navigation Study drewx039@umn.edu	Intersection Navigation Study drewx039@umn.edu	Intersection Navigation Study drewx039@umn.edu	Intersection Navigation Study drewx039@umn.edu	Intersection Navigation Study drewx039@umn.edu	Intersection Navigation Study drewx039@umn.edu	Intersection Navigation Study drewx039@umn.edu	Intersection Navigation Study drewx039@umn.edu	Intersection Navigation Study drewx039@umn.edu	Intersection Navigation Study drewx039@umn.edu	Intersection Navigation Study drewx039@umn.edu

Appendix BB Consent Form

CONSENT FORM

Decision Support System Feedback Study

You are invited to participate in a research study to examine the understandability of new systems designed to help with navigating intersections. You were selected as a possible participant because you responded to our ads requesting participants and were found to be a suitable participant for this study. We ask that you read this form carefully and ask any questions you may have before agreeing to be in the study.

This study is being conducted by:
Professor Caroline Hayes, University of Minnesota
Daniel Drew, Graduate Student, University of Minnesota

Background Information:
The purpose of this study is to investigate how well drivers comprehend new designs that will be used in an intersection decision support system.

Procedures:
If you agree to be in this study, we will ask you to do the following things: (1) provide us with some basic information about yourself and your driving history (e.g., age, number of years you have had your license); (2) examine and/or interact with the presented systems; (3) answer questions about each system; (4) discuss your thoughts on each system (discussion will be audio recorded). The total time to complete this study today is about 2 hours.

Risks and Benefits of Being in the Study:
There are no direct benefits to you for participating in this study. There is a slight risk of the loss of your confidentiality through your interactions with other participants. Your first name will be used during discussions, but this study does not require you to reveal any other information about yourself to other participants. Please use discretion if you choose to share more information about yourself.

Compensation:
You will receive a payment of $30 for participation. If you terminate the study early, you will still receive full payment.

Confidentiality:
The records of this study will be kept private. You name will not be associated with any of the data collected today. In any sort of report we might publish, we will not include any information that will make it possible to identify you or other participants. Research records are stored securely in locked offices and only researchers on this study will have access to the data collected. Audio logs will be kept confidential. Published transcripts of audio logs will not include names and will blank out any personal information that might have been said during discussion.

Voluntary Nature of the Study:
Participation in this study is voluntary. Your decision whether or not to participate will not affect your current or future relations with the University of Minnesota. If you decide to participate, you are free to not answer any question or withdraw at any time without affecting those relationships.

Contacts and Questions:
The researchers conducting this study are Caroline Hayes and Daniel Drew. You may ask any questions you have now. If you have questions later, **you are encouraged** to contact them at Mechanical Engineering, 111 Church St SE, Minneapolis, MN, 55455; 612-626-8391; hayes@me.umn.edu.

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher(s), **you are encouraged** to contact the University of Minnesota's Research Subjects' Advocate Line, D528 Mayo, 420 Delaware St. SE, Minneapolis, Minnesota 55455; (612) 625-1650.

You will be given a copy of this information to keep for your records.

Statement of Consent:

I have read the above information. I have asked any questions I had and have received answers. I consent to participate in the study.

Signature:____ Date: __________________

Signature of Investigator:____________________________ Date: __________________

Appendix CC Demographic Questionnaire

DEMOGRAPHIC QUESTIONNAIRE

The purpose of this questionnaire is to assess your driving experience and obtain background information. Your personal identity will not be associated with any of your responses. Only a unique number will be recorded and will be used by the researchers.

Please complete each question by responding in the space provided or selecting the appropriate response.

Part I. Demographic Information

1. What is your sex: ☐ Male ☐ Female

2. What is your age: ________ years

3. What is your highest education level completed:
   - ☐ High School / Vocational School
   - ☐ Associates Degree
   - ☐ Bachelor of Arts / Bachelor of Science
   - ☐ Masters
   - ☐ PhD

4. Are you currently taking any college level classes: ☐ Yes ☐ No

5. What is your current employment status: ☐ Full Time ☐ Part Time ☐ Retired ☐ Student ☐ Unemployed ☐ Other:____

6. Where do you currently live: ☐ Rural area ☐ Urban area ☐ Suburban area ☐ Other:______________________

Part II. Driving Experience

7. How many years have you had your driver's license (excluding learner's permit)?

____________ year(s)

8. On average, how many miles do you drive per year?________________ miles / year

9. How often did you drive last month?

☐ Never ☐ Rarely ☐ Sometimes ☐ Most Days ☐ Every Day

10. How often do you drive to and from your place of work?

☐ Never ☐ Rarely ☐ Sometimes ☐ Most Days ☐ Every Day

11. Do you drive frequently on *Highways*? ☐ Yes ☐ No

12. Do you drive frequently on *Main Roads other than Highways*? ☐ Yes ☐ No

13. Do you drive frequently on *Urban Roads*? ☐ Yes ☐ No

14. Do you drive frequently on *Rural Roads*? ☐ Yes ☐ No

15. In the last 5 years, have you ever been involved in a road accident where you were at fault?

☐ Yes ☐ No

If yes, how many *minor* road accidents have you been involved in?_______
A minor accident is one in which no-one required medical treatment AND costs of damage to vehicles and property were less than $1000

If yes, how many *major* road accidents have you been involved in?_______
A major accident is one in which EITHER someone required medical treatment OR costs of damage to vehicles and property were greater than $1000, or both

16. During the last 5 years, have you ever been convicted for:

a. Speeding ☐ Yes ☐ No
b. Careless or Dangerous Driving ☐ Yes ☐ No
c. Driving under the influence of alcohol/drugs ☐ Yes ☐ No

17. What type of vehicle do you drive most often (check one)?

☐ Motorcycle ☐ Passenger Car
☐ Pick-Up Truck ☐ Sport utility vehicle
☐ Van or Minivan ☐ Other:____________________________

18. How would you rate your driving skill compared to your peers?

☐ Very Poor ☐ Poor ☐ Average ☐ Good ☐ Excellent

19. How would you rate your overall health compared to your peers?

☐ Very Poor ☐ Poor ☐ Average ☐ Good ☐ Excellent

Appendix DD Participant Comments, Categorized and Summarized

Combined results from all three sessions

20 participants.

Notes:
Participant comments were frequently paraphrased.
Side Mirror Displays were not described as being on the side mirrors, just as being displays.

Q: What areas do you drive most often? (e.g. urban, suburban, rural)

Summary: This question was asked mainly to get participants thinking about driving. This question can tell us about the driving experience of the participants. In particular, no one mentioned that they drive in rural areas. Some participants mentioned driving on highways and freeways, thus they may have experience with thru-stop intersections from the point of view of highway traffic. Note that this only includes the responses from two of the three groups (for the first group, responses to this question were not recorded).

Suburbs and highways.
Suburban, urban, and freeways.
Cities and suburban.
To and from the suburbs.
Suburban.
Driving the first outer suburb area of the Minneapolis area (two people said this).
City.
City, I-35.
City, highway.
Downtown Minneapolis and freeway.
Freeways.
Freeways.

Q: What do you see as the most dangerous driving situations?

Summary: This question was asked to move the conversation in the direction of thru-stop intersections, which are one of many dangerous driving situations. The experimenter was curious to see the participants' point of view on this question, considering automobile accidents represent one of the leading causes of injury and death in the United States.

Thru-stop intersections were not mentioned by any of the participants. This is not surprising since Unmarked intersections were the closest anyone mentioned, but even so, unmarked intersections represent a different situation than thru-stop intersections. Unmarked intersections would be located at low-speed intersections, whereas thru-stop intersections involve high-speed highways. Unlike unmarked intersections, thru-stop intersections are partially controlled by stop signs.

Many of the participants' responses involve cases where traffic is crowded close together, or where visibility is limited in some manner.

Intersection-related
Red light – crowding around parked cars – crowding for left and right turns.
Blind intersections – can't see traffic before turning left. (this is also a visibility-related issue)
Stuck in intersection waiting on pedestrians (when turning left or right).
Running a yellow light.
Unmarked intersections.
Intersections where the stoplights are beside the road instead of hanging overhead (harder to see if by the side of the road).
Downtown intersections (e.g. 11th and Hennepin).

On/off ramps
Clover leafs – traffic on and off simultaneously.
Clover leafs every 2 miles – bad for rush hour.
Wisconsin – short ramps
An exit ramp that has a stop light at the end – error-prone (not sure how they meant), congested – this is especially bad with snow.
Short entrance/exit ramps – drivers getting on and off at the same time (e.g. 694/35W).
Close to on and off ramps, with people switching lanes a lot.

Weather/visbility
Raining.
Snow and ice – turning, stopping, switching lanes.
Snow – drivers are often going too slow or too fast (perhaps thinking "I have front wheel drive!").
Icy conditions.
Fog.
Freeway driving in dense fog (or other low visibility situations where you are forced to go at high speed).
Night.
Rural nighttime driving, especially in bad weather – Some roads are narrow – Some turns are hard to see.
Lanes not clearly marked – faded, or not reflective.

Heavy traffic
Driving on a major holiday.
Rush hour and traffic jams.
Events like baseball games.
Areas like on campus that have no pedestrian order – walkers and bicyclists go everywhere they want (especially bad if a driver is on the phone).

Highway/freeway
Weaving in and out to pass on the freeway.

Tailgating in the passing lane.
Driving next to semi trucks.

Distraction
Texting while driving.
Drunk driving.
Using a GPS while driving.—Another participant commented that he would feel tense if driving to an unfamiliar destination and did not have a GPS to help.

Other
Detour around construction. (not sure why this was dangerous, maybe due to heavy traffic)
I freak out when I hear sirens, and drive in an area where there are often a lot of large fire trucks.

Q: What are some of your experiences with thru-stop intersections?

Summary: The purpose of this question was to get the participants thinking about thru-stop intersections so that they would be more prepared to evaluate the DSSs.

Though participants did not mention thru-stop intersections in previous questions, we can see that they do have experience with them.

There were several comments related to the median, such as crowding in the median and unclear right-of-way for the median (such as when traffic from both the highway and the minor road want to use the median). The experiment has seen situations like this while assisting with on-road driving studies.

There were several comments relating to impatience or other time-related issues.

Median and traffic conflicts relating to the median
Waiting in the median.
On bus in median – back of bus might be in the way of highway traffic.
Manual transmission stalling in the median.
Hard to pick a time with both traffic directions clear. Sometimes I stop in the median, which is scary.
Sometimes many people will all be in the median at once, which isn't safe
Left turning highway traffic conflicts with median traffic – both want to use the right side of the median.
Highway traffic turning left while minor road traffic is crossing (or is at the stop sign?) at the same time.

Impatience and time issues
Have to wait a long time – 1 minute or longer at the stop sign.
At thru-stop intersections on rural roads, people tend to be impatient (e.g. people behind you honk).
More anxious when someone is behind me while waiting at the stop sign – perhaps they are honking at me.
Minor road cars creeping out too far while at the stop sign (or median?).

People shoot thru from the minor road – close calls.
Central – 80 mph – have to accelerate to this from a stop if entering the highway.
Scary – might turn left and get smacked (turn left after median, I believe).

Locations thru-stop intersections are seen
Seen thru-stop intersections after exit ramps.
Seen thru-stop intersections McCalister.
Seen thru-stop intersections on rural roads.

Other
Seen thru-stop intersections with the median filled in, so you can't go straight. You have to turn right, but you can make a u-turn later down the road if you wanted to go left. (i.e. The minor road doesn't extend into the median. If you tried to drive straight, you'd be driving across grass)
If there are stoplights, people may block traffic sitting in the middle of the intersection (like in downtown. They went because it was green, but there was too much of a pile-up, so they had to sit in the middle of the intersection and block cross traffic).
If a vehicle on the highway is in the middle of passing when it reaches the intersection, the driver won't see minor road traffic.
No scary experiences – wait, and then proceed quickly.
Haven't been in this situation.

Q: What information would you want when at a stop sign waiting to cross or enter traffic?
Summary: This question was asked to get participants thinking about the information that would be used in decision support systems and to see if they had any insights on what information to provide to a driver crossing a thru-stop intersection.

Several participants mentioned information such as speed, time to arrival, and distance, and there was even one comment on having multiple types of information at once.

Speed
Speed of approaching cars.
Speed of the closest car (i.e. the vehicle in the first lane you'll cross).
How fast approaching traffic is traveling.
Speed of highway traffic when you are turning left (from the stop sign or median?).
Problem: speed of approaching vehicle can change quickly (thus, information provided by the system can change quickly even if you only glace away for a moment).

Time to arrival
Time for traffic (time for traffic to arrive?).
Time to arrival of the first vehicle, and the time it would take me to move from the stop sign to the median.
If the road curves and there's no visibility, it would be good to know how many seconds are left.

Distance

Distance to approaching car.
How far to each highway vehicle that is approaching.

Multiple types of information
Distance and speed of oncoming traffic – time required to clear intersection (i.e. amount of time you have to clear the intersection when you are crossing from the stop sign or median).

Warning / decision support for minor road traffic
Do you have a wide enough window to slowly turn? (especially helpful in low visibility).
Gives warning message when not safe.
Thought of crosswalks that show the length of time for the light (how long it will be green).
Whether you can fit another car in the median.
Flashing lights at blind intersections at the top of hills.
If there's a stop light down the road – state of the stoplight.
Number of accidents in the past week/month.

Presence of vehicles
Which lanes are occupied by incoming cars.
What kind of traffic is approaching – e.g. is it a huge flood?

Warn highway traffic of upcoming intersection
Provide information to people on the highway, telling them there is a road coming up.
System for highway traffic to see if someone is crossing from the minor road (minor road cars often creep up).
If I'm driving on the highway, I flash my lights when I get near the intersection.

Icy conditions
How icy it is – especially in Minnesota.
Identify if the road is icy – often can't tell whether there's ice until you're on top of it.

Wouldn't use a computer
Don't trust computer, trust self.
Would look for self – takes time to watch both the road and the computer system.
Computer – expensive.

Other
Depends on the type of intersection – which direction each lane of traffic can go.
Certain danger areas – place intersection computer at problem areas.

System: Side Mirror Displays

Q: What are some strengths of this system?

Summary: A few participants thought the Side Mirror Displays would be easy to learn and understand, and would help in cases where visibility was limited.

Easy to learn
You would learn this quickly – just need to be told once.
Bar is simple, unusual, and easy to understand.
The bar is like a gas gauge.

Visibility help
If there are blind spots you could misjudge the speed or time to arrival of approaching traffic (hence the system would help).
It would be helpful downtown, where cars are parked by the sidewalk that prevent you from seeing approaching traffic.
It would be helpful in limited visibility cases (i.e. rain or fog).

Other
Good in general.
More information is always better.
Good that it's real-time.
Simpler than the stream of lights.

Q: What are some weaknesses of this system?
Summary: Some participants did not think the Side Mirror Displays would be intuitive, particularly the bar gauge. There was disagreement about how much information the system should provide.

Confusion
The bar may flicker as many cars pass one right after the other.
The bar might not be that intuitive.
Not intuitive.
Kind of busy. The car is the dominant image, which is kind of bad and doesn't get the point across well.
I don't know what the blank means.
Confusing – empty bar is dangerous, the full bar is less dangerous – It should be the opposite – The blank state is most similar to the full state in terms of danger, which is counterintuitive – Should have a filling bar instead.

Information gaps
Cars may be close to each other – there may be another car right after this one, and the display doesn't show this. It doesn't show the flow of traffic as well as the stream of lights.
Bar takes up a small portion of the display – visibility issue.
The bar doesn't convey much information – the rate of decrease may vary depending on the speed of the approaching vehicle. There's too much guessing.
Don't know whether to go – you contemplate and your time window to proceed gets used up.

Too much information

Too much of a stimulus if you have the suggested flashing light (mentioned below in how the system could be improved).
More information isn't always better – info overload.

Possible system errors

Margin of safety will vary if roads are icy.
The system could be mis-scaled if sensors are at what should be 7.5 s and 11 s away, but cars are speeding (or the comment might have been that the Side Mirror Displays should incorporate both 7.5 s and 11 s thresholds).

Other

If it takes extra time to use the system or the system tends to advise people to wait when they would have proceeded, it could cause a backup of cars on the minor road.
A ¼ full bar could be seen as daring you to cross.

Q: How could the system be improved?

Summary: Many participants wanted an advisory message of some sort, such as a color change to indicate level of danger. Often participants wanted a system that told them when to proceed, which violates department of transportation policy without also controlling the highway traffic. This is not desired since controlling the highway traffic (as with a stoplight) increases rear-end crashes.

There were several comments that the bar gauge should be filling with color instead of emptying of color.

There were several comments that numbers should be added to the bar. Numbers were deliberately omitted due to the poorer performance of systems that used them in the past.

Adding advisory message(s)

Need a strong advisory message – color change or caution message.
Combine the bar with a sign saying "don't go".
All-or-nothing would be better – the bar is unnecessary – all you need is "go" or "don't", for the system to decide for you.
Have a flashing light when it's not clear to go.
Would be good to have a flashing light to tell you to wait.
Rebuttal: Adding the flashing light would be vague.
Have a simple advisory message on the steering wheel – lights up if should wait.

Adding color changes – a type of advisory message

Color change as bar empties.
Tri-color would be good (red, yellow, or green depending on level of danger).
Use red/yellow/green color coding.

Bar gauge issues

Add numbers to the bar.
Progressing dot or filling bar instead of emptying bar.
Label 7.5 s, since people won't otherwise know that this is the maximum value of the bar.
Make the car into the bar – the car empties of color, or fills up with color, or blinks.
There was a suggestion at some point for a filling bar – more color means more danger.
Must educate driver on what bar means.

Car icon issues
Draw the car icon so it is easier to distinguish the front and back – Since there would be two displays, it might be hard to distinguish which refers to traffic from the left and which refers to traffic from the right – Could also just use an arrow icon instead of a car icon (and possibly color the arrow).
The car should move, not be stationary.

Information for highway drivers
Add speed monitoring for the highway drivers (i.e. sign says "your speed is X").
Add a system for the cars on the highway to see minor road traffic.

Infrastructure changes
Add a stoplight that only controls traffic on the minor road.
Build a tunnel or bridge – as a way to prevent traffic jams and gridlock.
Block highway traffic with a bar (participant seemed to be describing a system like a railroad crossing). This would be for extreme cases, such as when minor road traffic might be waiting 20 minutes.

Other
Could have a GPS screen with live traffic on it to be sure the system is referring to the traffic you think it is referring to.
Show the numerical value of the time to arrival (of whichever car is closest). Could also either be red and show the time, or be green and not show the time.
If the display was [multimodal], the driver would be unlikely to miss the message.
Make as simple as possible.
Display should be stop-sign sized (if external to the vehicle).
Does it account for speed? (i.e. the system needs to account for speed of approaching vehicles)

Q: Does the system communicate the information you need? (if not, what is missing?)
Summary: No particular theme, not many comments.

Is there another time to arrival below 7.5 s that is important?
Is there a need for a continuous display?
The near lane is most important – if visibility is an issue, need a large mirror to see traffic coming.
Add a numerical time to arrival value.

Yes, it tells you: whether a car is coming, when it will get there, and how fast it is coming.

Q: What location would be best for this DSS?

Summary: There were comments on having the Side Mirror Display(s) next to the stop sign or in the direction of approaching traffic. Participants acknowledged that they would be used to seeing things on the right, but that at the stop sign the traffic would be coming from the left and that it would be more helpful to be able to see the Side Mirror Display(s) while watching traffic.

For locations inside the vehicle, one participant commented on placing the displays on the side mirrors. There were a couple comments about locating the display on the dashboard, and a couple comments on locating the display where the GPS would be, or even integrating it into the GPS.

Comments on visibility

You need to be able to use your own eyes as well.
Impede vision as little as possible.
A location that does not block the view of incoming cars.

Outside the vehicle

Don't want it in the car – put it overhead (like a traffic light), or in the median.
Hanging over the intersection.
Direction you'll be looking – if you are in median (not sure what this comment meant).
Near the stop sign.
Below the stop sign (but then again, you don't want to keep attention off the road).
Off to the side, where you'll be looking anyway – maybe by the sign (did they mean yield sign?).
On the right – used to seeing things on the right while driving.
Put it on a sign on wheels, like the signs used for construction – put it on the right side of the road.
Off to the side where traffic is coming from.
One to the left at the stop sign and one to the right in the median – don't have both at one place.

NOTE: Above, there are a few comments about putting the DSS in a direction you'll be looking while watching traffic.

Inside the vehicle

On side mirrors.
On top of dash.
Above the dashboard.
Same area as GPS – center of windshield.
On a built-in GPS screen.
HUD.
Wouldn't want it inside the vehicle – if did, put on left hand window.

Q: Would you use the system if it was available to you at no additional cost?

1 maybe (especially bad weather)
3 yes
3 no

System: Side Mirror Displays with color change

Q: General comments:

Good.
The color is more important than the bar.

Q: What are some strengths of this system?

Summary: Participants thought the color change was an improvement, as well as the longer bar.

Color change

Color good (3 people definitely agree).
Color change. (i.e. the color change is a strength)
Red helps if your vehicle is very slow (e.g. pulling a load).
Good to have full 11 s – people will probably look at the percentage of the bar, so it is better to have 11 s instead of 7.5 s (e.g. 50% will be safer if it is 50% of 11 s).
Yellow means you are okay, red means you shouldn't go.
I like the yellow caution and red stop.

Comprehension

Older drivers are used to color, so this is easy to learn.
Simple – only 1 or 2 signals (2 if have one for each direction).
It has more information 7.5 s to 11 s out.
It has more information.
Easier to understand. (i.e. easier to understand than side mirror displays without color change)

Other

Can look at it and use your own judgment.
Having the 11 s is better for icy conditions.
I like it better.
Improved over previous.

Q: What are some weaknesses of this system?

Summary: There was still some dislike of the bar gauge, in that it was somewhat superfluous.

Bar gauge

Bar is still not needed, and not worth the extra money.
Don't need bar – Simpler is better – but for the yellow state, it's nice to see how long until it turns red.
Still don't like the bar.

Color change
Certain traffic conditions could cause flickering between red and yellow (although the flickering would draw your attention, which would be good)– would be good to have green show up (flickering between green and yellow would be good).
Color change could be distracting.

Other
You will miss the information of sequence of movement of array of cars in Stream of lights.
May miss if outside of car – can't see if too small.

Q: How could the system be improved?
Summary: Participants wanted a system state that would tell them to proceed, though some participants did acknowledge that this system was flawed (e.g. it would indicate right of way but minor road traffic never has right of way). There were some comments that a system using only color to indicate amount of danger would not work for colorblind people.

There were several comments that the Side Mirror Displays should never be blank, regardless of distance to approaching traffic.

Add green
Add green for >11 s.
Or green at 11 s, yellow at 7.5 s.
However, green would give entitlement – but on the other hand, green would be for when traffic is far away.
Have a green section too (11 s to 13s) – but then again, green would indicate right of way, which minor road traffic would not have.
Add green for >11 s – background green instead of gray, but blank besides the green background.
Just have red, green, yellow – no bar or numbers.

Other color issues
Have an "X" on the display when red.
Use a sharper red, like on a stoplight.
Have display flash when yellow and be solid when red.
Have some indication besides color for colorblind people.
Have two displays (for a single direction), one on top of the other (or one bigger than the other), so that there is a variable that is redundant with color. (not many details were offered on what this design would look like)

Blank screen
Blank screen would be confusing.
If the system breaks and the screen turns blank, people will think it's okay to go.
Better not to have dead/blank state – what if the system isn't working?
Blank makes you think it is not working.

Add an indication that the system is working and not broken.

<u>Car icon</u>
Would be good to have an arrow – speed lines are not obvious enough – also make the car less symmetrical (could also make it a truck sketch).

<u>Bar gauge</u>
Use the car as the bar.
Add a demarcation on the bar at 7.5 s.

<u>Other</u>
Add a blinking light like on a train crossing (flashing light when not safe, off otherwise) – driver's already know how a train crossing works.
Add a three-light stoplight.
Make the display as big as a stop sign.
Need to consider the second car behind the stop sign – limit this driver in some way. Could limit the system information to only be given to the first driver at the stop sign, so the second driver isn't tempted to immediately follow once the first driver proceeds. Could also have a speed bump behind the first vehicle.
Solar power the systems.

<u>Q: Does the system communicate the information you need? (if not, what is missing?)</u>
Color change more efficient.

<u>Q: What location would be best for this DSS?</u>
Next to the stop sign.

<u>Q: Would you use the system if it was available to you at no additional cost?</u>
More inclined.
Worth trying.

System: Side Mirror Displays with color change and warning icons

<u>Q: General comments:</u>
The two options show the same message.

<u>Q: What are some strengths of this system?</u>
Summary: The bottom option of the two warning icons is more obvious.

<u>Favoring the second option</u>
Clarity of consequences for the 2^{nd} one (one participant commented they definitely would not proceed if <7.5 s).

I like the second option – it is over the top, but it works – it conveys the message that you will crash (other everyday signs show things like this, such as showing a sketch of a person being hurt around heavy equipment such as escalators).
The bottom one is more obvious.

Other
Don't have to worry about colorblind people.
It's okay.

Q: What are some weaknesses of this system?
Summary: Both icons were somewhat confusing. There was some dislike of the icons in that they were too extreme of a message. There were a few more comments that the bar was unnecessary.

Confusion
First one confusing.
Unnecessary to have 2^{nd} car.
Complicated.
Mildly confusing – not intuitive it is you in the pictures.
The upper one is confusing.
The second one is not crash-y (i.e. not indicative of a crash).
The second one – not sure if accident has already happened.
The top option doesn't mean anything.

Dislike
Fear-mongering – would not go under any circumstances.
Stressful and irritating.
I don't like it, it looks hazardous.
I would be nervous.
It is scary.

Bar gauge
Bar appeals to risky behavior – but wouldn't these people be risky anyway? – the system would still help non-risky people.
The bar is useful but not entirely necessary.
The bar is not needed – color and icon enough.

Limitations
Icy conditions would change the 11 s and 7.5 s limits.
Not immediately obvious to foreigners.

Other

If you used the top one for the yellow state and the bottom one for the red state, they would not be different enough when viewed from far away.
Too distracting.

Q: How could the system be improved?

Summary: Most of the comments for this question did not seem to apply just to the two warning icons, but to the Side Mirror Displays in general.

Views

Show ¾ overhead view (picture drawn showing approaching car, driver's car, and road markings).
Show a top view.

Color coding

Use the top one for the yellow state and the bottom one for the red state.
Add an X for the red state, as suggested previously.
Add green background condition.

Dislike

Bottom one too drastic as an information system – too much – like something bad has already happened.

Training

Need a training program.
Need training if have bar gauge, vibration, etc.
Don't need training if have red/yellow/green.
There was some disagreement on the need for training for these systems (perhaps just a news announcement is needed).

Other

I don't care about the 7.5 s threshold, I just need to know whether to go.
Option 2 needs to look more like a crash.
Blinking might help.

Q: Does the system communicate the information you need? (if not, what is missing?)

Doesn't add anything over the previous system.
This system has more emphasis on consequences.

Q: What location would be best for this DSS?

(not asked)

Q: Would you use the system if it was available to you at no additional cost?

(not asked)

System: Stream of lights

NOTE: For the third of the three groups, the stream of lights was changed to use small car icons instead of dots. Also, the two streams of traffic on the display were offset.

<u>Q: General comments:</u>

(not asked)

<u>Q: What are some strengths of this system?</u>

Summary: Participants preferred the Stream of lights with the color coding option. They also commented that it was good to see multiple vehicles and multiple speeds.

<u>Color coding</u>

Color coding is an improvement.
The color option is better.
I like the color coding, but colors need to be picked carefully so that colorblind people can see them.
Red means stop, yellow means caution.
The second one is better, while the first one needs more interpretation and use of your experience.

<u>Multiple vehicles</u>

Good concept – tells you where vehicles are.
Good to see each vehicle.
Accounts for multiple speeds.
More information is better since it is a warning system instead of a traffic regulator.

<u>Other</u>

Gives a focal point – the center.
Real-time, real cars.

<u>Q: What are some weaknesses of this system?</u>

Summary: Participants commented that the system could be distracting and difficult to see.

<u>Distracting</u>

Dots are distracting.
Distracting
I like it, but it can be distracting (later, a participant commented that the side mirror displays would be simpler than the stream of lights).

<u>Visibility</u>

Hard to see – thin.
Too small to see.

Confusion / missing information
Confusing – all on same row; also, it's a lot to take in, especially considering both sides.
No concept of scale.
Left-turning traffic is not represented.

Other
Don't need the yellow cars. They are superfluous information.
If a vehicle at 7.5 s is not safe, the ones directly behind it are also not safe.
Other systems are better
Not as quick and easy.
Cost issue if implemented at minor roads with not much traffic.

Q: How could the system be improved?

Summary: Participants commented that the two strips of traffic should be offset, and this change was made after the first two groups. There were a couple comments that the display should show multiple lanes (e.g. show two lanes for traffic approaching from the left if there are two lanes of traffic approaching from that direction at the actual intersection).

Participants also critiqued that lack of scale on the Stream of Lights and suggested adding a scale or a landmark to the display.

Participants commented again that they would like an advisory message.

Show both lanes of traffic
Show multiple lanes.
Want to know what lane each vehicle is in.

Offset the two strips
Offset – right lane higher (separate the two strips).
Need to separate the two roads.
Move the right part of the display higher up than the left part.

Landmark / demarcations
Since it shows every car, also show a landmark before 11 s (i.e. on the display, show something that is physically at the intersection).
With a landmark, the display wouldn't need to be as long.
Label the scale.
Add a scale so we know how far away is the farthest dot on the left.

Add advisory message
Want to know if there's a big break in traffic coming up.
Just need to know go/don't go.

Other

Have full real-time GPS – and add verbal “don’t go now”.
Show little car icons instead of dots.
Show only one side at a time.
Need a continuous change in the display, not just lights at discrete locations along the display.
7.5 s seems large.
The 7.5 s mark would not always be the same location since vehicles would travel at different speeds.
The display should have a dimming option (or, it should be as dim as possible to not interfere with night vision).

Q: Does the system communicate the information you need? (if not, what is missing?)
(not asked)

Q: What location would be best for this DSS?
Summary: There were several ideas for location, though not much consistency across the ideas.

Inside the vehicle
Lower corner of the windshield.
Below the steering wheel – though this has the downside that you would need to look back and forth.
On the dash to the right.
On the windshield (the display would be transparent – this would make it easier to watch the road).
On the dashboard.

Outside the vehicle
Six inches off the ground.
Above (above what? After the discussion, this wasn’t so clear).
Over the intersection.
On the right – used to seeing signs there (e.g. stop signs).

Other
It’s kind of big.
In car, or gigantic sign.
Distracts if on dash.

Q: Would you use the system if it was available to you at no additional cost?
(not asked)

System: Vibrotactile Seat

Q: What are some strengths of this system?

Summary: Participants commented that the system could be attention-grabbing and had the advantage that it did not have a visual component that the driver would need to watch. These comments match with the experimenter's reasons for testing a vibrotactile seat.

This would help with low vision (e.g. older drivers).
The jolt would get your attention and make you aware of danger.
Unique.
Weakness of a visual system is that you might not look at it.
Like better than auditory.
More direct – less chance for missing the message.
Can learn to use – learn to pick up. (i.e. learn to notice the signal)

<u>Q: What are some weaknesses of this system?</u>
Summary: Participants commented that whether the driver will notice the vibration depends on the location of the vibrational pads as well as the driver's position at the time. Participants also commented that the vibration might not be noticed due to other vibrations or due to the driver concentrating on watching traffic.
It is interesting that there are few comments that the Vibrotactile Seat could be annoying.

<u>Dependency on driver position in relation to vibrational pads</u>
Depends on driver position – whether the vibration is coming from the steering wheel or the seat, the driver's ability to feel the vibration depends on the driver's position (the driver might be sitting in a position where his/her body does not contact the vibrational pads).
If legs are not flat on the seat, can't feel the vibration.
Does not accommodate different sizes of people.

<u>Not noticed</u>
The driver could mistake the vibration for his/her cellular phone or other externalities (e.g. could mistake for loud bass speakers).
Not notice the vibration over music.
Old cars vibrate and shake on their own, and would mask the system's vibration.
Might not notice – would need to be an aggressive vibration.
Since it uses a different sense, it might be hard to focus on so many senses/things at once (but at the same time, a driver could learn to associate).
May not be able to pick up the cue. Could miss it. Could be confusing. (example: participant sometimes thinks his cell phone is vibrating when it is not).
Driver may not notice the system if already confused by traffic (i.e. concentrating hard on traffic).
The stereo may be so loud that you can't feel the vibration.

<u>Left/right confusion</u>
Might be hard to differentiate left and right.
Possibility of left/right confusion.

Novelty problem
Would make the driver jump the first time s/he felt it.
People more conditioned to have visual information for driving.
Harder to train older drivers than for a visual or auditory system.
How do you know it'll work? (this comment appears to be a trust issue due to the novelty of the system)

Other
Speech is better than vibration.
More chance of a defect than a speech system (e.g. bass drowning out the vibration).
If vibrating due to very heavy traffic with a long wait time for the driver trying to cross, the vibration may become annoying over that long wait time.
Too much distraction, so kind of dangerous.
Practical issue of putting in lots of cars.

NOTE: Some people commented that they preferred auditory, some people preferred vibrational.
Also, people seem to have less trust in this system than in other systems.

Q: How could the system be improved?
Summary: Participants had several ideas for relocating the source of the vibration or having different haptic stimulators.

Locations for vibration
Put the vibration pads behind the shoulders – but wouldn't work if driver leaned forward.
Use different locations for the vibration instead of using different sides of the body.
Add a back pad too (have front and back instead of left and right).
Vibrate steering wheel.
Move the vibration to the entire steering wheel (so the entire steering wheel vibrates at once) – but this would make it harder to indicate left/right.
Would be more noticeable if it was a roller down the driver's back or a kick in the seat of the pants.

Use a different modality
Use a beeping device instead – less intrusive (the beeping device could be in the car or in the intersection).
Visual or auditory preferable to tactile.
Have a "don't turn" signal instead of a turn signal.

Other
Distance between the pads should be far enough to differentiate between them, but this might be too far to feel both of them.

If you get to customize your vehicle when you buy it and pick which system to use, then you will know what to expect.
Adjust threshold away from 7.5 s (more or less).
Turn off not needed side (i.e. turn off left side if in median).

Q: Does the system communicate the information you need? (if not, what is missing?)
Yes.
Obvious – each side refers to traffic from that direction.
Could be mistaken for something else in certain situations, but mostly good.
Immigrants may not know this system exists – complicates the issue.
Add required training (e.g. part of driver licensing test).

Q: What location would be best for this DSS?
(not asked)

Q: Would you use the system if it was available to you at no additional cost?
Comment that it is not practical, and would probably never be at no additional cost.
May have value as a backup system.

System: Auditory

Q: What are some strengths of this system?
Summary: Participants commented that the Auditory system would not have a visual component that would need to be watched.

Better than nothing.
A visual system could be blocked (e.g. by ice).
Audio or vibration system doesn't use occupied visual channel (especially in harsh conditions).

Q: What are some weaknesses of this system?
Summary: Participants expected the system would be irritating. It could also be easily drowned out and would not be usable by deaf drivers.

Irritation
Irritating (four comments on this).
Driver will soon ignore it after only brief use.
Irritating if the system is active a long time (i.e. hearing the warning for a long time).

Not noticed
Other noise would drown this out if it was external to the vehicle (music, kids crying).
May not be loud enough.

Not useful for the deaf
What if you're deaf?

Deafness – especially older drivers.

<u>Other</u>
Don’t need for all of 7.5 s (i.e. don’t need to keep hearing it the entire time you are waiting for the highway vehicle to pass the intersection).
If hear “stop” will unconsciously slam on the breaks.
No benefit over other systems.
Beeps would get mistaken for another driver honking.
A driver might try to proceed during the short pause between spoken “wait”s.

<u>Q: How could the system be improved?</u>
Summary: Participants wanted a stronger advisory message, either to show level of danger or to indicate when it was safe to proceed.

There were several ideas mentioned for different speech messages and for tones/beeps/buzzers.

Participants again commented that a multimodal system would be helpful.

<u>Add advisory message or caution state</u>
Voice screams when red.
Add caution state.
Different decibel level for yellow state.
Steady tone if need to wait, ding when you can go.

<u>Use a different message than “wait”</u>
Use a word besides “wait” – e.g. use “no” and “go”.
Use a full sentence instead of a buzzer or a word.
Sounds would be better than words, since not all drivers understand English very well.
Use a loud beep instead (the participant probably meant a single beep instead of a continuous one).
Clicking sound instead, like a turn signal or on pedestrian crosswalks at stoplights – but then again the clicking sound could be too subtle – some speech warnings for pedestrian crosswalks are pretty easy to hear over other noise.
Use a buzzer.
Have a continuous tone play when it is not safe (some participants expressed skepticism at this idea).

<u>Use a multimodal system</u>
Don’t have solely auditory.
Something visual would help.
Have a visual system showing the time to arrival.

<u>Radio issue (radio could drown out system)</u>

Maybe shut off the car's music to make sure they hear the auditory message – but the driver wouldn't like having their music shut off.
The auditory warning system needs to work even if the vehicle's radio is off.

<u>Other</u>
Turns on if the driver is about to proceed and traffic is approaching.
Add a blinking warning to the driver's GPS.
An auditory system would work better for pedestrians crossing.
Hire people to stand at the intersection and wave you through when it is safe.
Add fines if a driver disobeys a warning for a time to arrival of 2 seconds.
Use a seat vibration or a vibration in the vehicle's wheels (not sure whether the participant meant vehicle's wheels or steering wheel). (this comment was made before the vibrotactile system was presented)

<u>Q: Does the system communicate the information you need? (if not, what is missing?)</u>
(not asked)

<u>Q: What location would be best for this DSS?</u>
(not asked)

<u>Q: Would you use the system if it was available to you at no additional cost?</u>
(not asked)

<u>Q: Which system do you think is best?</u>
Summary: Participants most frequently liked the Side Mirror Displays with the color change, though some added the caveat that they would not want the bar gauge or would want an advisory message that told them when to proceed.

There was also some support for the Steam of Lights with the color coding.

<u>Side mirror displays</u>
Colored without bar (good even with bar) – 3 people agree.
Colored with bar.
Red & yellow displays
Red and yellow displays but with no bars.
Side Mirror Displays with red, yellow, and green (five supporters of this idea).

<u>Stream of lights</u>
Stream of lights if add a landmark.
Stream of lights with colors (three people agreed).
Stream of lights.

<u>Auditory</u>
Speech – with steady tone and a volume knob, or if it was only for repeat offenders.

Not decided on one
Haven't decided: Between stream of lights, and color change with warning icon.
Red and yellow or Stream of lights with colors.

Other comments from participants:
For a system that shows time to arrival: People may not know how long it takes to cross, so they may try even if there is only a 2 second time to arrival.

7.5 s too big, especially with the auditory system.

idea: For the Stream of lights, change the car symbols to numbers.

Must be able to see the system clearly, especially in bad weather.

Overall comment: Need color change

Sketch: participant conceptualized a system of sensors at various distances that would continuously report the closest vehicle to the intersection. I believe this was drawn during one of the mirror displays discussions. I'm not sure how this system would be different from any of the systems presented.

It would be good to have a system that warns of deer.

Q: Ways to improve the study:

Strengths
+ The experimenter remained objective.
+ Participants were able to bounce ideas off each other.
+ Name tags helped.
+ Started on time.
+ The experimenter offered to discuss the work afterwards.
+ Good.
+ Good prompts, important questions.
+ Not mad at the late participant.
+ Smooth, organized.
+ Name tags.
+ Having a reminder was good.

Areas for improvement
- Play devils' advocate more to get more feedback.
- Add more things to consider to get people to think about in different ways.

- Would have preferred a reminder the day before instead of 2 days before.
- Are these hypothetical systems? Want more information up front. It could help with the discussion.
- More information up front on why the issue is important.
- Video showing an accident at a thru-stop intersection.
- Show the displays in action – video or powerpoint.