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A Simulator-Based Evaluation of Smart Infrastructure Concepts for Intersection Decision Support for Rural Thru-STOP Intersections

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16. Abstract (Limit: 200 words)

This report describes the human factors basis for an intersection decision support (IDS) system intended to improve the safety of rural intersections in Minnesota's Interregional Corridors (IRCs). The purpose of the human factors effort is to understand the task of rural intersection negotiation, identify high-risk user groups, describe the human factors that contribute to intersection accidents, and determine what conceptual types of information to present in the IDS display to improve driver performance and safety. Consistent with the original infrastructure consortium proposal, this report emphasizes gaps, older drivers, and rural thru-STOP intersections (Donath & Shankwitz, 2001). This is because older drivers have a high accident risk at rural thru-STOP intersections and problems with gap detection, perception, and acceptance are contributing factors. A task analysis of rural thru-STOP negotiation was used to define the informational requirements for an IDS system for assisting with gap detection, perception and judgment. An abstraction hierarchy defined the operator (driver) constraints relevant to an infrastructure-based IDS system. Four design concepts were constructed and tested in a driving simulator with older (55+) and younger (20-40) drivers in day and night driving conditions. Two designs resulted in the largest mean gap acceptance across groups when compared to baseline. The two design concepts also were most favored by the majority of participants.

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Report #4 in the series: Developing Intersection Decision Support Solutions

Final Report

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Table of Contents

List of Tables

List of Figures

Executive Summary

This report describes the human factors basis for an intersection decision support (IDS) system intended to improve the safety of rural intersections in Minnesota's Interregional Corridors (IRCs). The purpose of the human factors effort is to understand the task of rural intersection negotiation, identify high-risk user groups, describe the human factors that contribute to intersection accidents, and determine what conceptual types of information to present in the IDS display to improve driver performance and safety. Consistent with the original infrastructure consortium proposal, this report emphasizes gaps, older drivers, and rural thru-STOP intersections (Donath & Shankwitz, 2001). This is because older drivers have a high accident risk at rural thru-STOP intersections and problems with gap detection, perception, and acceptance are contributing factors.

Introduction

Older drivers are 65 years of age and older. A rural thru-STOP intersection consists of a two or more lane highway intersection by a STOP-controlled minor road. A gap is the time or distance between successive vehicles in a traffic stream and a lag is the remaining part of a gap after a driver first arrives at an intersection. An acceptable gap is one that a driver indicates is acceptable for the intended maneuver (crossing or turning). An accepted gap is one that is actually accepted and crossed by a driver. A safe gap (tG) is based on an objective model that considers both driver perception response time (tPRT) and maneuver time (tMT). It is the minimum gap size needed to execute a maneuver without causing a conflict. If the IDS system advises drivers about the acceptability of gaps, it needs to make recommendations based on safe gaps. This is because accepted and acceptable gaps are subject to driver perceptual and decision making errors (Lerner et al., 1995).

Task Analysis

This section describes the results of a task analysis. Based on a compilation of earlier task analyses, drivers complete the following tasks at rural intersections in an approximate temporal order:

- Detect intersection
- Decelerate
- Enter correct lane (if required)
- Signal if intending to turn
- Detect traffic control device (signs or signals)
- Interpret traffic control device
- Monitor lead vehicle (if present)
- Detect traffic and pedestrians
- Detect, evaluate, and monitor gaps in traffic
- Accept gap and complete maneuver
- Continue to monitor traffic and control device until intersection is cleared

Driver Errors

This section summarizes driver errors made at intersections, including those most likely to cause problems for older drivers.

- Failure to detect intersection

- Failure to slow adequately before entering intersection (older driver error)
- Failure to change lanes properly (older driver error)
- Failure to signal or wrong signal (older driver error)
- Failure to detect traffic control device (older driver error)
- Failure to obey traffic control device
- Failure to comprehend traffic control device (older driver error)
- Failure to check sight lines obscured by lead vehicle
- Failure to estimate velocity, distance, or gap to lead vehicle (older driver error)
- Failure to detect traffic and pedestrians (older driver error)
- Failure to anticipate actions or intentions of other drivers and pedestrians
- Failure to estimate velocity, distance, or gap between other vehicles (older driver error)
- Failure to consider all factors when accepting gaps
- Failure to clear intersection

Design Process & Options

This section outlines the design process for identifying key concepts and features required in an IDS system. An abstraction hierarchy (AH) analysis for intersection negotiation identified a number of environmental constraints and information elements for the IDS concepts that were proposed. The skills, rules, knowledge (SRK) framework and an analysis of information processing in the Driver Error section (Laberge et al., 2003) were used to identify the operator (driver) constraints. This helped ensure the information content was represented in a form that is consistent with driver performance and information processing limitations (Lee et al., 2003). The ecological approach was a suitable supplement to the traditional task analysis method used to identify driver tasks (Laberge et al., 2003) and helped to identify new information requirements.

This describes potential information concepts for each driver task involved with negotiating a rural thru-STOP. Information requirements are not limited to the IDS system and also include changes to the intersection and in-vehicle solutions that can convey important information to drivers. Primary content elements directly support minor-road driver tasks related to gap detection, perception, and judgment. Secondary content either supplements or draws attention to specific information to help minor-road drivers make more efficient (rather than accurate) decisions. General limitations and design premises were identified to better define the boundaries for potential IDS solutions.

Gap specific design issues were related to identifying and highlighting vehicles and gaps at the intersection to help drivers make better decisions. Behavioral attributes of the driver and how drivers make gap acceptance decisions were also identified to explain how drivers may perceive or interact with an IDS system. A specific consideration for non-cooperative infrastructure IDS systems is that they must take into account the worst-case scenario of an older driver attempting to turn or cross at the intersection.

Design Concepts

Based on the preceding design process and a review of existing infrastructure-based systems applicable to IDS (see Appendix B), a preliminary set of design concepts was generated. These interface concepts include systems that provide alerting information, as well as systems that display gap-specific information, warn about unsafe actions and advise against unsafe actions at the intersection. The safe gap thresholds for all candidate interfaces take into account the worst-case gap acceptance scenario of an older driver making a left turn.

- Hazard Concept: A flashing yellow "Dangerous Traffic" message alerts drivers to the presence of traffic on the main roadway.

- Split-hybrid Concept: Two signs (one at the STOP sign for near-side traffic; one in the median for far-side traffic) provide drivers with a timer countdown indicating how far away (in seconds) approaching traffic is for each set of lanes and also uses icon messages to indicate prohibited actions (i.e., do not cross or turn left).

- Icon Concept: Two identical signs (one at the STOP sign for near-side traffic; one in the median for far-side traffic) provide warning indicators about approaching traffic and prohibitive message for each set of traffic lanes.

- Variable Message Sign Concept (VMS): Two identical signs (one at the STOP sign for near-side traffic; one in the median for far-side traffic) use icon messages to indicate prohibited actions (i.e., do not cross or turn left). The logic is the same as the Split-hybrid concept, but does not include the timer countdown.

Section 7: Concept Evaluation Study

This section explains the methodology and results of a simulator-based evaluation study to test the information concepts of the designs. The concepts presented to drivers in this study do not necessarily represent the final designs, but instead will be modified based on the results of the study. The sign concepts were tested with a group of older drivers (age 55-75) and compared to results from a group of younger drivers (age 20-40). The sign concepts were tested in both high (day) and low (night) visibility conditions. The crossroads of US 52 and County State Highway (CSAH) 9 in Goodhue County, Minnesota, were modeled in the simulation to test the sign concepts.

The Icon sign resulted in the largest mean accepted gap, which was significantly larger than the other three sign concepts and baseline. The Icon design had the highest comprehension rates for drivers in all conditions, and was rated as the second most useful and satisfying of the IDS signs by all young drivers and old drivers in the night condition. Some drivers, particularly old drivers in the day condition, found the complexity of the sign to be confusing. The Split-hybrid sign resulted in the second largest mean accepted gap overall and it was significantly different from baseline. This sign design had the second highest comprehension rates and was the most preferred design for all young drivers and for old drivers in the night condition. These groups also rated the Split-hybrid sign as the most useful and satisfying of all the IDS concepts. A majority of drivers reported using information from the Split-hybrid sign while making their crossing decisions, particularly in the night condition. The VMS sign resulted in the third largest mean accepted gap overall and was significantly larger than baseline. The VMS sign had the lowest comprehension rate of the sign concepts. It was ranked similarly to the Hazard sign for usability, and below the Split-hybrid and Icon signs. The Hazard sign resulted in the smallest mean accepted gap overall. However, the gap value was not significantly smaller than the mean accepted gaps for the Split-hybrid or VMS sign conditions, and it was significantly larger than

the baseline mean accepted gap. Most drivers identified the sign as an alerting system and it was most preferred by old drivers in the day condition.
The safe gap threshold was perceived to be conservative by many drivers. This most likely occurred because it was based on the worst-case scenario of an old driver making a left-turn maneuver. A single, global threshold for an IDS system is most likely not sufficient in terms of practicality and user acceptance.

Overall, the sign concepts that provided continuous, dynamic information about the intersection were better comprehended than those that did not. For example, the Icon and Split-hybrid signs change dynamically as traffic approaches. In contrast, the VMS sign only changes when a gap above the safe gap threshold is detected, thus appearing static to drivers and making its function more difficult to interpret.

Recommendations and Design Limitations

The informational content of both the Icon sign and the Split-hybrid sign were best understood by drivers and more frequently used to make crossing decisions. There are certain limitations associated with each sign. First, both must be altered to include MUTCD compliant sign content. Second, safe gap thresholds that are individualized to the driver may increase the usability of the signs' content and should be evaluated. Other issues that need to be considered include the way drivers interpret and interact with a prohibitive message set, as used in the current implementations and how best to educate drivers on the function and utility of such a support system.

Future Research Needs

- Expanding design options beyond alerting and information alone and including the full spectrum of intervention, such as notification, enforcement and automatic control.
- Develop MUTCD compliant variants of the IDS concepts for future deployment and testing.
- Develop and test "do not enter" symbols for use with the Split-hybrid sign that do not conflict with other traffic signs in the same area with a different function.
- Investigate and test alternate ways for presenting time-to-arrival information to drivers.
- Continue to investigate how drivers interpret the disappearance of prohibitive information and the presence of cautionary information.
- Investigate how best to disseminate information about the function of the IDS signs to drivers and how best to educate users on the purpose of the sign to better encourage usage, particularly among old drivers who may not be aware of their increased crash risk at intersections.
- Future research should test drivers in more complex gap situations. Some of the factors that should be evaluated include multiple vehicles on different paths and when a driver is approaching an intersection as opposed to stopped.

Parameterized models to predict discrepancy between safe and accepted gaps (safety margins) to dynamically target IDS functions to at risk drivers and intersection situations

1. Introduction

The goal of this project is to design and evaluate an infrastructure-based decision support system to help drivers safely negotiate rural intersections in Minnesota's Interregional Corridors (IRCs). IRCs are characterized by high-speed, high-volume roads that connect regional businesses, manufacturing, and tourist centers with rural districts. Intersection collisions are often fatal due to the high speeds, high volumes, and the heavy vehicles and trucks that routinely travel these routes (Donath & Shankwitz, 2001), making rural IRCs an important focus area for interventions.

During 2002, more than 22,000 fatal crashes took place in rural areas in the United States, with most crashes occurring at speeds greater than 55 mph (NHTSA, 2003b). These crashes accounted for 59% of the total number of fatal accidents for that year, and approximately 16% of fatal rural accidents are thought to occur at intersections (AASHTO, 1997).

The statistics for the state of Minnesota are similar. Between 2000 and 2002, there were 23,179 reported crashes on Minnesota rural two-lane roadways and 10,996 on rural expressways (6,838 and 4,231 crashes, respectively) (Preston & Storm, 2003b). Thirty percent of roadway and 39% of expressway crashes were intersection related. Of these, 121 roadway crashes and 70 expressway crashes were fatal (94 and 19 fatal rural crashes, respectively).

Rural intersections along Minnesota IRCs can be either signal or sign controlled. The latter type is the focus of this report. This is because a majority of rural intersection accidents occur at STOP-controlled (thru-STOP) intersections. Of the 425 fatal rural accidents that occurred in Minnesota during 2002, 22% were at thru-STOP intersections compared to only 4.5% for signalized locations (Preston & Storm, 2003b). These data suggest rural thru-STOP intersections are an important safety consideration for Minnesota drivers.

A rural intersection decision support (IDS) system in Minnesota can provide information that guides drivers through the intersection negotiation process. Consistent with the original infrastructure consortium proposal (Donath & Shankwitz, 2001), this evaluation emphasizes gaps, older drivers, and rural thru-STOP intersections. Specifically, it will explain the task of rural intersection negotiation, identify high-risk user groups, describe the human factors that contribute to intersection accidents, and determine what information to present in the IDS display to improve driver performance and safety. The report will conclude with a simulator evaluation of proposed driver-infrastructure interface (DDI) concepts.

1.1. Definitions and Important Constructs

Because this project is concerned with older drivers, thru-STOP intersections, and gap acceptance, these constructs are briefly defined. An important distinction is also made between safe, acceptable, and accepted gaps.

1.1.1. Older Drivers and Thru-STOP Intersections

Older driver usually refers to individuals 65 years of age or older, but anyone between the ages of 60 and 85 years may be considered 'old' (Dewar, 2002). Some researchers also make a distinction between old (65 to 69 years) and old-old (70 + years) drivers (e.g., Lerner, Huey, McGee & Sullivan, 1995; Parsonson, Isler & Hanson, 1996; Staplin, Harkey, Lococo & Tarawnch, 1997), while other research has included all drivers over the age of 55 in the older category when discussing intersection accident involvement (Staplin & Lyles, 1991).

The HumanFIRST experiment reported here used a liberal definition of "old driver" (i.e. 55 to 75). The inclusion of younger old drivers should tend to improve the overall performance of our older driver group. Therefore, any significant age-related findings from our analyses will be stronger evidence that age-related limitations on driving are having an affect on crossing performance at the intersection. The decision to include drivers as young as age 55 was made because studies on intersection accidents report older driver accident ratios starting as young as age 55 (e.g., Staplin & Lyles, 1991).

Thru-STOP intersections occur when a two- or more-lane IRC is intersected by a STOP-controlled minor road (Donath & Shankwitz, 2001). Thru-STOP intersections occur on either two-lane rural roads or four- or more-lane rural expressways divided by a median. The near side of a thru-STOP intersection refers to the lanes in the IRC closest to a driver (before the median) who is stopped on the minor road (Figure 1.1). The far side refers to those lanes farthest from the driver (opposite side of the median). Throughout this report, the IRC may also be referred to as the major road.

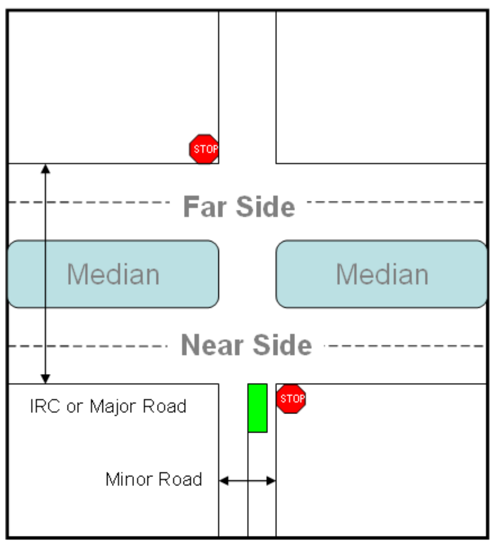


Figure 1.1. Layout of a thru-STOP intersection at a rural expressway.

1.1.2. Gaps and Lags

A gap (Figure 1.2A, B, C) is defined as the time or distance between successive vehicles in a traffic stream (Caird & Hancock, 2002). A lag (Figure 1.2D, E) is the time or distance to the nearest approaching vehicle(s) in the traffic stream after the driver stops. Gaps and lags can be represented in either time or distance units. The former are used here because studies have shown that a time gap is independent of approach vehicle speed and captures driver behavior in most gap-acceptance situations (AASHTO, 2001). Using time gaps also simplifies comparisons across studies because differences in approach speed do not have to be considered. This issue is discussed more in the section on gap acceptance.

Throughout this report, and unless otherwise stated, an emphasis is placed on gaps and lags on the IRC or major road. This is because at thru-STOP intersections, oncoming traffic on the minor road is required to stop before proceeding. Therefore, the left turn across path/opposite direction (LTAP/OD) crossing-path crash configuration is less relevant. In fact, Preston and Storm (2003b) found that only 4% of crashes were of the LTAP/OD configuration for rural thru-STOP intersections in Minnesota.

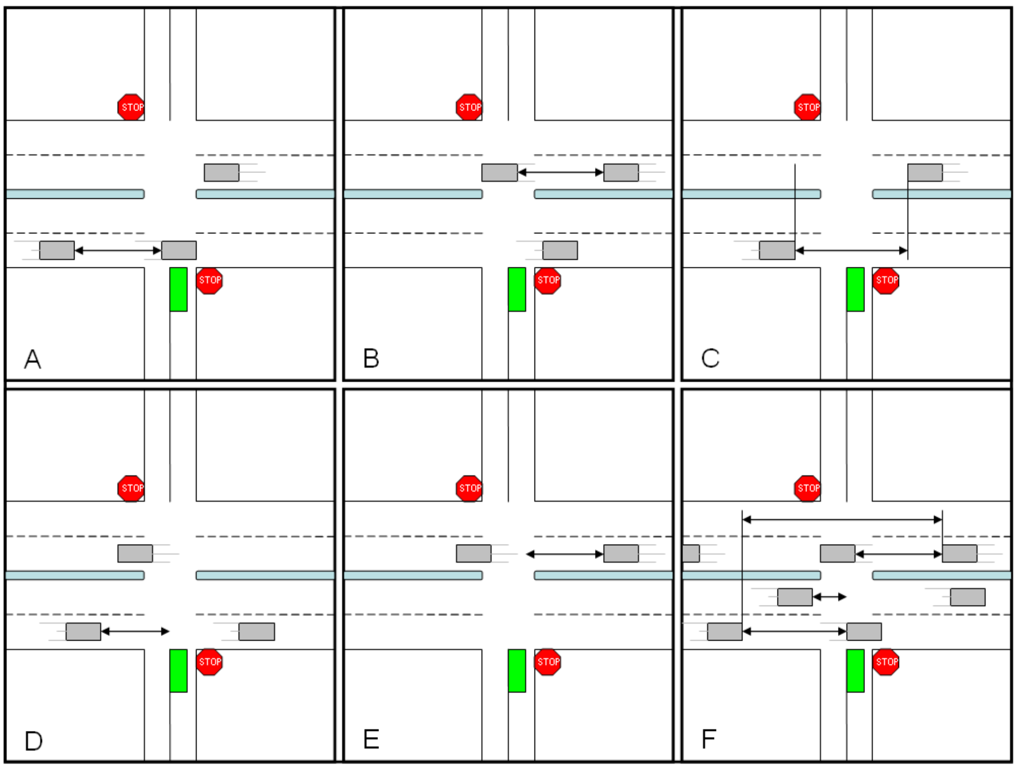


Figure 1.2. Gaps can occur in (A) the near side, (B) far side, and (C) near-far side of the IRC. Similarly, lags also occur in (D) the near side and (E) far side of the IRC. (F) Shows how the number of gaps and lags increase when traffic volume is high.

1.1.3. Safe, Acceptable, and Accepted Gaps

Across the gap acceptance literature reviewed, it was clear that terminology varied. An important source of confusion was the difference between acceptable, accepted, and safe gaps.

An acceptable gap is one that a driver indicates is acceptable for the intended maneuver (crossing or turning). In experimental studies, acceptable gaps are often indicated by verbal responses or overt behaviors (i.e., press the accelerator) that indicate the last safe moment that a driver would proceed across a gap.

An accepted gap is one that is actually accepted and crossed by the driver. In other words, after a driver determines a gap is acceptable, he or she accepts it by crossing and completing the maneuver. Acceptable gaps are not always accepted, since distraction, hesitation, or external events (i.e., sudden appearance of a pedestrian) can delay the maneuver and cause the driver to wait for the next gap in the traffic stream. The minimum accepted gap is also known as the critical gap.

A safe gap is based on an objective model of gap acceptance and is the minimum gap size needed to execute a maneuver without causing a conflict. A conflict occurs when a minor-road vehicle accepts a gap that is smaller than the safe gap and the major-road vehicle cannot decelerate and avoid a collision. The safe gap considers the time drivers need to detect, perceive, and judge gaps (i.e., perception response time or PRT) and the time needed to cross or enter the gap and merge with the major-road traffic (i.e., maneuver time). The safe gap corresponds to the sufficient gap (G) as defined in the original Minnesota proposal (Donath & Shankwitz, 2001).

If the Intersection Decision Support (IDS) system is to advise drivers about the acceptability of gaps, it needs to make recommendations based on safe gaps. This is because accepted and acceptable gaps are subject to driver perceptual and decision-making errors (Lerner et al., 1995 Experiment 1). The safe gap is objective because it is the time needed to safely perform a maneuver and is independent of all other considerations. Put another way, a distinction must be made between the gaps drivers would like to have (acceptable gap), the gaps they are ultimately willing to accept (accepted gap), and the gap needed to safely perform a maneuver (safe gap). Therefore, the factors that influence acceptable or accepted gaps may or may not affect safe gaps. This is discussed more in the section on gap acceptance.

For the purposes of this report, the safe time gap (t_G) is defined in equation 1 (see Lerner et al., 1995 Experiment 1).

- $t_G = t_{PRT} + t_{MT}$ (1)

Where

- t_{PRT} = the time necessary for the driver to detect, perceive, and accept a gap and initiate the maneuver (s)
- t_{MT} = the time required to accelerate to speed and cross the distance needed to clear or enter the major road (s)

In most cases, drivers accept gaps that are larger than the safe gap (Lerner, 1994). This reflects a margin of safety adopted by drivers. However, drivers occasionally choose gaps that are smaller than the safe gap. This occurs when a driver fails to detect a gap, misperceives gap size, underestimates his or her response time, is unaware of important road conditions (i.e., the road is wet), or is unfamiliar with the characteristics of his or her automobile (acceleration capabilities or length). Each possibility is discussed in other sections of this report and in Donath and Shankwitz (2001).

For the purposes of system design, safe gaps will be determined initially by estimating size based on the results of previous research. Afterward, safe gaps will be adjusted and refined as the IDS system is tested in the HumanFIRST driving simulator and deployed in the field. A full explanation of how our simulated gaps were produced can be found in the Methods section of the Evaluation.[FH1]

1.1.4. Section Summary

Older drivers are 65 years of age and older and thru-STOP intersections consist of a highway with two or more lanes that is intersected by a STOP-controlled minor road. A gap is the time or distance between successive vehicles in a traffic stream and a lag is the remaining part of a gap after a driver first arrives at an intersection. An acceptable gap is one that a driver indicates is acceptable for the intended maneuver (crossing or turning). An accepted gap is one that is actually accepted and crossed by a driver. A safe gap is based on an objective model and considers both driver PRT and maneuver time and is the minimum gap size needed to execute a maneuver without causing a conflict. Drivers occasionally choose gaps that are smaller than the safe gap and this occurs when a driver fails to detect a gap, misperceives gap size, underestimates his or her response time, is unaware of important road conditions (i.e., the road is wet), or is unfamiliar with the characteristics of the automobile (acceleration capabilities or length). If the IDS system advises drivers about the acceptability of gaps, it should make the recommendations based on the factors that influence the size of a safe gap.

1.2. Older Driver Intersection Accidents

In the accident literature, it is a common finding that older drivers (65+) have a higher risk of being involved in a collision at an intersection than younger drivers. Staplin and Lyles (1991) analyzed 7,015 crossing accidents at non-signalized (STOP- or yield-controlled) intersections in Michigan from 1986 to 1988. They found that 44% of all accidents and 52% of crossing accidents occurred in rural areas. Crossing accidents accounted for 3.1% of all accidents for drivers 26 and younger, 2.9% for drivers 27 to 55 years of age, 4.6% for drivers 56 to 75 years old and 7.4% for drivers 76 and older. A comparison with all multi-vehicle crashes in the United States showed that involvement ratios were lower for the two youngest groups and higher for the older groups. More specifically, drivers 26 and younger accounted for 41.6% of non-signalized crossing accidents, compared to 44.2% of all crashes in the United States. Drivers 27 to 55 years of age accounted for 35.8% of crossing accidents, but 41.2% of all accidents. Drivers between the ages of 56 and 75 accounted for 15.7% of crossing accidents versus 11.4% of all U.S. crashes. Lastly, adults over the age of 75 accounted for 6.9% of crossing crashes compared to 3.1% of all accidents in the United States. These data suggest older adults are overrepresented in crossing accidents at non-signalized intersections.

Stamatiadis, Taylor, and McKelvey (1991) also compared age differences in crash risk for intersections. They analyzed 135,813 two-vehicle crashes from the Michigan Department of Transportation database for the years 1983 to 1985. They calculated a relative accident involvement ratio by dividing the percentage of accidents in which the at-fault driver was represented by a given age group by the percentage of accidents in which the non-fault driver was represented by the same age group. A ratio less than 1.0 indicated a driver was less likely to be responsible for an accident. Their analysis showed that young drivers (less than 25 years of age) and older drivers (greater than 60 years) had ratios greater than 1.0 (Figure 1.3). Drivers over the age of 75 had the largest ratio, with a value of 1.91. Additionally, among all the accidents examined, an increasing number occurred at rural intersections as the age of the at-fault driver increased.

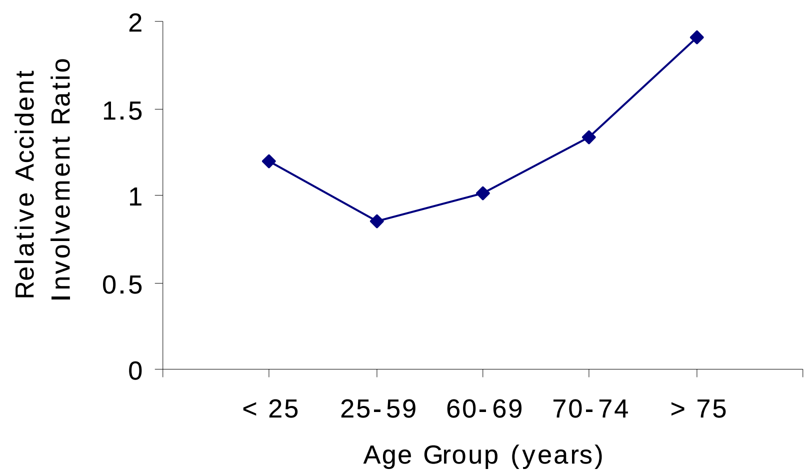


Figure 1.3. Relative accident involvement ratio for all intersection accidents as a function of at-fault driver age (1983 to 1985).

More recent national data found similar results. Preusser, Williams, Ferguson, Ulmer, and Weinstein (1998) analyzed 73,445 fatal accidents from the Fatality Analysis Reporting System (FARS) and the General Estimates System (GES) for the years 1994 and 1995. Approximately 13% of the drivers involved were 65 years of age or older and 30% of older-driver crashes were at intersections. Drivers over 65 years of age were 2.94 to 7.07 times more likely to be in a fatal crash at an intersection compared to drivers aged 40 to 49. The crash risk for older drivers was particularly high at uncontrolled and thru-STOP intersections.

1.2.1. Gaps and Intersection Accidents

In order to successfully complete a thru-STOP intersection maneuver, drivers must correctly detect, perceive, and judge gaps in the major road traffic. Figure 1.4 provides examples of gap acceptance maneuvers at thru-STOP intersections. Accidents resulting from maneuvers of this type are often referred to as crossing-path crashes. There are five common crossing- path accident scenarios at thru-STOP intersections (Figure 1.5). In some states (such as Minnesota), crossing-path accidents are separated into right-angle crashes, left turns into oncoming traffic, and right turns (Table 1.1). These differences are important when comparing Minnesota crash statistics to other data sources.

One of the most common driver citations for gap acceptance crashes is failure to yield. In the Stamatiadis et al. (1991) analysis mentioned earlier, researchers found that although rear-end accidents were the most common crash configuration overall, older drivers were over involved in right-angle accidents. Right-angle crashes are a configuration that requires drivers to detect, perceive, and accept gaps (Preston & Storm, 2003b). With regard to violations, drivers 60 to 69 years of age and those over 75 were more likely to have committed a violation that contributed to the accident. For all elderly drivers (greater than 60 years), the leading violations were failure to yield the right of way and having followed too close. Both violations were attributed to older driver problems with gap perception in a recent literature review (Staplin et al., 1998b).

Failure to yield was also cited in the Staplin and Lyles (1991) analysis of 7,015 crossing accidents at Michigan non-signalized intersections. Ninety to 95% of all violations were for failure to yield the right of way and citations increased for drivers over the age of 55. More recent data from the 1998 General Estimates System (GES) also found that failure to yield was the most common citation for crossing-path accidents (Najm, Smith, J. & Smith, D., 2001). It was cited in 17% of straight crossing-path (SCP) crashes, 21% of left turn across path/opposite direction (LTAP/OD) crashes, 18% of left turn across path/lateral direction (LTAP/LD) and left turn into path (LTIP) crashes, and 17% of right turn into path (RTIP) at STOP-controlled intersections. Only 6% of drivers were charged with running the STOP sign. Although several factors contribute to the failure-to-yield violation, the most relevant for this project are problems with gap detection, perception, or acceptance. This occurs when the at-fault driver crosses the path of a vehicle that could not stop or swerve to avoid the collision (Stamatiadis et al., 1991; Staplin et al., 1998b).

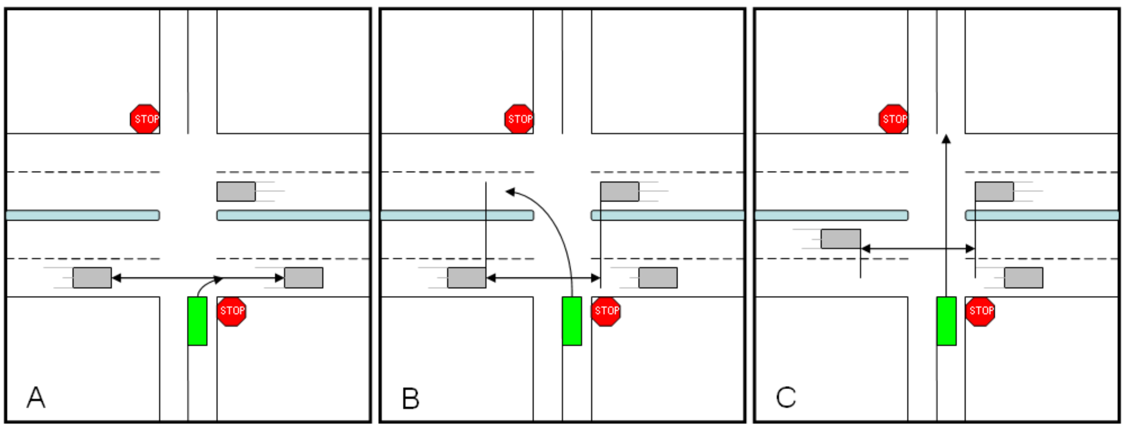


Figure 1.4. Common gap acceptance maneuvers at thru-STOP intersections including (A) right turns, (B) left turns, and (C) crossing maneuvers (adapted from Caird & Hancock, 2002).

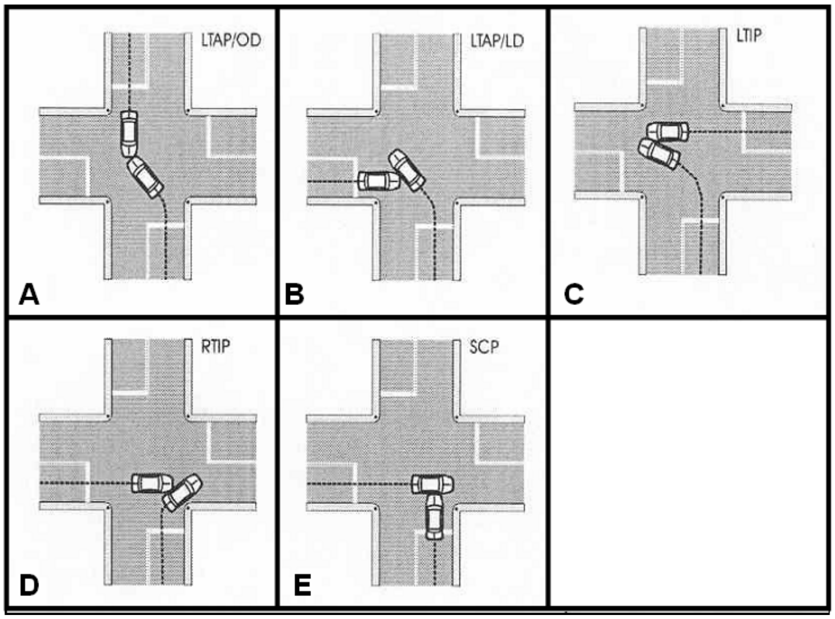


Figure 1.5. Common crossing-path crash patterns at thru-STOP intersections including (A) left turn across path/opposite direction, (B) left turn across path/lateral direction, (C) left turn into path, (D) right turn into path, and (E) straight crossing path.

Table 1.1. Mapping between Minnesota crash types and those used in other studies (Preston & Storm, 2003b).

Minnesota Crash Type	**Crossing-path Crash Type**
Right angle	Left turn across path/lateral direction (LTAP/LD)
	Left turn into path (LTIP)
	Straight crossing path (SCP)
Left turn into oncoming traffic	Left turn across path/opposite direction (LATP/OD)
Right turn into cross street	Right turn into path (RTIP)

Problems with gaps also affect drivers at rural intersections in Minnesota. Preston and Storm (2003a) analyzed 2,296 crashes at 1,604 rural thru-STOP intersections. They found that 33% of the collisions were right-angle crashes and these crashes accounted for 71% of all fatalities. Fifty-seven percent of drivers stopped before moving into the intersection and the authors concluded that the crash occurred either because the driver misjudged the size of the gap (faulty perception) or because the driver became so impatient that he or she drove into an inappropriately small gap (faulty decision making). An alternate explanation is that drivers did not see the leading and trailing vehicles and this led to a problem detecting the gap.

Comparable results were obtained in a recent safety audit of rural Trunk Highway 52 in Minnesota (Preston & Rasmussen, 2002). Results showed that older drivers accounted for 39% of the crashes in this rural area compared to the statewide average of 14.1%. In more than 90% of the crashes, it was noted that the older driver was "responsible" for the accident.

Problems with gaps are sometimes limited to particular intersections. Preston and Storm (2003b) found in their analysis of intersections in Minnesota that older adults were overrepresented in accidents at the thru-STOP intersection of US 52 and minor road CSAH 9. At-fault drivers over the age of 64 accounted for 33% of crashes, compared to other intersections (8% of accidents at US 52 and CR 43 and less than 1% of accidents at MN 65 and 177th Ave). Most of the accidents at US 52 and CSAH 9 were right-angle crashes (65%) and approximately 87% of the right-angle accidents occurred after the driver stopped at the control device. This suggests that in most cases, the crash did not occur because of a failure to detect the intersection or identify the STOP sign. Instead drivers (and older drivers in particular) experienced a problem with gap detection, perception, or acceptance after complying with the control device.

2. Task Analysis

To provide a basis for supporting safe driving, it is necessary to understand the driving task and the information requirements producing error-free driving. Understanding user tasks is part of the foundation of human factors engineering and user-centered design. Knowledge of driver tasks at rural intersections provides a framework for synthesizing and interpreting the results of the literature review. The task analysis also guides design decisions by identifying critical tasks and highlights the information needed to complete each task successfully.

2.1. Task Analysis

Driving is a complex interaction between the perceptual, cognitive, and motor systems of the driver. It requires the application of skills, rules, and knowledge but also information processing and decision making. Therefore, task analyses that describe rural intersection negotiation in strictly behavioral terms are of limited value. Table 2.1 describes intersection negotiation from a perceptual and cognitive point of view, as well as behavioral. Because previous analyses examined broader aspects of gap- acceptance tasks (Caird & Hancock, 2002; Staplin et al., 1998b) or emphasized specific maneuvers (Chovan et al., 1994a, 1994b; Tijerina, Chovan, Pierowicz & Hendricks, 1994), a task analysis was conducted to look specifically at rural thru-STOP intersection negotiation and the associated left-turn, crossing, and right-turn maneuvers. Tasks are listed in an approximate temporal order, but there may be some overlap between the subtasks. It is these tasks that must be supported by the IDS functions.

Table 2.1. Task analysis for rural intersection negotiation (continued on next page).

Task Goal	Task	Sub-Task(s)
Approach intersection	A. Detect intersection	A1. Detect intersection features such as signs, signals, pavement markings, and curb edges
	B. Decelerate	B1. Apply brake B2. Apply adequate braking force
	C. Enter correct lane (if required)	C1. Determine if already in desired lane C2. If not, scan rearview/side mirrors and/or shoulder for conflicting vehicle C3. If vehicle present, detect and estimate gap, accept or reject gap, and change lane
	D. Signal if intending to turn	D1. Apply correct signal for intended maneuver (left, right) D2. Apply signal well in advance of intersection

Table 2.1. Task analysis for rural intersection negotiation (continued from previous page).

Task Goal	**Task**	**Sub-Task(s)**
Assess safety of entering intersection	E. Detect traffic-control device (signs or signals)	E1. Detect signs or signals (if present)
	F. Interpret traffic-control device	F1. Understand sign or signal F2. Be knowledgeable of right-of-way rules F3. React appropriately and stop or slow down as needed
	G. Monitor lead vehicle (if present)	G1. Observe path of lead vehicle and anticipate stops G2. Estimate speed, distance, gap G3. Adjust headway as needed
Assess safety of entering intersection (cont)	H. Detect traffic and pedestrians	H1. Detect traffic and/or pedestrians H2. Yield as required
	I. Detect, evaluate, and monitor gaps in traffic	I1. Detect gap I2. Estimate speed, distance, arrival time I3. Perceive gap size I4. Evaluate whether gap is acceptable I5. Monitor changes in gap size
Traverse intersection	J. Accept gap and complete maneuver	J1. Determine when to initiate maneuver J2. Check pathway for obstructions J3. Yield and adjust velocity as required J4. If turning, turn steering wheel, accelerate, and adjust speed to traffic J5. If straight, accelerate
	K. Continue to monitor traffic and control device until intersection is cleared	K1. Monitor traffic, pedestrians, or lights K2. Anticipate light changes (if relevant) and sudden stops, accelerations, or violations by other traffic K3. Yield or slow down as required

2.2. Driver Example Case

To better illustrate the task sequence listed in Table 2.1, consider the following example:

> A 65-year-old male driver intends to turn left at an icy rural expressway thru-STOP intersection with a large, 40-ft median. He detects the intersection by locating both the traffic sign (STOP sign) as well as changes in the pavement markings (stop line, turn lane markings). The driver slows, applies his left turn signal, checks his mirrors for conflicting vehicles, and enters the left turn lane. The driver interprets the STOP sign and comes to a stop just behind the stop line. He detects approaching near-side and far-side vehicles in his peripheral vision. He turns his head and glances to the left and right to locate the cross traffic and detect the available gaps. The driver perceives the size of each gap by estimating the approach speed, distance, and/or arrival of the near-side and far-side vehicles. He monitors the changing size of the gap resulting from the vehicles approaching on the near-side and far-side traffic streams. He decides the first available near gap is too small considering the icy roads. The driver detects and locates other near-side vehicles farther down in the traffic stream. He detects and perceives an approaching gap and decides it is acceptable for crossing. He monitors the gap as it approaches and decides when to initiate his maneuver. Just prior to moving, the driver turns his head left and right and searches the intersection to ensure his path is free of obstacles. When the gap arrives, he accepts it by accelerating and proceeds to stop at the median crossover. He turns his head and glances to the right and perceives an approaching far-side gap and decides it is acceptable for crossing. He monitors the gap as it approaches and decides when to initiate his turn maneuver. After the lead vehicle passes, he accelerates and turns the steering wheel counterclockwise and merges with the far-side traffic stream.

This example is illustrative because it shows how the task analysis can be applied to older drivers at thru-STOP intersections. This scenario also highlights the difference between acceptable, accepted, and rejected gaps. The scenario further emphasizes the fact that drivers could detect and monitor multiple gaps when traffic volume is high. Lastly, the scenario suggests that when medians are large enough to store a vehicle, drivers may detect and perceive gaps separately for near- and far-side streams, and as a result, make multiple gap-acceptance decisions.

2.3. Information Processing

From the details presented in Table 2.1 and the example, it is clear that negotiating an intersection is an on-going information processing activity. To capture this process, Figure 2.1 presents a three-stage model of information processing that includes perception, cognition, and action. Activity at the perceptual stage includes the visual processes needed to detect, discriminate, and identify stimuli at an intersection. Drivers at thru-STOP intersections must detect other vehicles on the major road before gap detection and perception occurs.

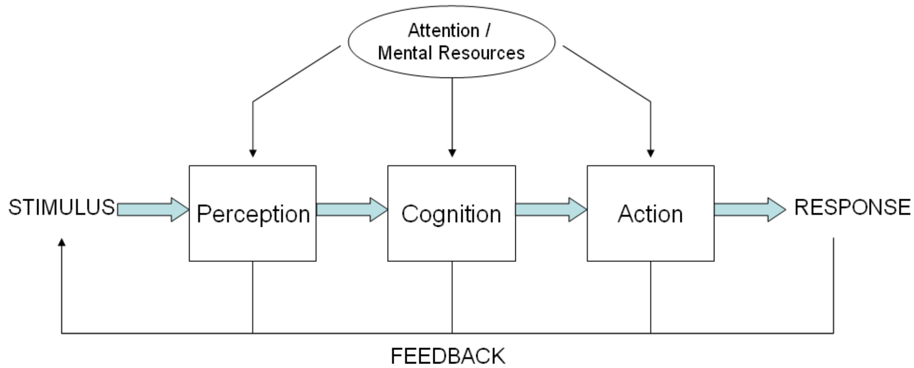


Figure 2.1. A simplified three-stage information processing model (adapted from Wickens & Hollands, 2000).

Throughout this report, an emphasis is placed on visual perception. This is because most estimates suggest 90% of the information a driver perceives is visual (Hills, 1980). Cognitive processes include retrieving information from memory and decision making. For example, drivers approaching a thru-STOP intersection must remember they need to stop before proceeding as well as consider the factors that influence a gap-acceptance decision. At the last stage, an overt action is selected, programmed and executed. For example, after a driver has decided a gap is acceptable, he or she must accept it by completing the desired maneuver. This involves moving one's foot from the brake to the accelerator and may also involve turning the steering wheel.

Each stage in the information processing model is mediated by attention. For a complex activity like driving, attention is divided among all three stages and the allocation of resources is constantly changing (Wickens & Hollands, 2000). Attention applied to the perceptual stage can help identify or filter irrelevant objects from future consideration. Attention at the cognitive stage can limit the speed that a driver makes turn decisions. Lastly, attention at the action stage can affect the speed and accuracy at which the complex motor responses occur.

An important characteristic of this simplified information processing model is that the results of actions are sensed by a feedback loop. The feedback loop can be triggered at any processing stage, and thus emphasizes the continuous flow of information. It should also be noted that the boundaries of the three stages are not as clearly defined as the model implies. In some situations, simultaneous activity occurs at each stage in the model. This further emphasizes the need to dynamically allocate attention while driving. For example, as a driver arrives at the intersection, they are engaged in stopping the vehicle (action), but may simultaneously begin scanning for oncoming traffic. Identifying vehicles (perception) and evaluating gaps (cognition) may continue repeatedly depending on the flow of traffic, until a driver finally perceives and identifies an appropriate gap and is able to cross the intersection (action).

Table 2.2 identifies the information processes drivers use to negotiate intersections (based on Dewar, Olson & Alexander, 2002; Staplin et al., 1998b) and provides information through the successful completion of tasks shown in Table 2.1. This information is important for showing how multiple processes bear on the successful completion of each driver task. In addition, a successful IDS display will support these critical processes.

Table 2.2. Information processes required to negotiate an intersection.

Processing Stage	Process Involved	Role in Intersection Negotiation
Perception	- Visual search (accommodation, eye movements)	- Move eyes to scan driving scene - Move eyes from in-vehicle displays to objects in environment - Move eyes to focus important objects on fovea
	- Spatial vision (static and dynamic acuity, contrast sensitivity)	- Detect control devices, navigation signs, traffic, gaps, and pedestrians while moving and stopped - Read in-vehicle displays and road signs
	- Depth and motion perception (angular movement, movement in depth)	- Estimate speed and distance of self and others - Perceive gaps
	- Color vision	- Detect and perceive traffic sign or signal state
Cognition	- Long-term memory	- Retrieve learned behavior regarding traffic rules - Retrieve information about route and navigation choices
	- Working memory	- Organize and integrate information for decision making
Action	- Response selection	- Select desired response from available alternatives
	- Response preparation	- Prepare motor program for execution
	- Response execution	- Execute motor program by moving the body
Attention	- Divided attention	- Divide attention between perception, cognition, and action stages -Divide attention between central and peripheral vision
	- Selective attention	- Discriminate and attend to the most important objects during perception - Switch attention between information processing stages as needed
	- Sustained attention	- Maintain vigilance at all stages in anticipation of hazards

2.4. Driver Errors

This section describes driver errors commonly made when negotiating an intersection. Information on driver errors is helpful for understanding the full range of contributing factors to rural intersection accidents and also in identifying how the IDS system may reduce, eliminate, or introduce new driver errors.

Several recent reviews have shown that a number of driver errors precipitate crashes at intersections (Caird & Hancock, 2002; Chovan, Tijerina, Everson, Pierowicz & Hendricks, 1994a; Chovan, Tijerina, Pierowicz & Hendricks, 1994b; Staplin, Lococo, McKnight, McKnight, & Odenheimer, 1998b). These reviews relied largely on accident analyses for information on pre-crash maneuvers, driver behavioral and cognitive factors, and problematic intersection features that contributed to the crash. In some cases, supplementary data was also gathered from task analyses and self-reported problems. Although none of the reviews specifically evaluated rural intersections, they help identify possible errors and probable consequences.

Table 2.3 shows a mapping between driver tasks, possible errors, and probable outcomes for rural intersection maneuvers. More general factors that contribute to intersection accidents include failure to compensate for weather-related problems and road conditions; driver impairment due to age, illness, drugs, fatigue, or alcohol; driver distraction by internal or external factors; and driver impatience or hurry (Caird & Hancock, 2002). These errors have the potential to affect all driver tasks at rural intersections.

Table 2.3. Driver tasks at rural intersections, possible errors and probable outcomes (continued on next page).

Task	**Possible Errors**	**Probable Outcome**
A. Detect intersection	Failure to detect intersection	Driver may miss intersection Driver may be delayed in completing subsequent tasks on approach
B. Decelerate	Failure to slow adequately before entering intersection	Driver may not have time to process intersection information completely Driver may slow suddenly to compensate
C. Enter correct lane (if required)	Failure to change lanes properly	Driver may turn from wrong lane Driver may make a lane change without checking for conflicting vehicles Driver may make a last minute lane change
D. Signal if intending to turn	Failure to signal or wrong signal	Other drivers may be surprised and have to adjust to unexpected maneuvers
E. Detect traffic-control device (signs or signals)	Failure to detect traffic-control device Failure to obey traffic-control device	Driver may fail to stop at intersection Driver may deliberately violate traffic-control device
F. Interpret traffic-control device	Failure to comprehend traffic-control device	Driver may violate right-of-way rules

Table 2.3. Driver tasks at rural intersections, possible errors and probable outcomes (continued from previous page).

Task	Possible Errors	Probable Outcome
G. Monitor lead vehicles (if present)	Failure to check sight lines obscured by lead vehicle Failure to estimate velocity, distance, or gap to lead vehicle	Driver may fail to detect other vehicles or pedestrians Driver might misperceive gap size
H. Detect traffic and pedestrians	Failure to detect traffic and pedestrians Failure to anticipate actions or intentions of other drivers and pedestrians	Driver might complete maneuver without having a clear pathway Driver may react suddenly (i.e., stop, accelerate, steer) to unexpected behavior
I. Detect, evaluate, and monitor gaps in traffic	Failure to estimate velocity, distance, or gap between other vehicles Failure to consider all factors when accepting gaps	Driver might misperceive gap size Driver might overestimate his or her capabilities or misjudge characteristics of his or her vehicle
J. Accept gap and complete maneuver	Failure to execute maneuver properly	Driver might hesitate Driver might turn too fast or too slow Driver might choose wrong trajectory or path Driver might stop before turn is completed
K. Continue to monitor traffic and signal until the intersection is cleared	Failure to clear intersection	Driver might be stranded in intersection during yellow (or red) phase

2.5. Older Driver Errors

Given that certain declines in psychological functioning may be evident with increased old age (see Appendix A) some errors are more likely to be committed by older drivers. In their review of left-turn and gap-acceptance crashes, Caird and Hancock (2002) cited a study that showed older drivers had problems understanding right-of-way rules and traffic-control devices. They also found that older drivers were more likely to suffer from inattention and fail to stop for traffic lights and STOP signs. Perceptual errors, such as a failure to judge the speed, distance, or gap between two vehicles, were also common. Problems with divided attention, visual search, narrowing of the useful field of view (UFOV), attention switching, and generalized slowing were cited as important general considerations for older drivers.

Other reviews have also found that older adults commit certain types of driver errors. Staplin et al. (1998b) analyzed accident data and identified more than 50 unsafe driving behaviors performed by older drivers at intersections. They had two experts assess the likelihood that older drivers would make each error and also the probability that the error would result in a crash. The ratings for error likelihood were based on the known tendencies of older drivers, the effect of intersection complexity, approach speed, and traffic volumes on older driver workload, and the probability that the error would be committed. Considerations for rating crash probability included traffic density and speeds, the extent to which the error would result in a deviation of path or speed, the ability of other drivers to compensate, estimates of time-to-collision, and the likelihood that other drivers would make a maneuver that could contribute to a crash. Two five-point Likert scales were used and total criticality ratings were obtained by multiplying the error and crash likelihood ratings. The Likert scale values corresponded to the following: 1 = < 1%, 2 = 1–5%, 3 = 6–25%, 4 = 26–50%, 5 = > 50%. From the total list of potential errors, those for thru-STOP intersections have been extracted in Table 2.4. Although the errors considered do not match perfectly with those listed in Table 2.3, an approximate mapping helps to identify the mistakes most likely to be made by older drivers at rural thru-STOP intersections.

Many of the errors identified in the expert review were confirmed in a follow-up study of older drivers at urban intersections. Staplin, Gish, Decina, Lococo & McKnight (1998) had 83 older adults drive a standard urban driving route and a route in their own neighborhood while accompanied by a driving examiner. Twenty-one participants did not complete the standard route because the examiner ended the test for safety reasons. An additional 11 participants were excluded from the neighborhood route because of poor performance on the standard course. Errors were collected and analyzed from video footage and examiner scoring sheets. The video-based analysis expressed the probability each error occurred in relation to the total number of opportunities to commit an error. Examiner errors were based on the number of drivers who made each error. Table 2.5 lists the 20 most common perception and maneuver errors from the video analysis. Table 2.6 lists the 20 most common driver errors noted on the examiner scoring sheets.

Table 2.4. Expert estimates of error probability, crash likelihood, and criticality for older driver at thru-STOP intersections (from Staplin et al., 1998b). Two five-point Likert scales were used and total criticality ratings were obtained by multiplying the average error and crash likelihood ratings.

Older Driver Error	**Error Likelihood**	**Likelihood of Crash**	**Total Criticality**	**Driver Errors from Table 4**
- Slowing suddenly due to inability to perceive lane assignments or understand destination signs quickly	3	2	6	- Failure to slow adequately before entering intersection - Failure to change lanes properly - Failure to comprehend traffic-control device
- Conflict with pedestrian crossing from the right due to limitations in attention sharing and peripheral vision	3	2	6	- Failure to detect traffic and pedestrians
- Entering path of vehicle from left or right due to difficulty in gap estimation	3 (left) 2 (right)	3 2	9 4	- Failure to estimate velocity, distance, or gap between other vehicles
- Beginning left turn too early and cutting across apex due to effort required to turn steering wheel	2	1	2	- Failure to execute maneuver properly
- Swinging wide and encroaching upon a far lane due to effort involved in turning steering wheel and limitations in attention sharing	2	2	4	
- Dragging right rear wheel across curb/sidewalk by initiating turn early to reduce effort involved in turning steering wheel and due to limitations in attention sharing	2	1	2	

Table 2.5. Observed probability of occurrence for perception and maneuver errors as a function of the standard and neighborhood routes (adapted from Staplin et al., 1998a).

Older Driver Errors	**Exam Route**	
	Standard	Home
Perception Errors		
Fails to observe behind within 5 s prior to beginning deceleration for intersection	0.87	0.96
Fails to look to the side while in intersection	0.75	0.75
Fails to check right mirror within 5 s prior to right lane change	0.73	0.77
Fails to look to the sides during approach to intersection	0.36	0.44
Fails to check right blind spot within 5 s prior to right lane change	0.35	0.33
Fails to check left mirror within 5 s prior to left lane change	0.31	0.35
Fails to check either right mirror or right blind spot	0.30	0.23
Fails to check left blind spot within 5 s prior to left lane change	0.29	0.37
Fails to check to the left (upstream) within 5 s prior to entering intersection when turning right from a STOP or YIELD sign (to check for potential conflict vehicles)	0.17	0.15
Fails to check to the right (downstream) within 5 s prior to entering intersection when turning right from a STOP or YIELD sign (to check for pedestrians or queue)	0.15	0.09
Fails to check either left mirror or left blind spot	0.07	0.10
Maneuver Errors		
Infringes on others' right of way when changing lanes	0.90	0.57
When lane change is necessary to cross intersection, changes lanes too close to intersection	0.19	0.12
Deceleration greater than -.3 g (abrupt or panic stop)	0.15	0.29
Rejects a safe gap (> 10 s)	0.13	0.06
Lateral acceleration greater than +/- .3 g during turns	0.10	0.13
Changes lanes prematurely in anticipation of left turn	0.08	0.10
Acceleration greater than + .3 g	0.08	0.13
Enters far lane during turn	0.04	0.06
Swings wide while turning	0.02	0.03

Table 2.6. Percent of sample committing perception and maneuver errors as a function of standard and neighborhood routes (adapted from Staplin et al., 1998a).

Older Driver Errors	**Exam Route**	
	Standard	**Home**
Perception Errors		
Failure to look left and right at through intersection (stares straight ahead)	76%	85%
Failure to check traffic when changing lanes or merging	69%	57%
Failure to check traffic when pulling to and from curb	63%	62%
Failure to check traffic on approach to turns	54%	43%
Maneuver Errors		
Failure to use turn signals for turning, lane changing, or merging	65%	20%
Failure to come to a complete stop at STOP sign	53%	57%
Turns too wide or too short	46%	26%
Stops over limit lines	45%	28%
Stops for no reason	39%	26%
Consistently drives too slow	24%	5%
Brakes before changing lanes or at other unnecessary time	19%	8%
Struck object (curb, median)	18%	0%
Stopped at STOP AHEAD sign or pavement marking	13%	2%
Straddles lanes or drifts in and out of lanes	10%	15%
Drives on shoulder or parking/bike lanes, confusing other drivers	10%	3%
Completes left turn in opposing traffic lane (wrong side of street)	9%	7%
Infringes on others right of way when changing lanes	8%	23%
Unknown Error Type		
Unsafe left turn gap acceptance	22%	15%
Unsafe right turn gap acceptance	16%	8%
Near miss (pedestrian/car) other than during gap acceptance	16%	20%

2.5.1. Implications

An intersection support system will not alleviate all driver errors at intersections. This is because infrastructure solutions cannot alter driver behavior with regard to impairment, illness, or fatigue. However, systems can be designed with these factors in mind and may be able to reduce or eliminate the associated error types. Some consideration should also be directed toward studying how the system changes, masks or worsens existing driver errors. For example, drivers approaching an intersection may be distracted by the IDS display, potentially increasing the likelihood that a signal or sign violation would occur. Table 2.7 lists each error and design implications for the IDS system. This information is helpful for understanding potential consequences of the design and effectiveness of the system. The errors in italics are the ones with the greatest possible ramifications for the system.

Table 2.7. Driver errors and possible implications for the IDS system (continued on next page).

Driver Error	**Possible Implication(s)**
Failure to detect intersection	- The IDS system will only be effective if drivers detect the intersection - The IDS display may be another cue to indicate the presence of an intersection
Failure to slow adequately before entering intersection	- Drivers approaching at high speeds may have less time to interpret the IDS display (also see visual search section)
Failure to change lanes properly	- The viewing angle from each lane should be considered when designing the IDS display - Turns from the wrong lane may increase maneuver times
Failure to signal or wrong signal	- The system should not infer maneuver type from the use of signals since the wrong signal can be applied
Failure to detect traffic-control device	- The IDS system will only be effective if the driver detects the display - Supplementary signage may be needed - The IDS display may distract drivers on approach
Failure to obey traffic-control device	- This may increase the probability that the IDS display is ignored
Failure to comprehend traffic-control device	- The information presented in the display must be redundant with the control device - Overreliance on the IDS system could cause drivers to ignore traffic-control devices over time
Failure to check sight lines obscured by lead vehicle	- It is unknown how drivers will know whether the information presented in the display applies to a lead vehicle or themselves

Table 2.7. Driver errors and possible implications for the IDS system (continued from previous page).

Driver Error	**Possible Implication(s)**
Failure to estimate velocity, distance, or gap to lead vehicle	- This error has unclear implications
Failure to detect traffic and pedestrians	- If vehicles are not detected, gaps are not detected - The IDS system may be able to draw attention to vehicles outside the driver's field of view - It is not known how the presence of pedestrians influences the IDS system - Depending on where the IDS display is located, sight lines may be obscured
Failure to anticipate actions or intentions of other drivers and pedestrians	- The IDS system may be able to warn drivers of potential violations by other intersection users
Failure to estimate velocity, distance, or gap between other vehicles	- The IDS system may be able to highlight vehicles approaching at speeds greater than the posted limit - The IDS system may be able to highlight gaps in the traffic stream
Failure to consider all factors when accepting gaps	- The IDS system may be able to recommend gaps so drivers do not have to make the gap-acceptance decision
Failure to execute maneuver properly	- Problems with steering and acceleration will increase maneuver time
Failure to clear intersection	- The IDS system should not recommend gaps until the previous vehicle has cleared the intersection
Failure to compensate for weather-related problems and road conditions	- The IDS display must be visible under conditions of poor visibility - The IDS system should take into consideration road conditions when determining safe gaps
Driver impairment due to age, illness, fatigue, alcohol or drugs	- Impairment due to age is particularly relevant when designing the IDS display - It is unclear whether adjustments will be made as a function of other sources of impairment
Driver inattention or distraction	- Drivers may be less likely to notice the IDS display - Supplementary signage may be needed

Driver impatience or hurry	- Impatience or hurry might result in smaller gaps being accepted - It is unclear how the IDS system would recognize or detect driver impatience or hurry

2.5.2. Driver Error Summary

For each of the tasks identified in the task analysis, drivers make errors. Some thought should also go into studying how the IDS system may introduce new driver errors or exacerbate existing problems. Older drivers are more likely to make specific errors at intersections (Caird & Hancock, 2002; Staplin et al., 1998a, 1998b). In general, perception errors were more common than maneuver errors. Perception errors included problems detecting other vehicles and pedestrians, a failure to check mirrors and blind spots, and difficulty understanding traffic signs. Maneuver errors were problems changing lanes, slowing and braking properly, and difficulty completing maneuvers. Older drivers also accepted unsafe gaps and the reasons for this error could be both perceptual and maneuver related. This is discussed more in the next section.

To summarize, the possible errors drivers could make at rural intersections include:

- Failure to detect intersection
- Failure to slow adequately before entering intersection (older driver error)
- Failure to change lanes properly (older driver error)
- Failure to signal or wrong signal (older driver error)
- Failure to detect traffic-control device (older driver error)
- Failure to obey traffic-control device
- Failure to comprehend traffic-control device (older driver error)
- Failure to check sight lines obscured by lead vehicle
- Failure to estimate velocity, distance, or gap to lead vehicle (older driver error)
- Failure to detect traffic and pedestrians (older driver error)
- Failure to anticipate actions or intentions of other drivers and pedestrians
- Failure to estimate velocity, distance, or gap between other vehicles (older driver error)
- Failure to consider all factors when accepting gaps
- Failure to execute maneuver properly (older driver error)
- Failure to clear intersection

A rural IDS system in Minnesota can provide information that guides drivers through the intersection negotiation process. Consistent with the original infrastructure consortium proposal (Donath & Shankwitz, 2001), this report and evaluation emphasizes gaps, older drivers, and rural thru-STOP intersections. This is because older drivers have a high accident risk at rural thru-STOP intersections due to contributing problems with gap detection, perception, and acceptance. Furthermore, this information was used to design, implement, and analyze driver performance at a simulated version of the problem intersection. Results from this analysis were also used to propose a decision support system to be implemented at the intersection.

3. Design Process

To this point we have discussed the specific tasks and information processes an IDS system should support. To be supportive, IDS can convey different types of information in a number of forms. Determining what information to present as well as when and how to present it can be a challenging design problem. Ecological Interface Design (EID) can help by identifying the information content and also the optimal form the information should take (Lee et al., 2003). EID uses the abstraction hierarchy (AH) and the skills, rules, knowledge (SRK) framework to identify environment and operator constraints that are relevant for display design (Figure 3.1).

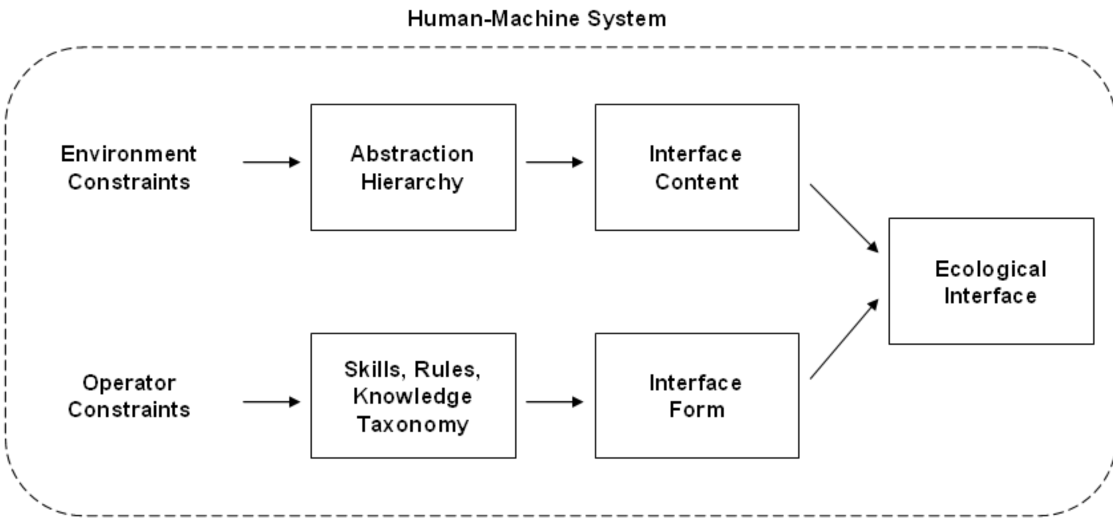


Figure 3.1. The analysis of environment and operator constraints in human-machine systems and the overall process of ecological interface design (adapted from Lee et al., 2003)

Constraints govern the manner in which the human-machine (operator and the environment) system interrelates. Constraints can be either limiting conditions (i.e., weather) or overall system goals (i.e., safety). The AH identifies environment constraints and the information elements that can be used to convey the constraints to operators. In this respect, the AH helps identify the information content that could be presented in an ecological interface. The SRK taxonomy identifies operator constraints by focusing on basic categories of human performance. This analysis helps ensure the information content is represented in a form that is consistent with operator performance and information processing limitations (Lee et al., 2003).

The AH is a framework that helps identify the environment constraints for an ecological interface (Lee et al., 2003; Rasmussen, 1983; Vicente, 2002). The AH determines the interface content because the environment constraints are made visible to the operator via one or more information elements in the display. In an AH environment, constraints are categorized into five levels of abstraction and three levels of detail. Means-end relationships connect each level of abstraction and whole-part relationships describe how constraints are connected at the detail level. The *functional purpose* level describes underlying goals of the system, such as operator (or driver) efficiency. The *abstract function* level lists constraints and principles that need to be satisfied to achieve the goals identified at the functional purpose level. The balance of performance (i.e., average speed) and cost (i.e., mileage) is an abstract constraint that affects the functional goal of operator efficiency. The *general function* level identifies standard processes and features that are the means to influence the constraints at the abstract level. Examples of constraints at this level include general traffic dynamics, such as elasticity and other driver intent, both of which affect the performance and cost balance and overall efficiency. Physical elements of the system, including their relationship to each other and the environment, are provided at the *physical function* level of analysis. This could include the road type and weather conditions. Lastly, *physical form* is where the appearance, anatomy, form, location, etc. of specific elements identified in the physical function level are listed. A stalled car in the left lane of I-494 just before the I-35W interchange would be an example of a constraint at the physical form level.

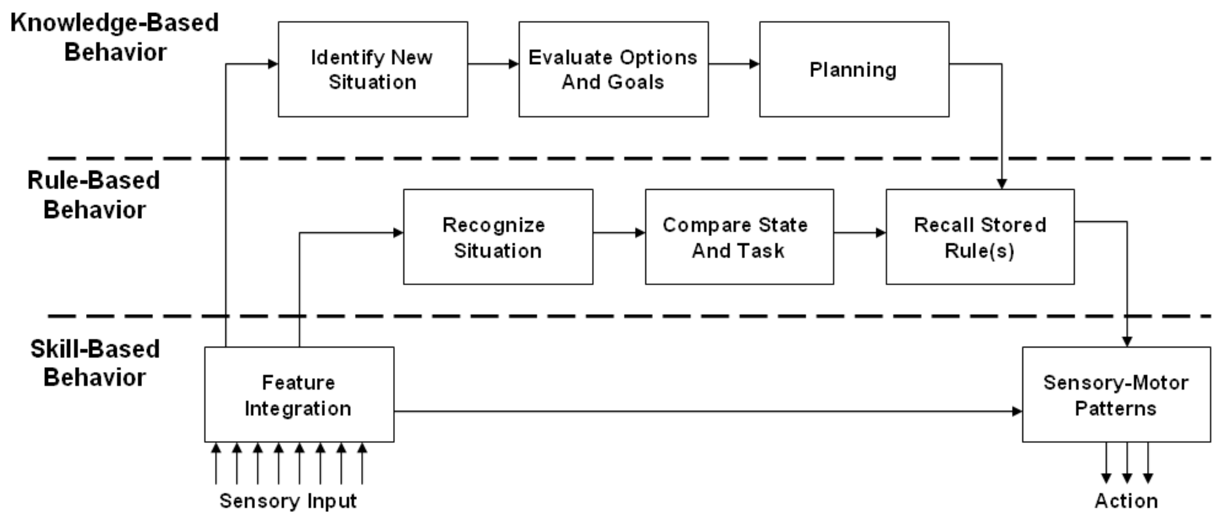


Figure 3.2. The skills, rules, knowledge (SRK) taxonomy of operator performance (adapted from Lee et al., 2003; Rasmussen, 1986)

The SRK taxonomy (Figure 3.2) describes three levels at which operators function (Rasmussen, 1983). At the *skill level*, operators integrate sensory input and identify features that trigger automatic sensory-motor patterns. The result is a smooth interaction with the environment that develops with practice and functions without conscious control. At the *rule level*, operators are limited to stored rules or procedures that can be activated from past experience. Rule-based behavior requires operators to recognize the situation as something they have encountered before, compare the current state of the world to their desired task and goals, and select the appropriate rule from memory. Lastly, at the *knowledge level*, operators have no prior knowledge of the situation and must rely on problem solving. Operators who exhibit knowledge-based behavior must identify the situation as novel, evaluate their available options and goals, and develop a plan based on their current understanding of the system (i.e., their mental model). Plans often consist of applying existing rules or combining rules using a trial-and-error approach. As a result, interaction at the knowledge level is slow, requires considerable effort, and is error prone.

Understanding how operators perform in different situations is an important constraint that can determine interface form. For instance, an in-vehicle interface might provide tactile feedback through the driver's seat to inform the driver of potential hazards in the environment. This direct feedback could help trigger an automatic braking response at the skill level. A different interface might provide information to help operators select an appropriate rule. For example, an IDS system could draw attention to approach vehicle speed and help drivers select an acceptable gap based on a rule that considers speed as opposed to distance. Lastly, an interface could provide information at multiple levels of abstraction to allow the operator the flexibility to solve problems at the knowledge level. An in-vehicle display could allow drivers to process information about specific vehicles (i.e., physical form level) as well as overall driving safety and efficiency (i.e., functional purpose level).

Three design principles are illustrated in the examples described above:

- *Skill level*: Operators should be able to interact with an interface directly.
- *Rule level*: There should be a clear and consistent mapping between the constraints identified in the AH and the perceptual elements in the display.
- *Knowledge level*: The system should represent information at all levels of abstraction.

If an interface violates any one of the three principles, it would not be considered a "pure" example of EID (Vicente, 2002). In other words, an interface is not ecological if (a) there is no direct manipulation, (b) the perceptual information does not map onto the constraints of the system, or (c) not all the information identified in the AH is represented in the display.

EID is different from traditional task analysis because it focuses on the entire work domain, but emphasizes environment constraints. EID also supports operator tasks at all three levels of performance and provides information at more than one level of abstraction. In contrast, traditional task analysis focuses only on known tasks and therefore may not identify information elements that operators need when they encounter novel situations. Traditional analyses also often represent information at only one level of detail. Therefore, EID encourages skill-based and rule-based performance but also supports more effortful knowledge-based performance when needed (Vicente, 2002). This could result in a more detailed and accurate internal representation of the system and higher operator trust in the resulting ecological interface (Lee et al., 2003).

3.1. EID and Intersection Decision Support

The driving domain is different than the other domains where EID has been traditionally applied (Lee et al., 2003). For example, driving consists primarily of skill-level (steering and braking) and rule-level (if light is red, then stop) performance, whereas industrial domains (like process control) focus mostly on the knowledge level of performance. Additionally, the driving domain is constrained by many goals including safety, efficiency, and pleasure. In contrast, domains where EID has been traditionally applied (such as a nuclear power plant) focus mostly on safety. Drivers are also bombarded with multiple sources of information coming from the vehicle, the environment, and other road users. Operators in most other complex domains often focus on a single integrated interface or closely related set of displays. Lastly, the driving domain is constantly changing as a result of other road users and changing traffic conditions. Therefore, it is unknown how well the principles and methods of EID will work for driving and the specific task of intersection negotiation.

In spite of these differences, Lee et al. (2003) suggested EID has promise for driving by highlighting the constraints of the driving system at different levels of abstraction and identifying the information drivers use to make decisions and otherwise negotiate complex driving situations. For driving, the system includes not only the driver and vehicle, but also the external environment. Lee et al. conducted an AH analysis to identify the constraints inherent to the vehicle and environment and used the SRK framework to focus on the characteristics of the operator (i.e., driver) that will help determine interface form. For the AH, they limited their analysis to the external environment up to a distance of 1 mile ahead and immediately surrounding the vehicle. They also excluded constraints inside the vehicle. This was done to focus the analysis on the constraints that have the greatest implications for interface solutions designed to improve driver safety in car-following situations. Information elements were identified for each constraint in the AH, but they only displayed a subset of the elements in their display. Therefore, their interface would not be considered a “pure” example of EID.

Although not part of the AH analysis for the driving domain, constraints can also be identified for specific driving situations, such as negotiating rural intersections. In this respect, intersections can be regarded as a subsystem of overall driving. Consequently, the constraints identified for overall driving may apply more or less to the subsystem of intersections. For instance, detecting other vehicles and pedestrians may be more important for intersections simply because there are more vehicles and pedestrians in the driving environment. Destinations are also important constraints because intersections are the location where most route choices are made.

New constraints and potential information elements can also be identified. The density and size of gaps in the traffic stream are examples of constraints that apply almost exclusively to intersections. When average gap size is small, drivers are forced to wait for a suitable gap to appear before executing their maneuver. Characteristics of the intersection are also an important physical feature of the driving system. For example, the presence of a large median may force (i.e., constrain) drivers turning left to pause in the crossover rather than negotiate the near and far sides in one movement. In

Figure 3.3, the original AH for the driving domain was expanded and new constraints were identified for intersections. In Table 3.1 to **Error! Reference source not found.**, new information elements were listed to guide the design of the concepts for the Minnesota IDS system.

Some of the information elements were also mapped onto those identified via a traditional task analysis (Laberge, Ward & Rakauskas, 2003). Much like similar analyses done in other domains (see Vicente, 2002), this activity showed that a greater number of information elements were identified using the AH compared to the task analysis method. This was particularly true at the functional purpose and abstract function levels.

Aggregate
Detailed

	Whole	Subsystem	Component
Functional Purpose	• Safe transport • Efficient transport • Rapid transport • Pleasure		
Abstract Function	• Field of safe travel and field zone ratio (time, distance, energy, acceleration and force balances) • Probabilistic balance of risk and success • Performance and cost balance		
General Function	• Stochastic properties of traffic • Traffic dynamics (traffic stream stability)	• Vehicle dynamics • Regulatory constraints • Norms and cultural conventions • Other driver intent	• Destinations • Paths and routes • Visibility • Coefficient of friction • Obstacles and associated hazard severity
Physical Function	• Environment types (dusk, dawn) • Weather conditions • Traffic density	• Road type (rural, urban, suburban) • Road boundary (sidewalks, shoulders) • Roadway furniture (medians, guardrails) • Road surface treatment (asphalt, concrete) • Intersection type (signal, sign, uncontrolled) • Gap density	• Vehicle state (acceleration/braking capabilities, steering radius, weight/length/width, tire condition) • Relative position, velocity and acceleration of other vehicles, pedestrians and road boundaries • State variables describing vehicles, pedestrians and animals • Lanes • Maneuver type (left/right turn, straight) of self and others • Pavement surface conditions
Physical Form		• Lane width • Curve geometry • Surface features • Shoulder features • Median width • Intersection angle/grade • Number of driveways • Sign/signal characteristics • Intersection sight distance • Proximity to other intersections • Average daily traffic • Presence of other devices (lights, rumble strips, stop-ahead signs, etc.) • Speed limit	• Particular car, truck, bike • Particular dog, cat, deer • Particular gap (actual size, safe or unsafe) • Particular lane • Particular sign/signal • Particular pavement surface conditions • Particular maneuver

Figure 3.3. Abstraction hierarchy analysis showing constraints in the driving system. Constraints for intersections are in regular text; those originally identified for overall driving are in grey text.

Table 3.1. Constraints and information elements at the functional purpose level. Grey text is used to show original entries from Lee et al., 2003. New constraints and information elements are shown in regular text. Note that no information elements from this level of the AH map onto those identified in the traditional task analysis.

Constraint	Possible Information Element
Safe transport	Post-drive safety assessment Instantaneous risk estimator Number of violations per trip/unit time Type of violations Probable consequences of each violation Current attention state (vigilant, distracted, fatigued, etc.) Number of near misses/conflicts
Efficient transport	Instantaneous fuel efficiency Overall fuel efficiency (i.e., mpg per trip/unit time)
Rapid transport	Time remaining to destination Speed relative to permissible speed Total trip time Relative trip time (i.e., actual versus estimated) Number of shortcuts used Total miles traveled Relative miles traveled (i.e., actual versus estimated) Total wait time
Pleasure	Scenic value of route Visceral cues of sound and acceleration

Table 3.2. Constraints and information elements at the abstract function level. Grey text is used to show original entries from Lee et al., 2003. New constraints and information elements are shown in regular text. Note that no information elements from this level of the AH map onto those identified in the traditional task analysis.

Constraint	**Possible Information Element**
Field of safe travel and field zone ratio (time, distance, energy, acceleration and force balances)	The magnitude of the lateral and longitudinal disruptions to the field of safe travel
Probabilistic balance of risk and success	Risk associated with current situation Probability of field of safe travel disruptions Probability of receiving a traffic ticket Probability of reaching destination on time
Performance and cost balance	Rate of fuel consumption as a function of speed and acceleration

Table 3.3. Constraints and information elements at the general function level. Grey text is used to show original entries from Lee et al., 2003. New constraints and information elements are shown in regular text. Letters are used to map the information elements onto those identified in a traditional task analysis.

Constraint	**Possible Information Element**
Stochastic properties of traffic Traffic dynamics (traffic stream stability)	Speed of disruption propagation Anticipated wait time due to disruption
Vehicle dynamics Coefficient of friction	Traction and slippage information (I3) Vehicle stability Stopping distance Maximum curve speed
Regulatory constraints	Speed limit relative to current speed Acceptable and unacceptable maneuvers (F1) Distance to stop line or crosswalk at intersection
Norms and cultural conventions	Norms and conventions that influence driver intent and proper driving
Other driver intent	Intention of other drivers (K1) Trajectories of other drivers
Destinations	Time to destination Distance to destination Direction of destination (i.e., north, south, east, west)
Paths and routes	Anticipated choice of alternate paths (i.e., shortcuts) Proximity to path boundary Direction of current path (i.e., north, south, east, west) Time or distance remaining on current path
Visibility	Current and future sight distances Presence of obstacles limiting sight distances
Obstacles and associated hazard severity	Proximity to lead and approaching vehicles (G2) Proximity and likelihood of obstacles in path (H1) Proximity and likelihood of obstacles on the edge of the chosen path Consequences of a collision with an obstacle

Table 3.4. Constraints and information elements at the physical function level. Grey text is used to show original entries from Lee et al., 2003. New constraints and information elements are shown in regular text. Letters are used to map the information elements onto those identified in a traditional task analysis (continued on next page).

Constraint	**Possible Information Element**
Environment (dusk, dawn)	Onset of dusk or dawn
Weather conditions	Rate of precipitation Wind speed Temperature Snow and ice accumulation Fog density Current and long range weather forecast for region
Traffic density	Density (i.e., vehicles per minute) of current and upcoming traffic (by lane/direction of travel)
Road type (rural, urban, suburban)	Indicator of transition to different road type Current road type Distance of transition to different road type
Road boundary (sidewalks, shoulders)	Indicator of road boundary Distance to road boundary
Roadway furniture (medians, guardrails)	Indicator of roadway furniture Distance to roadway furniture
Road surface treatment (asphalt, concrete)	Indicator of current and upcoming surface characteristics (e.g., asphalt, concrete, gravel road) Condition of surface treatment (i.e., good, fair, poor)
Intersection type (signal, sign, uncontrolled)	Indicator of current and upcoming intersection and type (A1) Proximity and approach speed to next intersection (A2)
Gap density	Average gap size (I2) Average number of safe gaps Anticipated wait time for safe gap (I4)

Table 3.4 Constraints and information elements at the physical function level. Grey text is used to show original entries from Lee et al., 2003. New constraints and information elements are shown in regular text. Letters are used to map the information elements onto those identified in a traditional task analysis (continued from previous page).

Constraint	**Possible Information Element**
Vehicle state (acceleration/braking capabilities, steering radius, weight/length/width, tire condition)	Current speed (B2) Current acceleration/braking forces (J2) Relative speed to other traffic Current tire condition Vehicle length, width, weight
Relative position, velocity and acceleration of other vehicles, pedestrians and road boundaries	Distance to and direction of other vehicles, pedestrians, road boundaries (H1) Speed of other vehicles (I1) Relative speed of other vehicles
State variables describing vehicles, pedestrians and animals	Turn indicator and brake application (D1)
Lanes	Current lane boundaries Center line for current lane
Maneuver type (left/right turn, straight) of self and others	Current and upcoming maneuver type Anticipated maneuver type of other vehicles (i.e., based on turn indicator)
Pavement surface conditions	Current and upcoming slippage information at intersection (I3)

Table 3.5. Constraints and information elements at the physical form level. Grey text is used to show original entries from Lee et al., 2003. New constraints and information elements are shown in regular text. Letters are used to map the information elements onto those identified in a traditional task analysis (continued on next page).

Constraint	**Possible Information Element**
Lane width	Current and expected changes in lane width
Curve geometry	Distance to curve Curve radius/angle
Surface features	Presence and distance to potholes or other surface irregularities Presence of slippery sections (i.e., black ice)
Shoulder features	Presence of shoulder Width of shoulder Road type of shoulder (grass, concrete, asphalt)
Median width	Presence and distance to median Width of median
Intersection angle/grade	Indication of change in grade or angle Absolute value of angle or grade
Number of driveways	Presence and distance to driveways
Sign/signal characteristics	Indicator of upcoming sign/signal (i.e., stop ahead, E2) Type of sign/signal (i.e., STOP/yield, all stop, etc., E2) State of signal (i.e., green light ahead, E1) Distance to sign/signal (E3)
Intersection sight distance	Current intersection sight distance Required intersection sight distance Obstacles limiting intersection sight distance
Proximity to other intersections	Presence and distance to other intersections (A1,A2)
Average daily traffic	ADT for time of day and direction (I2) Current traffic relative to ADT

Table 3.5.Constraints and information elements at the physical form level. Grey text is used to show original entries from Lee et al., 2003. New constraints and information elements are shown in regular text. Letters are used to map the information elements onto those identified in a traditional task analysis (continued from previous page).

Constraint	Possible Information Element
Presence of other devices (lights, rumble strips, stop-ahead signs, etc.)	Indicator and distance to other devices (i.e., stop ahead 500 ft)
Speed limit	Current and changes in speed limits
Particular car, truck, bike	Presence and distance to specific cars, trucks, and bikes (I1, H1)
Particular dog, cat, deer	Presence and distance to specific animals
Particular gap (actual size, safe or unsafe)	Presence of specific gaps as safe or unsafe (I6) Size of current gap (I5)
Particular lane	Current lane number Desired lane number given destination/route/path (C1)
Particular sign/signal	Characteristics of specific signs/signals (size, location, material, etc., E1-E3) Operating status of signal (working or broken)
Particular pavement surface conditions	Surface conditions at different parts of the intersection (stop line, middle of intersection, far side, near side, etc., I3)
Particular maneuver	Maneuvers allowed given current system configuration (i.e., current gap is safe for right turn but NOT left turn)

Lee et al. (2003) also used the SRK framework to develop an understanding of operator or driver constraints. More specifically, the researchers suggested driver age and experience are important moderators of how the SRK model applies to driving. For instance, a novice driver who encounters slippery road conditions will be more likely to function at the knowledge level of performance and engage in trial and error behaviors. An experienced driver would readily recognize and diagnose the situation, select the appropriate rule, and activate the desired skill (i.e., counter-steering or braking).

Experience tends to increase with age, but older drivers also suffer from reduced skills and potentially slower and more-error-prone performance at the knowledge level. There is also some evidence that older adults may use inappropriate rules in some driving situations. Staplin et al. (1998) found that older drivers suffered from reduced driving skills since they had problems turning at intersections. Keskinen, Ota & Katila (1998) and Lerner et al. (1995) also found that older drivers took longer to execute their maneuvers. Hills and Johnson (as cited in Hills, 1980) found that older drivers used a faulty rule when accepting gaps at intersections. More specifically, older drivers accepted gaps at an average constant distance of 55 ft and failed to take approach vehicle speed into consideration. A better rule would be to accept a constant time gap, which is independent of approach vehicle speed (AASHTO, 2001). Evidence of potential problems at the knowledge level comes from studies that found older adults have reduced working memory capabilities (see Craik & Jennings, 1992), and as a result, may not be able to consider all factors when making turn decisions at intersections (Caird, Edwards, Creaser & Horrey, 2002).

Other constraints related to driver age were less clearly revealed in the SRK framework used by Lee et al. (2003). Examples of these age constraints include problems with peripheral vision and divided attention and slower and less accurate movements. These constraints have been discussed in more detail in a supplementary report (Laberge et al., 2003).

3.2. From Analysis to Design

Much like traditional user interface design, the choice of visual form for an ecological interface remains largely an art rather than science (Vicente, 2002). Creativity is needed to transform the results of the AH into distinct perceptual elements in a display. An additional challenge is deciding exactly which information elements to include.

Admittedly, it is not possible to design a "pure" ecological interface using an infrastructure solution based on the extension of the AH for intersection negotiation. Although an in-vehicle display would support direct manipulation, an infrastructure display has to be passively viewed and interpreted by the driver. An in-vehicle solution could support more than one level of abstraction, but presenting information at all levels would potentially take a driver's eyes off the road for significant periods of time. Additionally, an infrastructure solution would not be able to display information at all levels because of limited display space and no opportunity for direct manipulation.

Infrastructure solutions do support rule-level performance by mapping the constraints to distinct perceptual elements in the display. For instance, if the speed of other vehicles is an environment constraint identified in the AH, the display could show the absolute speed of each vehicle independently. Therefore, the IDS concepts proposed in the next section support rule-level performance, but not the skill and knowledge levels.

3.3. Section Summary

The task analysis, example case scenario, and information processing requirements distinguish between the perceptual (detecting, locating and perceiving vehicles, pedestrians, and gaps), cognitive (deciding whether gaps are large enough), and behavioral (braking, accelerating, steering movements) aspects of rural intersection negotiation. Based on a compilation of earlier task analyses, drivers complete the following tasks at intersections in an approximate temporal order.

- Detect intersection
- Decelerate
- Enter correct lane (if required)
- Signal if intending to turn
- Detect traffic-control device (signs or signals)
- Interpret traffic-control device
- Monitor lead vehicle (if present)
- Detect traffic and pedestrians
- Detect, evaluate, and monitor gaps in traffic
- Accept gap and complete maneuver
- Continue to monitor traffic and control device until intersection is cleared

An analysis of the information processing requirements at intersections highlighted the perceptual, cognitive, and action processes needed to negotiate an intersection that the IDS system must support. The processes identified included visual search, spatial vision, depth and motion perception, color vision, long-term and working memory, response selection, preparation, execution, and divided, selective, and sustained attention.

Based on the definition of an ecological interface (Vicente, 2000), it is not possible to design a “pure” ecological interface using an infrastructure solution. Nevertheless, the ecological approach was a suitable supplement to the traditional task analysis method used in an earlier report and helped to identify new information requirements.

Although the AH identified environment constraints and possible information elements to support intersection negotiation, only the rule-based elements can be represented in the proposed IDS infrastructure solutions.

The skills, rules, knowledge (SRK) framework and an analysis of information processing requirements in an earlier report were used to identify the operator (driver) constraints. This will help ensure the information content was represented in a form that is consistent with operator performance and information processing limitations (Lee et al., 2003).

4. Design Options

Based on the above discussions, it was possible to identify potential information elements for each driver task involved with negotiating a rural thru-STOP. Table 4.1 lists the possible information elements for each driver task and additional comments. Information requirements are not limited to the IDS system and also include changes to the intersection and in-vehicle solutions that can convey important information to drivers.

Table 4.1. Information requirements and comments (continued on next page).

Driver Task	**Possible Information Elements**	**Comments**
A. Detect intersection	A1. Lights, signage, or pavement markings to indicate intersection A2. Proximity to intersection	The IDS display may serve as a cue to drivers ICAV/CAMP may be able to warn drivers of possible violations
B. Decelerate	B1. Signage or pavement markings to remind drivers to slow B2. Approach speed to intersection	Rumble strips are a common solution
C. Enter correct lane (if required)	C1. Signage to indicate correct lane for each maneuver or direction	
D. Signal if intending to turn	D1. Warn drivers if signal not activated and steering wheel turned	
E. Detect traffic-control device (signs or signals)	E1. State of traffic-control device E2. Type of traffic-control device E3. Proximity traffic- control device	This does not apply for thru-STOP intersections This is sometimes communicated by signs or pavement markings ICAV/CAMP may be able to warn drivers of possible violations
F. Interpret traffic-control device	F1. Required action based on traffic-control device state	Redundancy between IDS display and control device will increase understanding
G. Monitor lead vehicles (if present)	G1. Velocity of lead vehicle G2. Gap to lead vehicle	Unknown whether gap should be based on absolute time or distance

Table 4.1. Information requirements and comments (continued from previous page).

Driver Task	**Possible Information Elements**	**Comments**
H. Detect traffic and pedestrians	H1. Proximity to obstacles in the driving scene	Not clear which obstacles should be highlighted This would become overwhelming when traffic volumes are high
I. Detect, evaluate, and monitor gaps in traffic	I1. Distance and velocity of approaching vehicles I2. Density and average speed of traffic I3. Traction and slippage information I4. Anticipated wait time for safe gap I5. Size of current gap I6. Location of safe gap	Could highlight vehicles approaching significantly faster than posted speed limit (expectation violation) May provide information on the availability of gaps downstream May help drivers make cost-benefit decisions Unknown whether gap should be based on absolute time or distance Identify which gap meets the requirement for the safe gap
J. Accept gap and complete maneuver	J1. Time remaining to clear intersection J2. Minimum acceleration	Could be based on maneuver time used to calculate safe gap (i.e., = 5.5 s) Based on assumptions re: vehicle size
K. Continue to monitor traffic and signal until the intersection is cleared	K1. Possible violators of traffic-control device	This may be particularly relevant for oncoming traffic that fails to stop ICAV/CAMP may be able to warn drivers of possible violators

From the problem scope described earlier, the IDS system must present information that supports drivers who are crossing and turning in a format that is readily understood. The "interface" for this system is the content (information concepts) and format (e.g., text or symbols) used to convey this information. In this section, nine information concepts are proposed. The format used to convey these concepts are not intended to be the final display set. Future research will develop formats that are MUTCD compliant.

4.1.Content Domain

A number of information elements can be conveyed to the minor-road (and major-road) driver using an IDS system. Based on the results of the AH and the earlier task analysis for intersections, the first five elements define the primary content for the interface solutions (Laberge et al., 2003). These information elements directly support minor-road driver tasks related to gap detection, perception, and judgment. Minor-road drivers may use this information in a sequential manner and the information can be viewed as hierarchical (see Figure 4.1). Put another way, localizing a gap as safe assumes the vehicles that make up the gap are detected; speed, distance and arrival time are estimated; the size of the gap has been determined; and the gap has been judged as safe or unsafe. Therefore, more complex solutions that include information at the fourth and fifth levels (judging and localizing gaps) will be more comprehensive by also supporting some driver tasks at earlier levels (detecting vehicles; estimating speed, distance, and arrival time; perceiving gap size). However, interface solutions that communicate information at the first level (detecting the presence of vehicles that make up gaps) will not necessarily help drivers make decisions at subsequent levels.

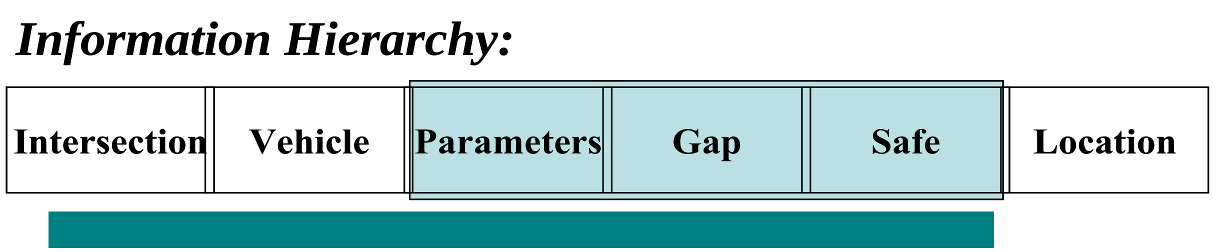


Figure 4.1. Information Hierarchy

The other information elements that define the content domain are secondary and do not directly support a specific task of the minor-road. Instead this secondary content either supplements or draws attention to specific information to help minor-road drivers make more efficient (rather than accurate) decisions. Some of this information may be incorporated into specific interface solutions at the detailed design stage.

4.1.1. Primary Content

A. **Presence of vehicles that make up gaps.** Before a gap can be perceived and judged, the vehicle that forms the gap must be detected. Therefore, interface solutions can draw attention to and make major-road vehicles more salient.

B. **Convey speed, distance, and arrival time**. After a vehicle is detected, the temporal and spatial characteristics of the vehicle must be perceived. This is thought to occur based on estimates of speed, distance, and/or arrival time and forms the basis for perceiving gap size (Laberge et al., 2003). Interface solutions can make speed, distance, and arrival time of major-road vehicles explicit and improve the accuracy of gap perception for minor-road drivers.

C. **Size of available gaps.** Rather than force the minor-road driver to interpret the speed, distance, and/or arrival time information of individual major-road vehicles, interface solutions can convey gap size directly. This could take the form of time (s) or distance (ft) units.

D. **Judge whether a gap is safe.** Based on a finite list of factors (number of lanes, minor-road vehicle size, surface conditions) that influence the size of the safe gap, each major-road gap can be judged as safe or unsafe by the system. Interface solutions can inform the minor-road driver when a gap is safe. This takes the decision-making component away from the minor-road driver.

E. **Localize a safe gap and/or inform when a safe gap is about to arrive.** After the available major-road gaps have been identified as safe or unsafe, interface solutions can inform the minor-road driver which gaps in the traffic stream are safe and potentially when the next safe gap will arrive.

4.1.2. Secondary Content

F. **Alert minor-road and major-road drivers to the presence of the intersection.** Installing some of the interface solutions at intersections may have the secondary benefit of informing major-road and minor-road drivers that they are approaching an intersection. This could increase the probability that minor-road drivers stop before proceeding.

G. **Alert major-road drivers to crossing minor-road vehicle.** Some of the interface solutions could inform major-road drivers (directly or indirectly) that a minor-road vehicle is waiting to cross or has already entered the intersection. This may increase vigilance toward specific minor-road vehicles and reduce driver perception response time (PRT) if evasive or emergency maneuvers are required.

H. **Traction or friction information.** Minor-road drivers will require more time to accelerate and complete their maneuver when the minor road is slippery. In some cases, minor-road drivers may not be aware of traction or friction information at a specific intersection and therefore fail to take this factor into consideration when judging gaps as safe. Interface solutions could incorporate traction or friction information into calculations for the safe gap or communicate the information directly so minor-road drivers can compensate by increasing their internal representation of what is an acceptable gap.

I. **System state.** All interface solutions must communicate the current system state to minor-road drivers. This is important because it is possible the system could fail and the minor-road driver needs to be able to differentiate between “no signal” because the intersection is safe versus “no signal” because the system is not functioning. Although most of the interface solutions fail to specify how this information will be conveyed, it is an issue that will be considered during detailed design.

J. **Time to clear intersection.** Minor-road drivers who have started their maneuver may stop at the median crossover. In some cases, this could disrupt traffic and result in a queue on the minor road. Interface solutions could tell drivers how long they have to clear the intersection based on the size of the current queue. The disadvantage of this information is that drivers could feel rushed and may accept more unsafe gaps.

K. **Wait time.** Minor-road drivers have been shown to accept less-safe gaps as wait time increases. Interface solutions could inform minor-road drivers of the anticipated wait time given the current traffic volumes and distribution of safe gaps. This may improve driver decision making.

4.2. General Limitations and Design Premise

In order to narrow down the list of potential interface concepts, it was important to define clear boundaries for all the solutions that are proposed. This implies identifying both general limitations of these solutions as well as the overall design premise. The following limitations and design principles guided the selection of the interface solutions that were derived and subsequently evaluated.

- **Technically feasible**. Each interface solution is both technically possible and feasible. In other words, the technology exists and is readily available. Experimental technology is not considered and, when possible, the solutions assume or estimate parameters (i.e., driver age and PRT) to avoid adding additional technology that would measure them directly.

- **Infrastructure solution.** For the reasons outlined in the original project proposal, the interface solutions are based only in the infrastructure (see Donath & Shankwitz, 2001).

- **Infrastructure solution supports rule-level performance only.** Because the interface is based in the infrastructure, direct manipulation at the skill level of performance is not supported. It is also not possible to present information at multiple levels of abstraction, which is needed to support knowledge-level performance. However, the constraints that are represented match specific perceptual elements in the display and thus support rule-level performance.

- **Applies to all thru-STOP intersections.** The interface solutions apply to all rural thru-STOP intersections regardless of specific geometry. This is important because designing for specific intersections would reduce the extent to which the solutions generalize to other intersections and other states.

- **Minor-road driver is focus.** The interface solutions are targeted toward the minor-road driver and it is assumed the minor-road driver is responsible for any crash that would result. Improving the decision making of minor-road drivers will therefore reduce the likelihood that the same type of crash occurs.

- **Minor-road driver stops.** The interface solutions assume the minor-road driver stops before proceeding. The solutions do not address situations where minor-road drivers violate the control device (willfully or due to inattention). A secondary benefit of some solutions is that the interface could increase the conspicuity of the intersection and reduce the likelihood of unintended sign violations.

- **System does not impede traffic on the major road.** According to AASHTO (2001) guidelines for intersection sight distance, safe gaps are based on the assumption that major-road vehicles decelerate up to 30% to avoid a collision. The interface solutions assume the same limits by intending not to reduce the speed of major-road traffic by more than 30%.

- **Minimal training required.** When possible, the interface solutions use stereotypic coding of information (color, frequency, symbols) to ensure meaning and that required actions are intuitive. This should increase understanding by drivers with minimal exposure and it is hoped this will reduce the need for training.

- **Minimal additional signage required.** For some of the interface solutions, signage is needed to explain how the system works. To minimize cognitive overload, the number and complexity of the signs will be limited.

- **Robust to winter conditions.** Each interface solution is visible in winter conditions, such as blowing and drifting snow. The interfaces can also withstand plowing and do not interfere with plow operations.

- **Visible at night.** The interface solutions are visible at night.

- **No interference with existing control devices**. The interface solutions complement and do not interfere with existing control devices. Obscuring a STOP sign by placing a display in front of it would be an example of interfering with an existing control device.

- **Use a prohibitive frame.** All the interface solutions use a prohibitive frame (e.g., "Do not turn left or cross"). This is important because a permissive frame is more liable if compliance leads to a crash (see Donath & Shankwitz, 2001).

- **Gaps calculated relative to the minor-road driver.** To minimize complexity, gaps are calculated from the minor-road driver to the next closest vehicle on the major road (Figure 4.2). This metric is also referred to as a "lag" in the research literature. In other words, it is assumed the first available gap is the one that is of greatest interest to the minor-road driver. Consequently, gaps between leading and trailing vehicles farther down in the major-road traffic stream are not directly referred to in any of the interface solutions.

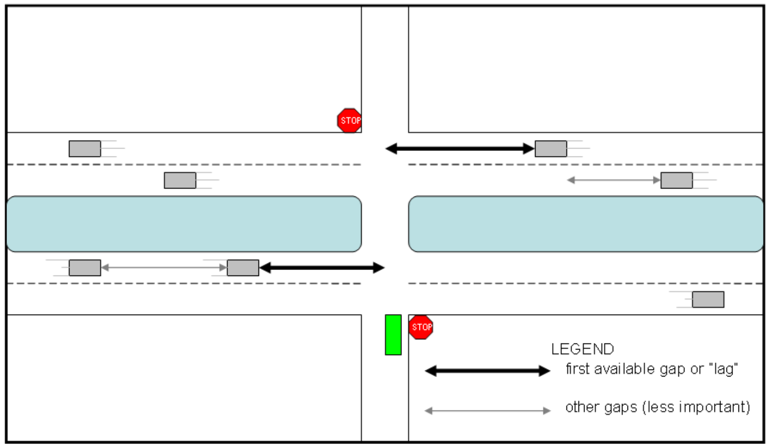


Figure 4.2. Thru-STOP intersection showing the first available gap or "lag" and other gaps between leading and trailing vehicles

- **Median crossover is empty.** In some situations, minor-road drivers may complete their maneuvers in two-steps (Preston & Storm, 2003a). For example, when an intersection has a large median, minor-road drivers could negotiate the near-side stream, pause at the median crossover, and then negotiate the far-side stream. The interface solutions assume the median crossover is empty and may require a facility to monitor and track when this condition is satisfied.

- **Assume major-road traffic does not exit at minor road.** The interface solutions only detect the presence or absence of major-road vehicles and do not make assumptions about their maneuver type. Therefore, it is assumed the detected major-road vehicles continue along the major road and do not exit at the intersection. It is possible a major-road vehicle could exit at the minor road, but some of the interface solutions would declare the intersection unsafe. Under these circumstances, a large queue could develop on the minor road and increase driver frustration and impatience.

- **Safe gap assumes worst case of older driver and left turn.** For those solutions that rely on the safe gap, the formula is:

  - $t_G = t_{PRT} + t_{MT}$ (Laberge et al., 2003)

  Where

  - t_G = the safe gap (s)
    - The safe gap can be represented in time or distance units (see AASHTO, 2001).
  - t_{PRT} = the perception response time (PRT) needed for the minor-road driver to detect, perceive, and accept a gap and initiate the maneuver (s)
  - t_{MT} = the time required to accelerate to speed and cross the distance needed to clear or enter the major road (s)

- The factors that affect either driver PRT (t_{PRT}) or maneuver time (t_{MT}) are:

  - Age = older drivers may be slower to detect, perceive, and accept a gap as well as slower to accelerate and complete their maneuvers (Keskinen et al., 1998; Lerner et al., 1995; Olson, 2002; Wagner, 1965). This will result in increased t_{PRT} and t_{MT}. It is assumed there is no way to detect driver age, so older drivers will be the default case. This is justified because older drivers have been identified as the highest-risk group for whom the system is being designed (Laberge et al., 2003). The exact adjustment to the size of the safe gap for older drivers will be determined during the detailed design stage.

  - Distraction = distracted drivers could be slower to detect gaps and decide which is acceptable and may not consider all factors when making decisions. This may increase t_{PRT}. It is assumed there is no way to detect driver distraction, and therefore it is not a parameter that is used when calculating the safe gap.

  - Maneuver type = left turns are a more complicated decision and require a greater distance to cross as well as more time to merge with far-side traffic. This will increase t_{PRT} and t_{MT}. It is assumed there is no way to detect maneuver type for the minor-road vehicle in advance of the intersection. Therefore, the default maneuver type will be the left turn. According to AASHTO (2001), left-turn maneuvers require a safe gap that is 1 s longer than crossing or right-turn maneuvers and a greater adjustment is needed for larger vehicles.

  - Lanes = more lanes to cross for left-turn and crossing maneuvers will increase t_{MT}. The number and width of the lanes at each site can be calculated in advance and adjustments made to the safe gap. According to AASHTO (2001), 0.5 s is required for each 12-ft lane the driver is required to cross and a greater adjustment is needed for larger vehicles

  - Minor-road vehicle size = larger vehicles are slower to accelerate and will require a larger gap to enter or cross, increasing t_{MT}. If minor-road vehicle size can be detected from the infrastructure, some interface solutions can accommodate safe gaps that increase as vehicle size increases. According to AASHTO, the safe gap for passenger cars is 7.5 s, 9.5 s for single-unit trucks, and 11.5 s for combination trucks

  - Surface conditions = slippery roads will reduce traction and increase t_{MT}. If the infrastructure can detect pavement surface conditions at the intersection, some interface solutions can accommodate safe gaps that increase as surface conditions become more slippery. The adjustment required for slippery surface conditions will be determined during the detailed design stage

4.2.1. Gap-Specific Design Issues for IDS

Several issues were identified in this report that relate to the limitations of supporting research and design aspects of an IDS system:

- A critical issue is whether the IDS system will highlight vehicles and gaps so drivers can make better decisions or recommend safe gaps so drivers do not have to decide. The latter approach is more consistent with automation, whereas the former is more characteristic of a decision support system.

- An important issue identified in the section that defined gaps and thru-STOP intersections is how drivers cope with multiple gaps. It is unclear whether drivers actually perceive near-far gaps and also whether multiple gaps are detected, perceived, and judged simultaneously. This is an important consideration if the IDS system is installed at intersections where multiple gaps exist. Consequently, the display must distinguish between near, far, and near-far gaps (see Figure 1.2).

- Also related to gap acceptance is how drivers make gap acceptance decisions when there is a large distance to cross. For left-turn and crossing maneuvers, drivers may stop at the median crossover and make two gap acceptance decisions (one for the near side and one for the far side). Although some data has been collected that implies this may not be the case (Preston & Storm, 2003b), it is unclear how intersection geometry and sight lines affect driver behavior. Some observations of drivers at the candidate intersection would help shed light on this important issue.

- There exists a possibility of overreliance and negative behavioral adaptation to the IDS system. Drivers who repeatedly negotiate intersections with IDS systems deployed may change their driving behavior. For example, drivers familiar with IDS systems may ignore the traffic-control device and rely solely on information in the IDS display to make right-of-way judgments. Another possibility is that if the IDS system recommends safe gaps at intersections, drivers who are familiar with the system may have problems negotiating intersections without an IDS system.

- It is unclear if and how the system will determine maneuver type. The analysis of driver errors showed that failure to activate a signal and using the wrong signal are common problems. Therefore, relying on the signal to infer maneuver type seems inappropriate. Some thought should go into assuming a left turn for all drivers since this is the most complicated and time-consuming maneuver.

- It is unclear how the display is activated and whether an activation region is needed so drivers know whether the information in the display applies to them or a lead vehicle. A related requirement is that the IDS display only recommend gaps when the previous vehicle has cleared the intersection (i.e., they are not waiting at the median crossover).

- If the IDS system is to be installed at intersections with traffic signals (i.e., sometime in the future), the information in the display should be consistent with the state of the signal. If the IDS display tells the driver it is safe to proceed but the light is red, a conflict may occur. One solution is to activate the IDS display only when the traffic signal is green.

- It is unclear how the IDS system will cope with pedestrian movement. For example, if the system recommends a safe gap, a driver may proceed without checking the turn pathway for pedestrian conflicts. This may be less of an issue for rural locations, but should be a consideration if the system is installed at urban intersections.

- Although the report discussed gap detection, perception, and acceptance as separate serial information processing activities, little is known about the relationship between each process.

- It is unclear how the IDS system will detect driver vehicle size, age, and gender. Research showed that drivers of large vehicles, older drivers, and female drivers accepted larger gaps. If the system intends to adjust for reduced capabilities of older drivers, larger vehicle lengths, and slower acceleration, a means of detecting these factors is required. A careful evaluation of the demographics of the drivers at the candidate intersection is suggested.

- It is unclear how the IDS system will detect surface conditions. If roads are slippery, drivers will require longer maneuver times and as a result, the safe gap should be larger.

- The research literature on driver time requirements at intersections is scarce. Lerner et al. (1995) found no age differences in PRT and only marginal slowing for maneuver time. Naylor and Graham (1997) found that older drivers were slower, but more than 90% of responses were below the 2.0 s design value assumed for the safe gap. Although these findings can be used to set an initial safe gap value, more research is needed that measures these values at the candidate intersection. Maneuver time, in particular, is influenced by intersection geometry since it includes the distance needed to cross.

- The visual search literature identified that an important design consideration is where to put the display at the intersection. In one study, drivers typically glanced to the left first (Theeuwes, 1996), therefore the display may have the greatest conspicuity if placed in the left portion of the visual field. Related issues include whether the display should be integrated with the existing STOP sign, whether the display obscures or changes current sight lines, and where drivers would expect to find the display. Supplementary signage may be needed to address the later issue.

- Another issue is how to ensure drivers do not ignore the display. There appears to be a need to not only draw attention to the display, but also to emphasize its purpose. Possible suggestions include additional signage, training, and education programs.

- The research on visual search highlighted the possibility that drivers approaching at high speeds may not have time to process information in the display on approach. One suggestion is to install speed reducing countermeasures (i.e., rumble strips) at intersections where IDS systems are deployed.

- Preston and Storm (2003a) emphasized the need for driver education when developing and deploying any countermeasure device. Ideally, any IDS system we deploy would be intuitive and require no learning by drivers. However, some concepts may require explanation, either at the site using supplementary signs or via more traditional outreach and education programs. This issue can be addressed during the evaluation by asking comprehension questions and clarifying whether the subjects understood what the displays were communicating.

- Some thought should go into testing responses to the IDS system by both major-road and minor-road drivers. Although the major road driver will not be the focus of the system evaluation, some consideration should go into testing both major-road and minor-road reactions when the system is deployed in the field.

- When traffic volume is high, timing elements (countdown timers such as those in the Split-hybrid) will fluctuate as the lead vehicle passes the intersection and the next lead vehicle is tracked. Figure 4.3A shows two near-side (coming from the left) vehicles approaching. The (original) Split-hybrid concept would initially display the arrival time of vehicle A (9 s). After vehicle A enters the region that defines the safe gap (i.e., 8 s), the arrival time would be highlighted in red and the corresponding speed and image would be displayed. After vehicle A passes the intersection (Figure 4.3B), the Split-hybrid concept would display the arrival time of vehicle B (as the next lead vehicle). If vehicle B is initially tracked at an arrival time greater than the safe gap, the prohibitive message would briefly change to the default CAUTION, but then quickly change back to DO NOT ENTER after vehicle B enters the safe gap. This rapid fluctuation would increase as traffic volumes increase and more lanes exist on the major road. It will be difficult for minor-road drivers to understand which vehicle is being tracked and comprehend the rapid changes in prohibitive messages. One solution may be to track a swarm or group of vehicles with the hope of minimizing rapid fluctuations.

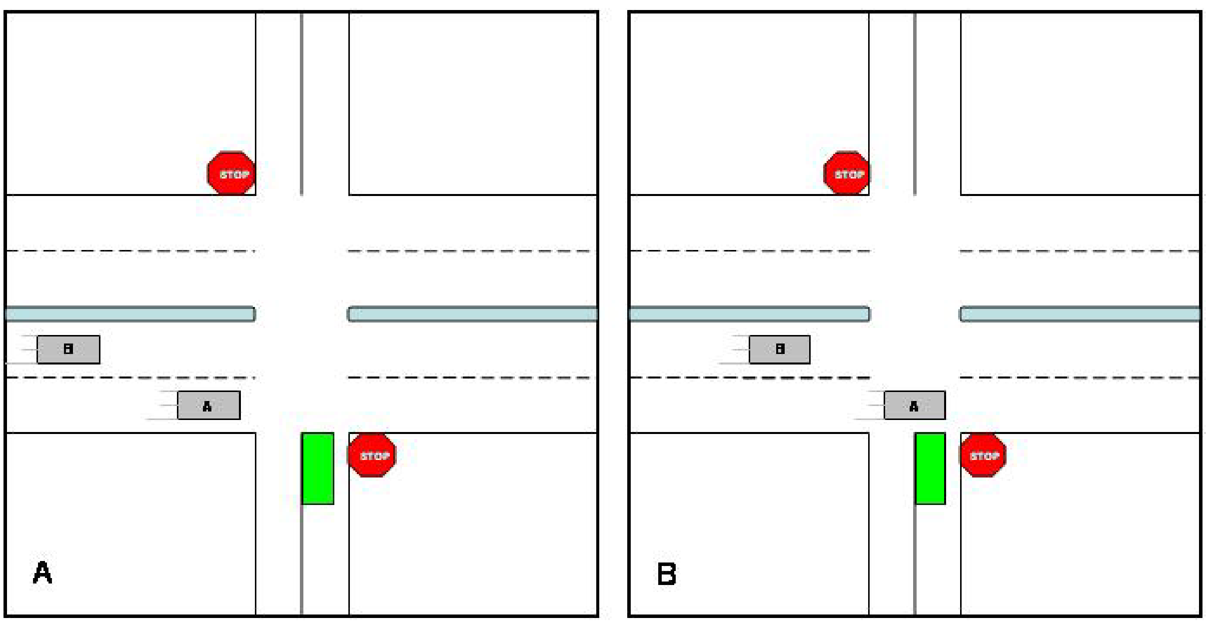


Figure 4.3. Vehicles approaching close together may result in rapid fluctuation as Vehicle A arrives at the intersection and Vehicle B begins to be tracked very shortly afterwards.

- All displays will need to be crashworthy to meet MUTCD guidelines. It is not clear how this will affect the initial designs, and in some cases, the displays may need to be enlarged to make them more robust. This could increase the amount of visual clutter at the intersection and be an obstruction for the driver.

5. Design Concepts

Based on the preceding design process and a review of existing infrastructure-based systems applicable to IDS (see Appendix B), a preliminary set of design concepts was generated. These preliminary concepts were then critiqued by a multi-state panel of traffic engineers (see Appendix C) to produce a subset of candidate concepts for evaluation.

5.1. Candidate Interface Descriptions

The set of candidate interface concepts can be structured with the information processing framework used to describe the driver interaction with the traffic environment (see Figure 5.1). As shown in Figure 5.1, the concept set can be classified as either supporting detection of a hazard or providing information about the nature of the hazard. Across this general classification, there is a gradient defined by amount of support provided to the driver. However, as a fundamental design premise, the driver is ultimately responsible to decide upon a safe gap and take appropriate action.

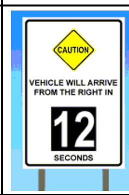
	Detect		Inform		
	Baseline	**Alert**	**Display**	**Warn**	**Advise**
Driver Role	Driver recognize hazard, gather information, decide on safety condition, and choose action	Driver must gather information, decide on safety condition, and choose action.	Driver must decide on safety condition, and choose action.	Driver must choose action.	Driver must choose to comply.
					
System Role		System detects hazard.	System detects hazard & presents information relevant to vehicle gap. Prohibited actions also indicated.	System detects hazard and provides warning levels based on gap information. Prohibited actions also indicated.	Prohibited actions indicated (unsafe action advisory).

Figure 5.1. Matrix of interface concepts highlighting information elements and role of driver.

The following tables (Tables 5.1-5.4) provide description of each candidate interface concept.

Table 5.1. Hazard Sign Description

1. Title

Hazard

2. Content Domain

Primary Content

A. Presence of vehicles that make up gaps.

D. Judge whether a gap is safe.

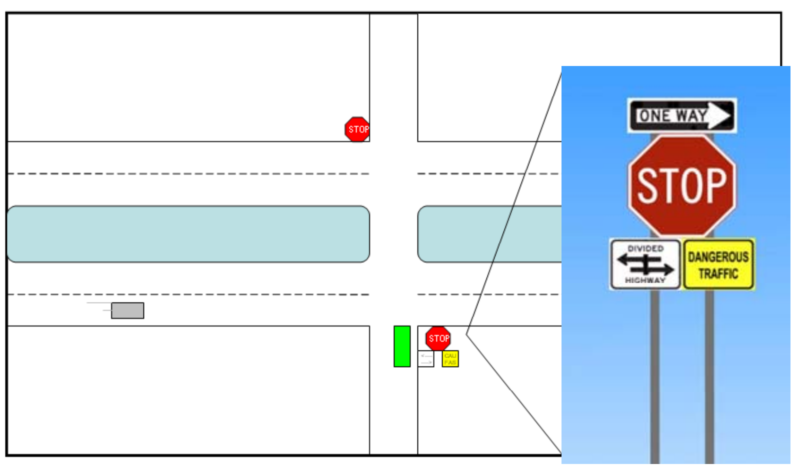
Secondary Content

F. Alert minor-road drivers to the presence of the intersection.

3. Description

A changeable message sign flashes the message “Dangerous Traffic” when the lead major-road vehicle in either direction is within the arrival time that defines the safe gap for the near and far lanes. The message flashes until the hazardous condition(s) has passed and the illuminated period of the flash cycle is 500 ms. When the system does not detect traffic within the safe gap zones of the near and far side lanes (i.e., no vehicles within safe gaps of near and far lanes), no message is displayed and the background is yellow. When active, the background is yellow and the message “Dangerous Traffic” is shown in black text. This sign is intended to alert drivers to potentially dangerous traffic conditions, rather than provide information regarding specific vehicles or specific gaps.

4. Diagram



5. Options/Variants

Changes in the wording of text.

The sign could be placed separately from the STOP sign, installed on both sides of the road and/or at the median.

6. Limitations/Caveats

The sign will only stop flashing when vehicles are outside the safe gaps for both sets of lanes; heavy traffic in both directions or a single direction will result in the sign continuing to flash “Dangerous Traffic.”

The sign does not provide specific information to help minor-road drivers make better gap acceptance decisions.

Table 5.2. Split-hybrid Sign

1. Title

Split-hybrid

2. Content Domain

Primary Content

A. Presence of vehicles that make up gaps.

B. Conveys arrival time.

D. Judge whether a gap is safe.

Secondary Content

F. Alert minor-road drivers to the presence of the intersection.

I. System state.

3. Description

Two separate displays draw attention to the arrival time of major-road vehicles while also conveying when it is unsafe to enter the intersection. The association between arrival time and the prohibitive message should help minor-road drivers learn when it is unsafe to complete each maneuver. The system tracks the lead vehicle in both the near and far lanes, starting at a distance of 12.5 s from the intersection and counts down in 1 s increments as the major-road vehicle(s) approaches. The timer background changes to red when the lead vehicle is within the arrival time that defines the safe gap. The near-side display is located on the driver's left when he or she is at the STOP sign and angled to provide a good view of the sign. The far-side (right) display is located on the right side of the median and angled to be seen by the minor-road driver. When no vehicles are present, the arrival time box is left blank and the CAUTION icon is present. When the system is not functional, a white flashing question mark (?) is displayed in the arrival time boxes (black background) with the CAUTION icon present.

The near-side display shows the following prohibitive messages based on the status of both the near-side and far-side vehicles. Three possible states exist for the near-side sign: DO NOT ENTER, DO NOT CROSS/TURN LEFT or CAUTION. When the minor-road vehicle enters the median area, the far-side (median) display only shows the CAUTION and DO NOT ENTER symbols based on the status of the far-side vehicles. When a major-road vehicle is stopped in the median, the near-side (left) display shows the DO NOT ENTER symbol to discourage drivers from creating a queue in the median.

Condition	Message/Symbol
Near-side vehicle within safe gap Near- and far-side vehicles within safe gap	 OR "UNSAFE TO ENTER"
Far-side vehicle within safe gap	 OR "UNSAFE TO TURN LEFT/ CROSS"
No vehicles within safe gap (default) in near or far-side lanes	 OR "ENTER WITH CAUTION"

Table 5.2. Split-Hybrid Concept (continued from previous page)

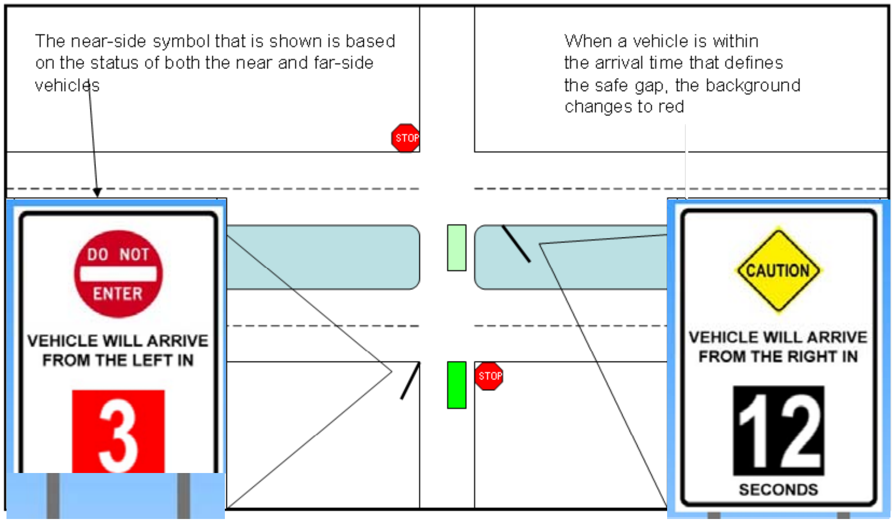
4. Diagram 
5. Options/Variants The size of the safe gap could be adjusted based on the type of vehicle detected on the minor road and pavement surface conditions. The amount of the intersection that is monitored can be changed. This may be particularly useful for intersections that have known sight distance problems. Arrival time can count down in different increments (1 s, 0.5 s, 0.1 s, etc.). The current default is 1 s.
6. Limitations/Caveats Drivers may not be able to interpret absolute values for arrival time. In other words, drivers may not perceive arrival time as a numerical value or may not be sensitive to small differences in arrival time. A fill bar alternative could help address this issue. Reading text and interpreting symbols can be cognitively demanding and error prone. There may be some issues related to text legibility and comprehension (especially for older drivers). This will need to be tested during the evaluation. There exists a potential for rapid fluctuation between symbols/messages (especially when traffic volumes are high). This may be confusing for the driver. This is discussed in more detail in the Issues Section. When traffic volumes are high, there exists a chance that no safe gaps will be present and the DO NOT ENTER symbol is shown for long periods of time. This could result in a long queue on the minor road and drivers could ignore the display as both wait time and driver frustration increase.

Table 5.3. Variable Message Sign Concept

1. Title

Variable Message Sign

2. Content Domain

Primary Content

A. Presence of vehicles that make up gaps.

D. Judge whether a gap is safe.

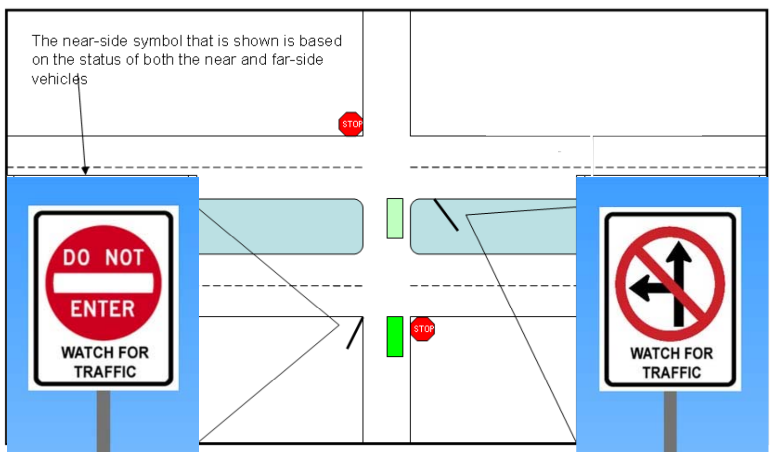
Secondary Content

F. Alert minor-road drivers to the presence of the intersection.

3. Description

This sign is the variable message portion of the Split-hybrid sign without the time-to-arrival countdown. Therefore, it provides information about the unsafe nature of gaps based on the presence of near or far-side traffic but does not provide direct information about the size of the gap. Icons are used in the current design and are identical to the Split-hybrid icons. As with the Split-hybrid sign, one VMS sign is located on the driver's left when at the STOP sign while a second sign is located on the driver's right in the median.

4. Diagram



5. Options/Variants

The size of the safe gap can be adjusted based on the type of vehicle detected on the minor road, pavement surface conditions, and speed.

The variable message sign can be placed at different locations (e.g., below STOP sign, at median, before STOP sign).

Rather than mix text and symbols, all text or all symbols can be used.

6. Limitations/Caveats

Reading text and interpreting symbols can be cognitively demanding and error prone.

There may be some issues related to text legibility and comprehension (especially for older drivers). This will need to be tested using a diverse driver population.

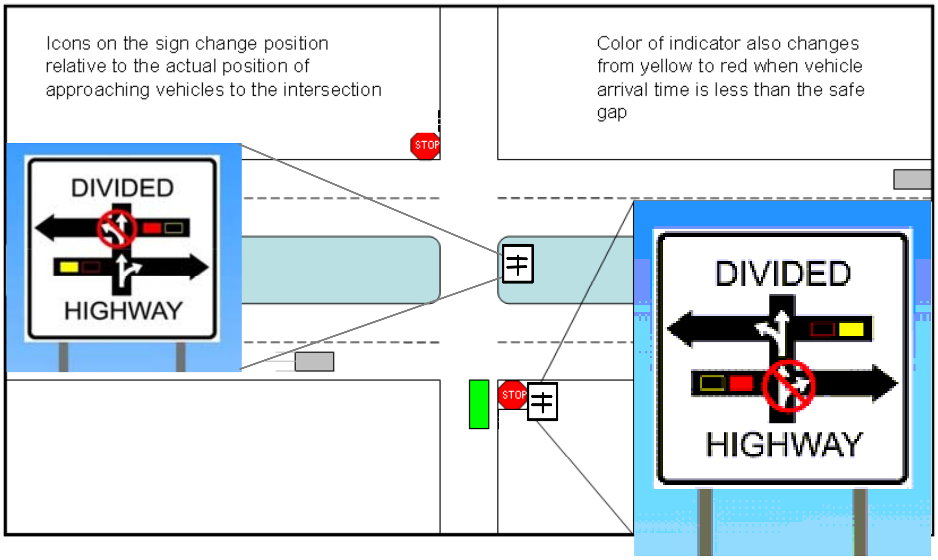
There exists a potential for rapid fluctuation among symbols/messages (especially when traffic volumes are high). This may be confusing for the driver.

Table 5.4. Icon Concept

1. Title Icon
2. Content Domain Primary Content A. Presence of vehicles that make up gaps. C. Size of available gaps. D. Judge whether a gap is safe. Secondary Content F. Alert minor-road drivers to the presence of the intersection. I. System State.
3. Description This system was created later in the design phase when the need to test an interface that directly addresses the two-stage crossing maneuver was recognized. This interface displays information that specifically provides the option to cross to the median, even if it is not safe to cross over or enter the intersection. Notifications are displayed when traffic is within the safe gap and drivers are told which individual section of the intersection they may not cross. The display consists of an iconic image of the intersection, similar to the Pac-Man concept (see Appendix III), placed to the right of the STOP sign. A second sign is also located on the right side of the median that provides information to cross the far lanes. The bottom portion of the median sign fades out when a driver is in the median, allowing them to focus on the appropriate portion of the sign. Icons display different levels of warning information about the unsafe nature of detected gaps in the near and far lanes. When a vehicle is within the specified safe gap, a red icon is illuminated and the arrows indicating maneuvers are covered with a prohibitive red circle and slash. This represents the UNSAFE TO ENTER information. When a vehicle is outside the minimum safe gap but within 12.5 s of the intersection, a yellow icon is presented, but the red circle and slash are not. This yellow icon is intended to indicate that a vehicle is approaching the intersection and that caution should be taken if the driver chooses to cross. When vehicles are not detected within the safe gap of the intersection, only the maneuver icons are illuminated.

Table 5.4. Icon Concept (continued from previous page).

4. Diagram



5. Options/Variants

- The sign could be placed to the left of the intersection on the near side.
- The size of the safe gap can be adjusted based on the type of vehicle detected on the minor road and pavement surface conditions.
- The amount of the intersection that is monitored can be changed. This may be particularly useful for intersections that have known sight distance problems. The current default is 15 s from the intersection with the yellow icon turning on when a vehicle reaches 12.5 s from the intersection.

6. Limitations/Caveats

- The sign may need to be large in order to convey the necessary information. Its size may block the minor-road driver's view of traffic.
- Interpreting symbols can be cognitively demanding and error prone when multiple levels of information are presented.
- There may be some issues related to icon legibility and comprehension (especially for older drivers). This will need to be tested during the evaluation.
- There exists a potential for rapid fluctuation between symbols (especially when traffic volumes are high). This may be confusing for the driver.
- When traffic volumes are high, there exists a chance that no safe gaps will be present and the DO NOT ENTER symbol, for one or both sides of the intersection, is shown for long periods of time. This could result in a long queue on the minor road and drivers could ignore the display as both wait time and driver frustration increase.

6. Evaluation Study

The main goal of the evaluation study was to test the informational concepts and design functions of the proposed IDS systems. The concepts presented to drivers do not necessarily represent the final designs, but instead will be modified based on the results of the study. That is, we wanted to discover what concept elements were most supportive of the driving tasks rather than testing deployable systems. By completing this evaluation, it is hoped that we can achieve a good understanding of what information should be conveyed in a decision support system. Eventually, the results of this study can help guide the content for deployable signs that are MUTCD compliant.

6.1. Participants

Volunteers were recruited from the Twin Cities and surrounding communities using newspaper advertising. All participants received information regarding the purpose of the study and were screened over the phone to determine eligibility for participation; drivers had to be in the age ranges of 20-40 (young group) or 55-75 (older group) to participate, had to have a valid driver's license, and be a low-risk candidate for simulator sickness. The phone screening questionnaire is located in Appendix IV.

Twenty-five young and 33 older participants were recruited into the study, with 48 of those (24 young; 24 older) completing the study. Ten participants (1 young; 9 older) dropped out of the study due to simulator sickness. The 27% drop-out rate for older drivers is on par or lower than that reported in other driving simulator studies examining older drivers (e.g., Caird et al., 2004).

Participants in each age group were randomly assigned to either the day or night driving conditions, resulting in 12 participants per experimental condition. Table 6.1 shows the sex, age, number of years licensed, annual mileage and ratings of driving skill for each group. There were no significant differences between the experimental groups for driving skill assessment or annual mileage, nor were there any significant differences within the young and older groups for mean age or number of years licensed (p's > 0.10).

Table 6.1. Demographic and driving experience data for age by Light Condition groups.

	Young				**Older**			
	Daylight		**Darkness**		**Daylight**		**Darkness**	
	M/n	**SD/%**	**M/n**	**SD/%**	**M/n**	**SD/%**	**M/n**	**SD/%**
Sex								
Male	6	0.50	7	0.58	8	0.67	8	0.67
Female	6	0.50	5	0.42	4	0.33	4	0.33
Age (years)	26.5	4.44	25.58	2.75	62.75	5.19	62.08	5.13
Years licensed	10.67	4.10	8.75	1.86	41.75	10.17	44.17	6.78
Annual mileage	14,833	5,424	10,666	3,869	10,683	4,561	10,833	4,041
Driving Skill	4.17	0.27	4.17	0.21	4.09	0.25	4.42	0.15

Major Accidents	4	0.33	3	0.25	0	0	2	0.17
Minor Accidents	3	0.25	1	0.08	1	0.08	1	0.08

Note: *M* = mean; *n* = sample size for cell; *SD* = standard deviation; *%* = proportion for each cell.

6.2. Driving Simulator

The study used a state-of-the-art driving simulator. All driving routes were created and managed using the Virtual Environment for Surface Transportation Research (VESTR) operated by the HumanFIRST Program. It was linked to a full-sized Saturn vehicle with realistic operational controls and instrumentation. The visual scene was projected to a high-resolution (2.5 arc-minutes per pixel) five-channel 210-degree forward field of view. The rear visual scene is projected to a screen behind the driver and is visible in the vehicle's rear-view mirror. The side mirror views are provided by LCD panels placed on the side mirrors that present a simulated side view of the driving environment from that perspective. Auditory feedback and haptic feedback were provided by a 3D surround audio system, subwoofer, car body vibration, and a three-axis electric motion system (roll, pitch, z-axis).

The simulated environment was developed so as to exactly match the features and geometry at the crossroads of US 52 and CSAH 9 in Goodhue County, MN (Figure 6.1). The model represents this intersection as closely as possible, in terms of roadway geometry and signage. The intersection angle, curves in the roadways and elevation changes present on each roadway are recreated in the simulation. The roadway was modeled using blueprints of the Goodhue County C.S.A.H. 9 Reconstruction (1991), and the State of Minnesota Department of Highways Construction Plan for Grading Trunk Highway No. 52 (1965). The sign and pole locations along the roadway were reconstructed from an onsite survey conducted by the simulator engineer and the nearby terrain, such as fields, were reconstructed using GIS data from a LIDAR survey of the area provided by the Goodhue County Engineer's office.

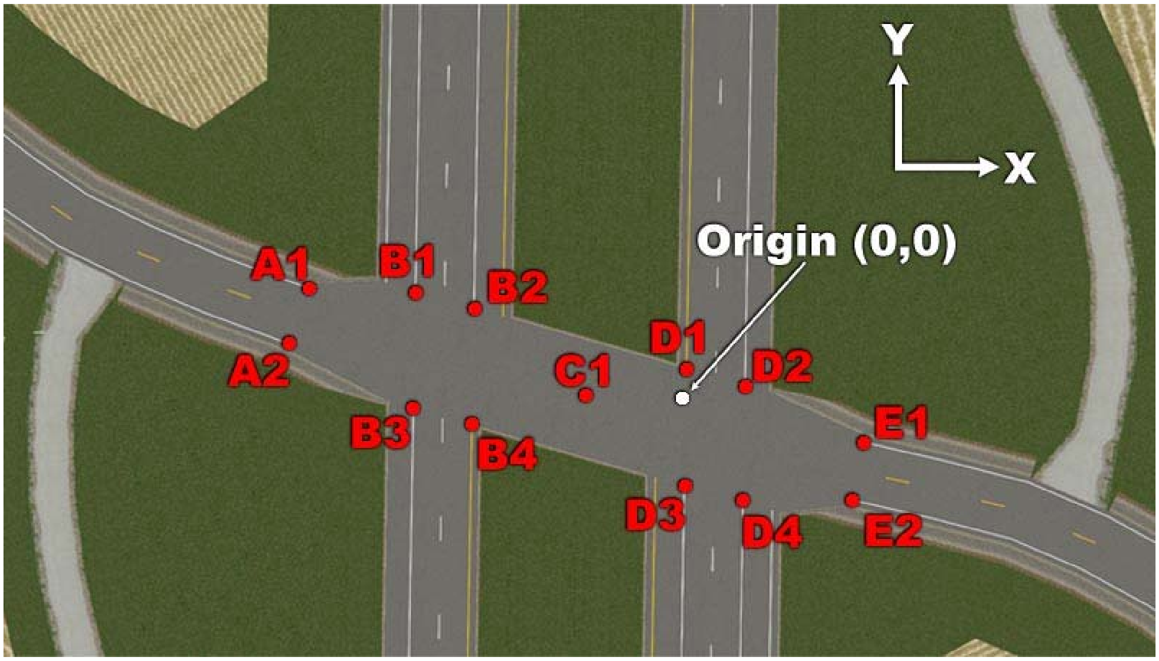


Figure 6.1. Model of TH52.

6.3. Safe-Gap Threshold

This section describes the calculations and assumptions used to determine the safe gap threshold for each sign. The threshold is based both on the time for the closest vehicle to arrive at the intersection as well as the amount of time it would take for a driver to react to this gap and take the appropriate actions to drive through the intersection.

Only a straight crossing maneuver was examined in this study. Despite this, the safe gap thresholds for the far-side lanes are based on the (more conservative) left turn in order to examine acceptability of a system that assumes the most conservative case that. This choice recognizes the fact that we cannot currently detect maneuver intent in advance of the intersection and therefore must use the most conservative case as the default maneuver. In addition, the riskier one-stage strategy of crossing is assumed.

The AASHTO (2001) left-turn critical gap value of 7.5 s was modified as per the older driver handbook (FHWA, 2001) to define a minimum safe gap threshold for use on the IDS signs:

> *Where determinations of intersection sight-distance requirements for a left-turn maneuver from a major roadway by a stopped passenger car are based on a gap model (see NCHRP Report 383), it is recommended that a gap of no less than 8.0 s, plus 0.5 s for each additional lane crossed by the turning driver, be used to accommodate the slower decision times of older drivers.*

The FHWA older driver handbook (2001) and the NCHRP (Harwood, Mason, Brydia, Pietrucha, and Gittings, 1996) suggest that a minimum left turn gap is 8 s for older drivers. Therefore, the ASHTO minimum of 7.5 s for a left-turn maneuver has been replaced with the recommended 8 s for older drivers. AASHTO (2001) also indicates the necessity of adding 0.5 s for each lane and for calculating a crossing adjustment in relation to the size of the median. This consideration has been adopted for the safe-gap thresholds used on the IDS signs. However, the critical gap changes depending on which lanes the driver is crossing and whether the sign supports a one-stage or two-stage maneuver. A one-stage strategy is when a driver accepts gaps in order to complete the crossing maneuver without stopping in the median. A two-stage strategy occurs when drivers first accept the near-lane gap in order to reach the median, then stop in the median and evaluate the far lane gaps independently for an appropriate gap, eventually accepting a gap that allows them to complete their desired maneuver (i.e., turn left or cross over). The gap-size calculations for each maneuver type are described below.

6.4. Two-Stage Crossing Strategy

The Icon, Split-hybrid and VMS signs provide far lane gap information while the driver is stopped in the median, thus, they support completing the second stage of a two-stage maneuver. Each of these signs also provides gap information for the southbound lanes that indicates when it is unsafe to cross to the median and unsafe to cross the entire intersection. Therefore, an appropriate safe gap threshold was designed to accommodate the following maneuvers for this intersection:

- Turning left from the STOP sign without stopping in the median (one-stage strategy)
- Crossing to the median from the STOP sign only (first stage of two-stage strategy)
- Turning left from the median (second stage of two-stage strategy)

6.4.1. Near-Side Lanes (Southbound) Safe Gap

Values were calculated for a driver who stopped at the STOP sign and assumed dry pavement. AASHTO (2001) recommends a minimum of 6.5 s to make a right turn or to cross one lane of traffic. It also recommends the addition of 0.5 s to cross each additional lane of traffic. We have also added 0.5 s to take into account older drivers because the AASHTO minimums do not consider the older driver. We chose to add 0.5 s for the older drivers for this maneuver because AASHTO recommends a general gap of 7.5 s for a left turn (all drivers), whereas the Older Driver Handbook recommends a gap of 8 s for a left turn for older drivers. This 0.5 s difference is what we are considering as the extra time needed for an old driver to complete the same maneuver as a young driver. The Handbook does not address the issue of crossing extra lanes when not making a left turn, but if an increase of 0.5 s over the AASHTO minimum is prudent for an older driver for a left turn, it seems likely that it would also apply to other gap acceptance maneuvers. The calculated minimum safe gap while stopped at the STOP sign for crossing to the median was 7.5 s. This value accounts for the first stage of a two-stage crossing strategy, and is used to inform drivers about turning right or crossing to the median. Because the minimum safe gap required to complete a right turn is 6.5 s, the 7.5 s threshold for the Icon, Split-hybrid and VMS signs for crossing to the median accommodates this threshold. Only the icon sign explicitly indicates when a right turn is prohibited.

Crossing to Median

Passenger car crossing 1 lane	=	6.5 s
Additional lanes to cross (1)	= +	0.5 s
Older driver adjustment	= +	0.5 s
		7.5 s

6.4.2. Far-Side Lanes (Northbound) Safe Gap

When drivers are stopped in the median, they are able to make two maneuvers. The first is to cross over both lanes and continue driving on the minor road, which would require the same gap as crossing the near-side lanes to the median (7.5 s). The second is to make a left turn into the far-side lanes. Either of these maneuvers constitutes the second stage of a two-stage strategy (provided the driver has actually stopped in the median). As with the first stage, the worst-case scenario must be considered, namely, making a left turn. In this case, AASHTO recommends 7.5 s for making a left turn, but this value does not take into consideration the older driver. The FHWA Older Driver Handbook recommends a minimum of 8 s to make a left turn for older drivers. Therefore, the median signs required a gap to be 8 s or larger to be considered a safe gap for the second stage of the two-stage crossing strategy. The minimum gap for a one-stage crossing strategy is discussed below.

6.5. One-Stage Crossing Strategy

While sitting at the STOP sign, a driver may also choose to complete either a left turn or cross over the entire intersection without stopping in the median. This means they would traverse the near-side lanes, the median, and either turn into the far-side lanes or cross the far-side lanes in a one-stage process. The safe gap for a one-stage strategy takes into account the worst-case scenario of making a left turn into the far lanes, and includes time to cross the southbound lanes and the median.

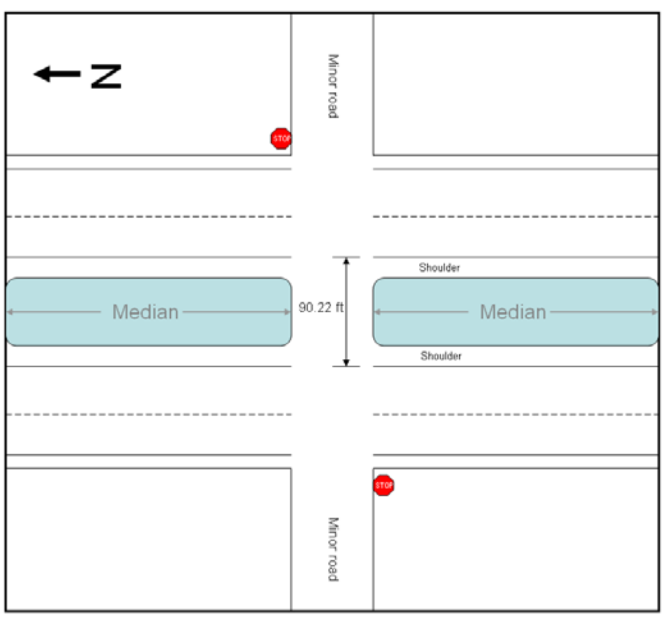


Figure 6.2. Median width for candidate intersection used for safe-gap calculation.

First, the one-stage safe gap assumes the minimum left turn value of 8 s recommended for older drivers by the Older Driver Handbook to cross to the median and make a left turn. Second, it includes a 0.5 s increase for crossing the extra southbound lane. Finally, it also includes a 4 s adjustment for crossing the median. The median of the modeled intersection is 90.22 feet across (Figure 6.2) from the edge of the near-side (southbound) lanes to the edge of the far-side (northbound) lanes. According to AASHTO (2001), the following would apply for both left turns and crossing maneuvers:

Left turn	
Passenger car turning left (1 lane)	= 8.0 s
Additional lane to cross (1 southbound)	= + 0.5 s
Median converted to equivalent lanes	
(90-ft median / 12-ft lane = 7.5 lanes)	= + 4.0 s
	12.5 s safe gap

6.5.1. Simulated Traffic Stream

The gaps in the traffic flow that participants experienced were standardized to better facilitate testing the signs. The specified traffic stream (also see Appendix E) was developed around the determined safe gap for each set of lanes, as described in the previous section. Two sets of traffic streams, with the same gap pattern, were developed, but each stream had different types of vehicles in the pattern to reduce the likelihood of drivers learning when a gap might appear (i.e, after a specific truck/car type).

Figure 6.3 shows the southbound traffic stream. The scenario starts with a series of 3 s gaps for the first two minutes, producing a heavy flow of traffic while the participant is stopped at the STOP sign. The purpose of this was to give participants an opportunity to examine the signs before crossing. At the same time the near-side lane experienced the two minutes of 3 s gaps, the far-side traffic was spaced 10 s apart for the first two minutes of the scenario (see Figure 6.4). The purpose of this was to provide an opportunity for drivers to attempt a one-stage maneuver if they felt comfortable crossing on the small 3 s gap. In this case, they could cross the near lanes on the smaller gap in order to cross completely over the far lanes without stopping in the median using the larger 10 s gap.

After two minutes, the near-side traffic provided an increasingly larger gap to drivers after every few vehicles. Thus, drivers would see 2-5 vehicles with a 3 s gap, followed by a 4 s gap. They would then see another set of 3 s gaps, followed by a 5 s gap. The presented larger gaps increased by 1 s increments each time, up to a maximum value of 9 s. At the same time, the far--side traffic stream experienced a series of vehicles with a 3 s gap separation from 120 s to 207 s in the scenario. This near-side gap pattern allowed data to be collected about driver's minimum accepted gap values and also allowed drivers to eventually see the signs change when the 7.5 s safe gap threshold was exceeded. The far-side pattern of short gaps was used to encourage drivers to make a two-stage maneuver. That is, drivers who accepted a larger gap in the near-side lanes (e.g., 4 s, 5, s, 6 s, etc) were faced with a stream of small gaps when they arrived at the median, if they chose not to wait at the STOP sign for a larger gaps in both directions.

After 207 s, there was no more near-side traffic. At 210 s the far-side traffic presented larger gaps to the drivers, spaced by 2-5 vehicles with 3 s gaps. The larger gaps increased by 1 s

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increments each time a large gap was presented in this stream with a maximum value of 15 s. No vehicles appeared in the northbound lanes after 312 s into the scenario. Drivers who chose to wait at the STOP sign for this length of time would eventually be able to make a one-stage maneuver, either because a large gap appeared in the far-side lanes that accommodated a one-stage maneuver, or because they would eventually see all traffic cease in both directions. Drivers who entered the median and stopped would eventually be provided the opportunity to cross on a larger gap. These drivers could also see changes in any median signs (Icon, Split-hybrid, VMS) when the first 9 s gap appeared.

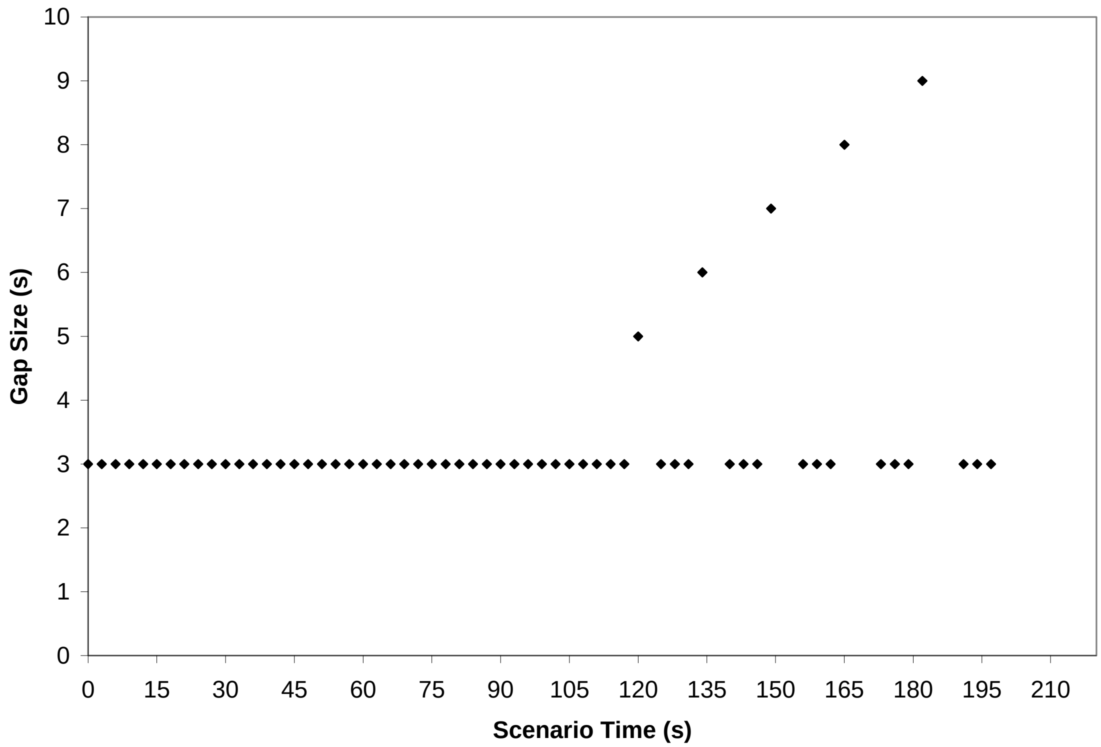


Figure 6.3. Near-side (southbound) traffic stream from start of scenario until 207 s, when traffic stops coming in the southbound lanes.

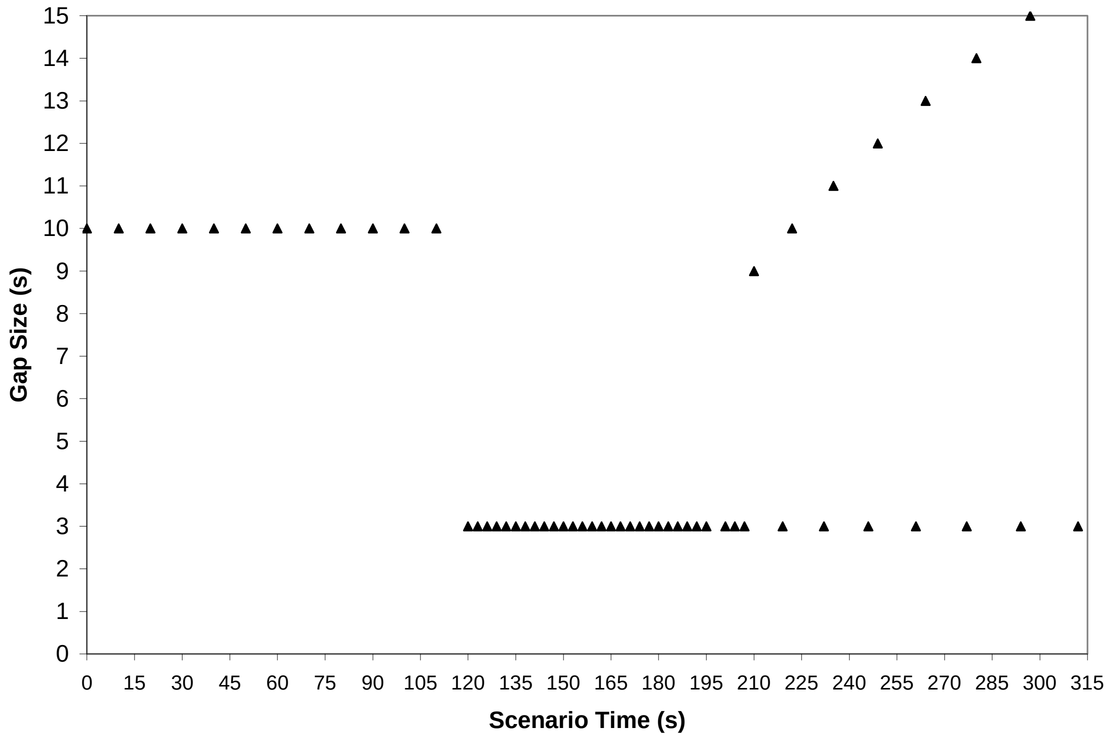


Figure 6.4. Far-side (northbound) traffic from start of scenario to 312 s, when traffic stops coming in the northbound lanes.

This traffic pattern was developed to meet several experimental goals. First, the pattern would potentially induce frustration in the drivers as they waited for a larger gap to appear. Including frustration due to the traffic pattern better represents the conditions of decision making that would exist for drivers at this intersection in the real world. Second, the systematic exposure to increasing gap sizes allowed for a minimal acceptable gap to be measured and allowed us to test drivers' acceptance of gaps above and below the safe gap threshold. Third, if the gaps were random, a gap larger than the safe gap threshold could appear early and be taken by a driver before information about the safe gap threshold could be presented to drivers. In this case, no data would be available about the minimum accepted safe gap.

6.6. Interface Conditions

Based on the above discussion of derived safe gaps, this section describes the tested interfaces in terms of the threshold gap values used for each type of maneuver the sign accounts for and the information presented to the driver is shown. Table 6.2 indicates which signs support a one-stage or a two-stage crossing strategy.

Table 6.2. Which signs support a one-stage versus a two-stage crossing strategy.

	Supports 1-stage Strategy	Supports 2-stage Strategy
Hazard Sign*	Yes	No
Icon Sign	Yes	Yes
Split-hybrid Sign	Yes	Yes
VMS Sign	Yes	Yes

*Note: The Hazard sign could support a 2-stage strategy if a second sign was placed in the median to only monitor the far-side traffic. However, this was not done in this study and the current iteration only supports a 1-stage strategy.

6.6.1. Baseline

The Baseline interface is a STOP sign (R1-1) mounted on two posts (Figure 6.5). Below the STOP sign is a divided highway sign (R6-3) and above it is a double-sided one-way sign (R6-1). This is the traffic control that actually exists at the intersection. This sign does not help drivers make a crossing decision. It only conveys information that tells the driver to stop at the intersection.

Figure 6.5. Baseline condition signage.

6.6.2. Hazard Sign

The tested version of the Hazard sign took into account the time-to-arrival of approaching vehicles in both the near and far lanes. One potential problem that is recognized with this implementation is the potential for confusion over how the sign functions if two or more vehicles are at similar distances from the intersection in both directions. For example, if two cars are each 10 s from the intersection in each set of lanes (near and far) the warning message will be triggered, even though it may be safe to cross to the median because the near-side vehicle is more than 7.5 s away from the intersection. Originally, the sign (see Appendix C) also took into account the speed of approaching vehicles. However, the former implementation was seen as redundant, in that vehicles traveling at excessive speeds are taken into consideration once they are within proximity to the intersection by virtue of their arrival time based on their speed.

Second, the former implementation would not be as understandable to drivers in that it performed under two sets of stipulations instead of just one. This could have made the sign less credible and potentially less accepted by users. The control logic for the Hazard sign is defined in Table 6.3. Figure 6.6 shows the states of the hazard sign depending on the location of traffic in relation to the safe gap thresholds for the near and far-side lanes.

Table 6.3. Control logic for the Hazard sign.

Condition	**Message**
Near-side vehicle within safe gap (7.5 s) (far side vehicle absent or outside 12.5 s safe gap) - OR - Near-side vehicle within safe gap (7.5 s) and far-side vehicle within safe gap (12.5 s)	Sign turned on to display, DANGEROUS TRAFFIC. 
Near-side vehicle <u>not</u> within safe gap (7.5 s) - AND - Far-side vehicle <u>not</u> within safe gap (12.5 s)	Sign turned off. 

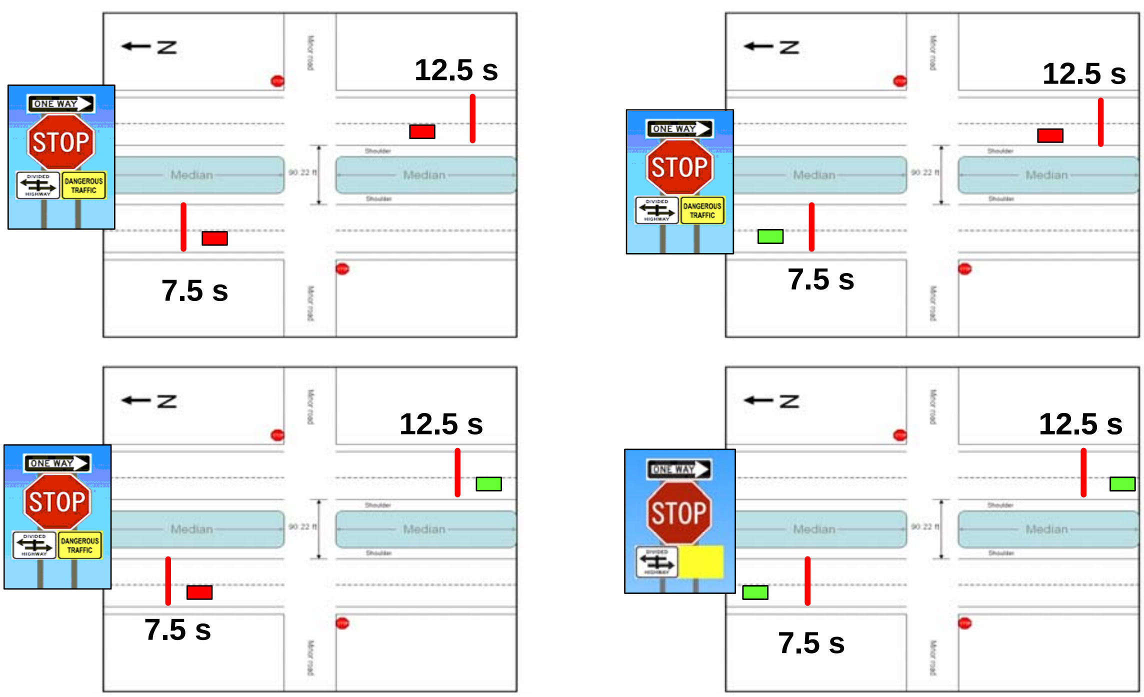


Figure 6.6. Hazard sign states based on location of approaching traffic in near and far lanes.

6.6.3. Split-hybrid

The Split-hybrid uses two signs; each sign has a top element and a bottom element. At the bottom, elements show the gap (in seconds) for each direction of travel. At the top, an element displays either a DO NOT ENTER sign (R5-1), a sign indicating no left turn or straight crossing, or a yellow warning diamond with the text CAUTION. The gap times are displayed in white text on a black background for safe gaps, and in white text on a red background for unsafe gaps. Vehicles outside of 12.5 s in either the near-side or far-side lanes are not tracked, resulting in a blank gap display. The sign for traffic from the left (near-side) is placed on the left side of the road, across from the STOP sign, angled toward a stopped driver. This location facilitates scanning the traffic scene in conjunction with the sign. The sign for traffic from the right (far-side) is placed in the median, to the right of the yield sign.

It should be noted that the Split-hybrid sign does not directly support a two-stage strategy when stopped at the STOP sign. A two-stage strategy is implied to drivers by the presence of the median sign that provides information about the far-side lanes when in the median. However, the information presented on the near-side sign also accounts for the more conservative safe gap threshold for a one-stage strategy. The control logic for the near-side sign warning messages of the Split-hybrid is defined in Table 6.4.

Table 6.4. Control logic for the near-side sign warning messages of the Split-hybrid interface. Median signs are shown in Table 20. Note: when sitting at STOP sign, the icon shown for the far-side vehicles corresponds to that being shown for the near-side vehicles.

Condition	**Message/Symbol**
Near-side vehicle within safe gap (7.5 s) (far side vehicle absent or outside 12.5 s safe gap) - OR - Near-side vehicle within safe gap (7.5 s) and far-side vehicle within safe gap (12.5 s)	DO NOT ENTER icon is presented. Near-side vehicle's time-to-arrival is shown below. 
Near-side vehicle not within safe gap (7.5 s) - AND - Far-side vehicle within safe gap (12.5 s)	Do not turn left or cross symbol is shown. Near-side vehicle's time-to-arrival is shown below. 
Near-side vehicle not within safe gap (7.5 s) - AND - Far-side vehicle not within safe gap (12.5 s)	CAUTION icon is shown. Near-side vehicle's time-to-arrival is outside the 12.5 s gap. 

The control logic for the median sign for the Split-hybrid design is defined in Table 6.5. These are presented to the driver once they have reached the median and now only have to cross the far-side traffic lanes or turn left into the far lanes. These signs assume the worst-case gap scenario of a left-turn (8.0 s). Only the DO NOT ENTER and CAUTION icons are used for the median sign. The median sign displays the same icon that the near-side sign does when a driver is stopped at the STOP sign. Once the median is occupied (vehicle sensed), the logic switches to display only the icons relevant for the far lane traffic. If another vehicle arrives at the STOP sign while a vehicle is occupying the median, the near-side sign will continue to display the DO NOT

ENTER icon, even if the near-side gap is larger than the safe threshold. This is to prevent drivers from queuing in the median. The system allows for only one vehicle in the median at a time.

Table 6.5. Control logic for the median warning messages of the Split-hybrid interface.

Condition	**Message/Symbol**
Far-side vehicle within safe gap (8 s)	DO NOT ENTER icon shown. Time-to-arrival for far-side vehicle shown below. 
Far-side vehicle not within safe gap (8 s)	CAUTION icon shown. Time-to-arrival for far-side vehicle shown. 

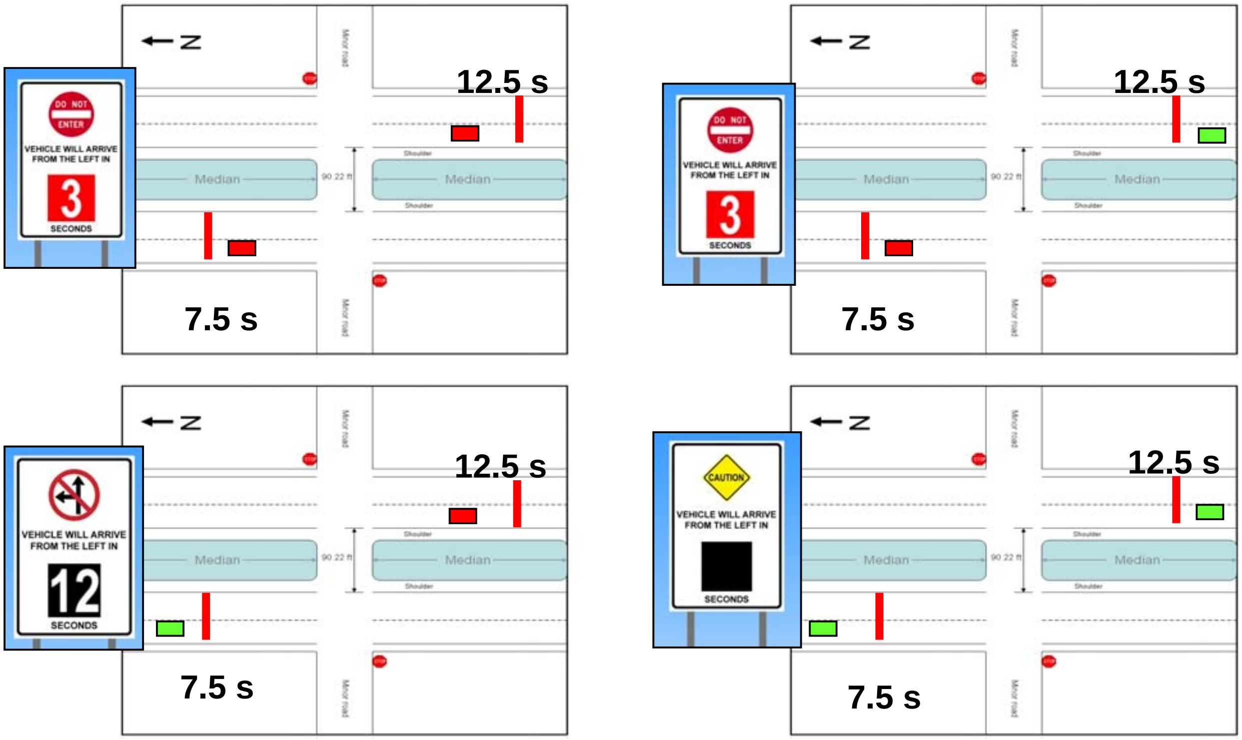


Figure 6.7. Split-hybrid sign states based on location of approaching traffic in near and far lanes.

6.6.4. Variable Message Sign (VMS)

This concept takes the logic and warning message signs from the Split-hybrid concept, but only displays the icons (see Table 6.6). No countdown timer exists on the VMS. Below each warning sign are the words WATCH FOR TRAFFIC. As with the Split-hybrid sign, the DO NOT ENTER and the CAUTION icons are the only two presented on the median sign (see Table 6.7). Figure 6.8 shows the VMS sign states based on where traffic is in relation to the safe gap thresholds for the near and far lanes.

Table 6.6. Control logic for the Variable Message Sign ("VMS") for near-side sign.

Condition	Message/Symbol
Near-side vehicle within safe gap (7.5 s) (far side vehicle absent or outside 12.5 s safe gap) - OR - Near-side vehicle within safe gap (7.5 s) and far-side vehicle within safe gap (12.5 s)	DO NOT ENTER icon is presented. 
Near-side vehicle not within safe gap (7.5 s) AND Far-side vehicle within safe gap (12.5 s)	Do not turn left/cross symbol is shown. 
Near-side vehicle not within safe gap (7.5 s) - AND - Far-side vehicle not within safe gap (12.5 s)	CAUTION icon is shown. 

Table 6.7. Control logic for VMS median sign.

Condition	Message/Symbol
Far-side vehicle within safe gap (8 s)	DO NOT ENTER icon shown. 
Far-side vehicle not within safe gap (8 s)	CAUTION icon shown. 

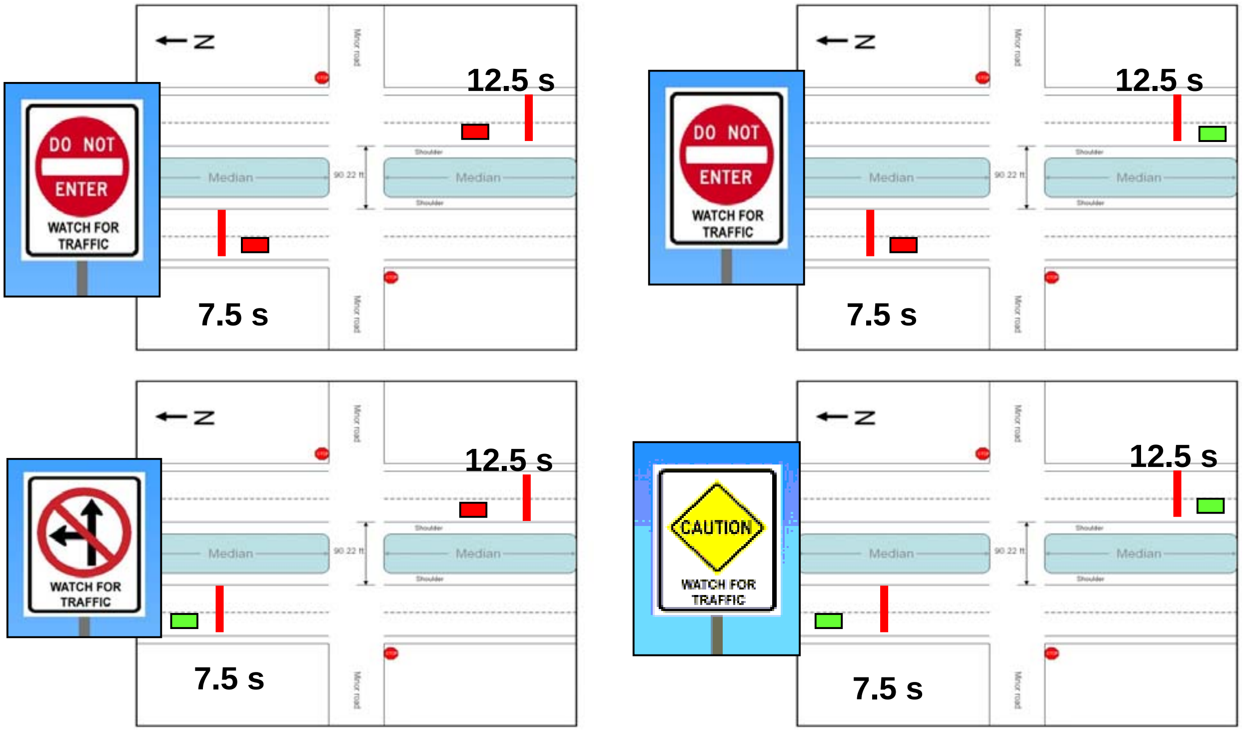


Figure 6.8. VMS sign states based on location of approaching traffic in near and far lanes.

6.6.5. Icon

The Icon sign was developed after the concept development process since none of the other signs explicitly gave drivers information pertinent to both one- and two-stage maneuvers in a unified display. The Split-hybrid and VMS signs potentially facilitate a two-stage maneuver by providing information in the median specific to the far-side crossing. However, the initial information presented at the crossing is based on the more conservative safe gap threshold for a one-stage maneuver.

The Icon sign is a graphic representation of the intersection to provide complete information to support both a one-stage and two-stage strategy simultaneously in a simple interface. It uses red and yellow icons to represent whether a car is within 7.5 or 12.5 s of the intersection. The median model uses faded icons (60% opacity) for the bottom half of the display to draw attention to the current maneuver being performed (i.e., crossing the far lanes). When a car is within 7.5 s, it uses a slashed-circle to warn the driver to not proceed. Table 6.8 shows three examples of the warning logic. Overall, the Icon sign shows the most information about the intersection and has the potential to be confusing or overwhelming for drivers when they first interact with it. Figure 6.9 shows the Icon sign states based on where traffic is in relation to the safe gap.

Table 6.8. Control logic for Icon interface. Three possible conditions are shown for when driver is stopped at the stop sign.

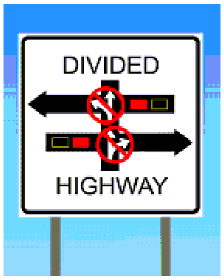
Condition	**Message/Symbol**
Near-side vehicle within safe gap (7.5 s) - OR - Near-side vehicle within safe gap (7.5 s) and far-side vehicle within safe gap (12.5 s)	Sign displays no right, no left, and no straight-through maneuvers. Vehicles are red for both directions 
Near-side vehicle <u>not</u> within safe gap (7.5 s); near-side vehicle within 12.5 s gap - AND - Far-side vehicle within safe gap (12.5 s)	
Near-side vehicle <u>not</u> within safe gap (7.5 s) - AND - Far-side vehicle <u>not</u> within safe gap (12.5 s)	Vehicles are not filled in with any color. Sign shows right, left or straight-through maneuver possible. 

Table 6.9. Control logic for Icon interface. Two possible conditions are shown for when driver is stopped at median sign. The bottom portion would be 60% faded.

Condition	Message/Symbol
Far-side vehicle within safe gap (8 s)	Do not turn left/cross symbol present. Vehicle from right is red. Bottom icons faded out in actual implementation. 
Far-side vehicle not within safe gap (12.5 s)	Left-turn/cross symbol present. Vehicles are not filled in with any color. 

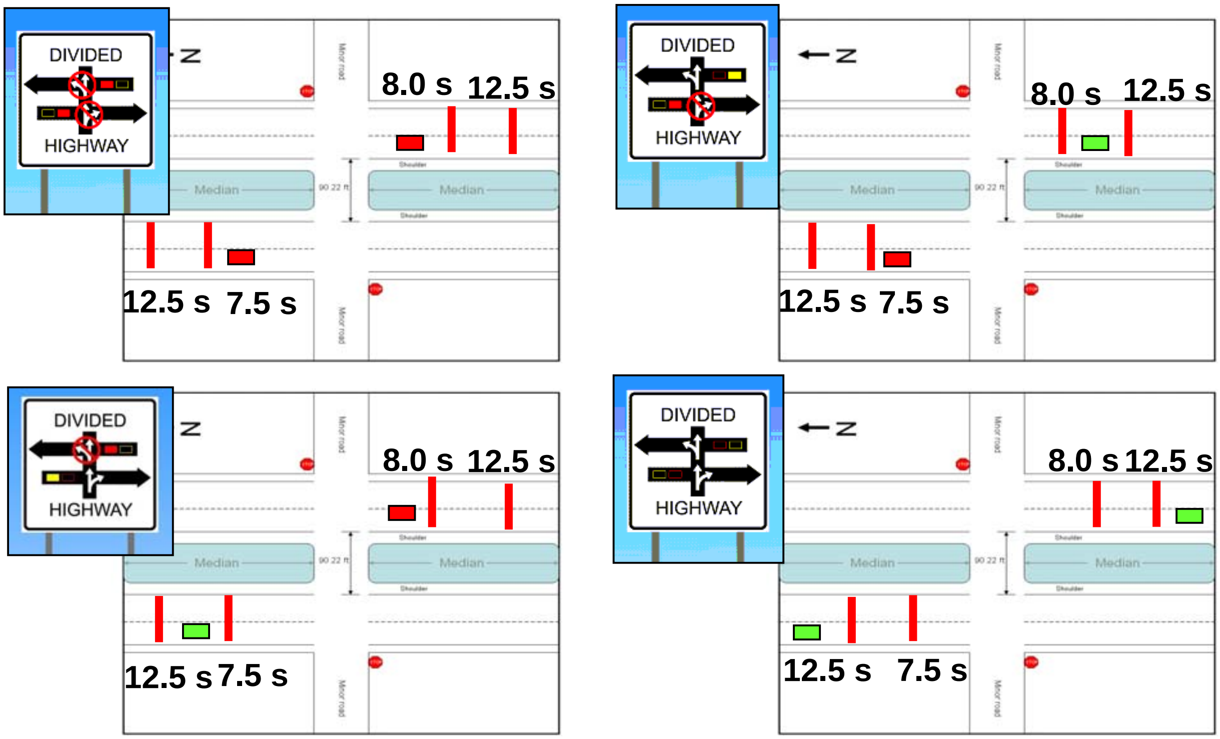


Figure 6.9. Icon sign states based on location of approaching traffic in near and far lanes.

6.7. Lighting Conditions

Participants experienced either daytime or nighttime conditions so that the proposed interfaces will be assessed during different lighting conditions. The same traffic patterns will be used in both lighting conditions so that the level of visibility is compared without confounding traffic density. There are several reasons for including darkness as an additional condition. First, a recent safety audit and analysis of crash records for TH52 (including the test site) suggests that there are more crashes in darkness than expected in comparison to comparable rural highways. Second, it is relevant to evaluate the proposed signs under suboptimal conditions represented by darkness when viewing conditions are limited and workload is expected to be higher. This will provide conclusions about the performance and usability of the proposed interfaces under high-risk conditions when drivers are least able to cope with additional demands. In this manner, the evaluation will assess the interfaces under conditions most likely to demonstrate undesirable characteristics of the proposed designs.

6.8. Independent Measures

The independent measures included the following:

- Sign Condition (within): Baseline, Hazard Sign, Split-hybrid, Icon, and VMS
- Age Group (between): Young [20-40 years], Older [55-75 years]

- Lighting Conditions (between): Day versus Night [i.e. low light]

6.9. Experimental Design

Each participant crossed the intersection twice using each sign, for a total of 10 trials. The order of sign presentation was randomized using six presentation orders, but drivers completed two drives with each sign before moving onto the next sign in the order. Each sign appeared at the beginning of a presentation order at least once and each sign appeared at the end of a presentation order at least once. For each sign, a participant saw both traffic streams with the different vehicle patterns (see Simulated Traffic Stream section above).

6.10. Dependent Measures

The dependent measures of this study consisted of variables derived from data recorded by the simulator as a participant drove and questionnaire data. The variables are described in three categories. The first category, crossing maneuver variables, deals with how much time drivers spent crossing the intersection. The second category, performance variables, relates directly the driver's performance, such as the size of the gap they accepted, their safety margins, or whether or not they experienced a collision. Figure 6.10 shows the intersection boundaries.

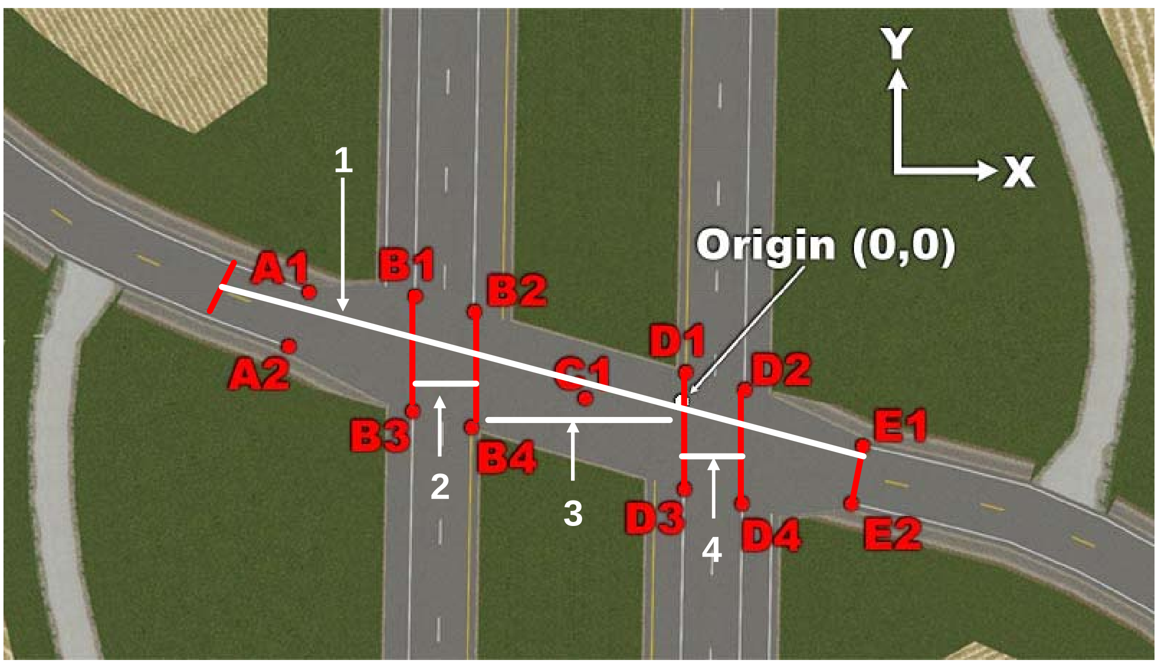


Figure 6.10. Intersection boundary definitions. 1: Entry and exit boundaries for intersection. 2: Near-side (southbound) lane boundaries. 3: Median boundaries. 4. Far-side (northbound) lane boundaries.

6.10.1. Crossing Maneuver Variables

6.10.1.1. Wait Time (s)

Wait time is the time from the start of the crossing maneuver until the first time the foot depressed the accelerator in which the participant continued to accelerate into the intersection after being stopped OR when participant's vehicle crossed over the intersection lane boundary. This is equivalent to the movement time subtracted from total time.

6.10.1.2. Minimum Speed Through Median (mph)

Minimum speed (mph) of the vehicle while crossing the median from when the front bumper entered the median until the rear bumper exited the median. Drivers showing a minimum speed in the median of less than 4 mph are considered to have paused sufficiently to examine the northbound traffic (two-stage maneuver). Drivers showing a minimum speed of 5 mph or greater are considered to have not slowed sufficiently to check for northbound traffic.

6.10.1.3. Travel Time to Intersection (s)

The amount of time it takes from the start of the scenario to the beginning of the crossing maneuver (18.24 m from intersection) was used to calculate total time. This time may potentially be used as a covariate for wait time and total crossing time, which has wait time as a component. Travel time to intersection could potentially affect wait time at the intersection because drivers taking more time to get to the intersection would see larger gaps appear sooner, thus reducing their wait time compared to drivers who approached faster. This is because the traffic stream began as soon as the scenario started. Travel time will be correlated with wait time and total time to determine whether it affected gap acceptance (inverse relationship). An ANOVA analysis will also be run for all conditions to determine if travel time differed significantly between age groups or light conditions. For example, if older drivers approached the intersection significantly slower than younger drivers, the older drivers may show larger gap-acceptance values overall because larger gaps will be available to them more readily. Drivers approaching the intersection quickly will see mostly 3 s gaps for the first two minutes before the larger gaps start to begin to be available.

6.10.2. Performance Variables

6.10.2.1. Accepted Gap (s)

The accepted gap is the maximum size of the gap accepted as defined in the traffic flow model. All vehicles are traveling at the same speed with a pre-determined gap; this measure captured this pre-determined gap size (i.e., 5 s, 6 s). The accepted gap is reported for both the near-side and far-side lanes.

6.10.2.2. Initial Time-to-contact (s)

This is the time-to-contact (TTC) value for when the participant begins crossing the intersection. It will be similar, but not identical, to the predetermined gap. For example, a person selecting a 6 s gap in the traffic stream may have an initial TTC of 5.25 s. The 0.75 s difference is the time it takes the participant to begin moving into the intersection once selecting a gap. The difference between accepted gap and initial TTC represents the response time of the individual after selecting a gap. The initial TTC is reported for both the near-side and far-side lanes.

Initial TTC is similar to lag as it constitutes what is remaining of a gap once a vehicle in the lead that makes up a gap passes the intersection.

6.10.2.3. Safety Margin (s)

The safety margin is the minimum TTC during each stage of the crossing maneuver. It best describes what is left of the gap the driver has chosen when the driver is at maximum exposure in the intersection. Safety margin is similar to Initial TTC in that it will change depending on how quickly a driver moves through the intersection. Because safety margin examines the size of the gap at maximum exposure (i.e., when the driver is in the middle of the lanes) it can be used as a measure of the safety of a driver's acceptance of a gap. For example, a slow driver may accept a larger gap than a faster driver but could potentially have the same safety margin. There were two safety margins, one for crossing the near-side lanes and one for crossing the far-side lanes. For each stage of crossing, the TTC (safety margin) was taken when the participant's vehicle was at the midpoint of the lanes. At this point, the vehicle was at maximum exposure for a conflict or collision. Safety margins are reported for both the near-side and far-side lanes of traffic.

6.10.2.4. Speed (mph)

Speed (mph) was logged for each phase of crossing. A speed value was taken when the midline of the participant's vehicle was in the midline of the near-side lanes and when the midline of the participant's vehicle was in the midline of the far-side lanes.

6.10.2.5. Collisions (number)

The number of collisions that occurred during each gap-acceptance scenario was collected. A participant could potentially experience two collisions per crossing maneuver (1 in the near-side lanes; 1 in the far-side lanes). Therefore, the total number of potential collisions was 960 for the study (2 per trial x 10 trials x 48 participants). Collisions will be reported as a frequency variable.

6.10.2.6. Conflict Count (number)

The number of conflicts that occurred during each gap-acceptance scenario was collected. A participant could potentially experience two conflicts per crossing maneuver (near-side and far-side lanes). Conflicts occurred when the safety margin (TTC) with nearest major-road vehicle was less than 1.5 s (see Carsten & Tate, 1999). The total number of potential conflicts was 960 for the study (2 per trial x 10 trials x 48 participants).

6.10.2.7. Sign State

The sign state is the state the sign was in when the participant began the crossing maneuver for each phase of crossing. For the Icon, VMS and Split-hybrid signs, there were two sign states to report. The first was the near-side (by STOP sign) sign state when the participant began his or her maneuver from the STOP sign. The second was the sign state of the median sign when the participant entered the far-side lanes from the median. For the Hazard sign, there was only one sign state to report. This was the state of the sign when the participant began the crossing maneuver from the STOP sign.

6.10.3. Questionnaire Data

The following questionnaires can all be found in Appendix D.

6.10.3.1. Demographics

Participants were asked to fill out a demographic questionnaire before driving the simulator scenarios. These questions included general demographic, driving experience, and medical questions. Age (older and young) and lighting (daytime and nighttime) groups will be compared in order to detect differences between subject variables which may serve as independent variables or covariates for analysis.

6.10.3.2. Mental Workload Ratings

To evaluate mental effort, the NASA Raw Task Load Index (RTLX) was completed after each trial. In this way, comparisons within each sign condition were compared to see if a participant's mental effort level changed with sign experience in addition to comparing mental effort experienced between comparisons. The raw (non-weighted) average of all scales and the scores from each of the six scales are taken separately to evaluate these mental workload components: mental demand, physical demand, time pressure, (participant's level of) performance, effort, and frustration level.

6.10.3.3. Post-Condition Questions

The post-condition questionnaire asked participants their dis/agreement with 10 statements relating to the usage of each sign. Then participants were shown an image of the sign and asked:

To describe how they thought the sign worked and what type of information it provided.

If they used the information provided by the sign to help make their decisions during the crossing maneuver.

- What they liked most about the sign.
- What they liked least about the sign.
- To note any additional comments they had about this sign.

Comments were sorted by age, lighting condition, and sign type and used to emphasize driving performance results and to get a general opinion about the signs.

6.10.3.4. Usability Questionnaire

Participants completed a measure of usability that assessed their satisfaction with the signs and their perceived usefulness of the signs (as described in Van der Lann, Heino & de Waard, 1997). The drivers completed a series of questions that asked them to indicate where their experience with the sign fell on a continuum between two antonyms (e.g., between "bad" and "good"; "useful" and "useless"). Satisfaction and usefulness results will be compared across signs.

6.10.3.5. Sign Ranking

Participants were shown images of all five sign conditions and asked to rank them from "1" to "5" based on preference and how helpful they felt each one was for making the crossing maneuver. They were also given space to explain their rankings.

6.10.3.6. Comprehension of Sign States Questionnaire

At the end of the study, drivers were presented with a questionnaire that showed each of the signs they had viewed in each of two or three states that could occur while stopped at the STOP sign. The states correlated to one of the following meanings:

- Stop and wait
- Proceed to median and wait
- Cross entire intersection

Participants were asked to decide what the sign was telling them to do if they were stopped at the STOP sign. This questionnaire included the five signs tested in the experiment. The Hazard sign only has two states: stop and wait or cross entire intersection, while the Split-hybrid, Icon and VMS signs can show all of the three states listed above. A frequency count of the number of participants who answered correctly for each presented sign state was conducted and the values converted to percentages.

It also included the Speedometer sign and two icons that could be used for the Split-hybrid or VMS signs in lieu of the DO NOT ENTER sign. The goal of this questionnaire was to test comprehension of the signs that were seen and also to see how drivers interpreted other potential signs that could be used. The Speedometer was included in the quiz even though implementation in the simulator did not occur. There were 16 items total on this questionnaire.

6.11. Procedure

All participants completed the informed consent process. An experimenter explained the form to them and then had the participant read and sign the form if they agreed to participate in the study. Participants then read a description of what the study would involve and filled out the demographic and driving experience questionnaires, followed by the visual acuity screening. Study materials are located in Appendix D.

Table 6.10 shows the order of tasks completed by participants in the evaluation.

The driver was talked through at least two practice driving sessions, which presented the same intersection the driver would experience during the experiment, only approaching it from the opposite direction. Drivers were given instructions on how to operate the car and what they could expect in the simulation, such as road speed, traffic and what their task was (i.e., to cross the intersection safely). The participant drove the practice sessions in the same light condition they experienced in the experimental drives (i.e., day or night). Light traffic was used during the practice drive to give participants an understanding of how the traffic flowed. Participants were able to ask questions during the practice drive so that they could better familiarize themselves with the simulator and their task. Once participants completed two crossings, they were asked if they felt comfortable with the simulator tasks. If they responded positively, the experimenter moved on with the study. If participants wanted more practice they were able to complete a third practice drive. The goal of the practice session was to ensure drivers were comfortable with driving the simulator and crossing the intersection before being exposed to the experimental conditions.

Before the experimental drives, participants were informed that they would be crossing the same intersection that they had seen in the practice drive, but that there would be new signs present at the intersection. Participants were told they would see five different signs and they would drive the intersection twice with each sign, completing questionnaires after each drive. They were informed the signs were smart signs that monitored the crossing traffic at the intersection to detect safe gaps, and that the messages on some of the signs would change to display different types of information depending on traffic conditions. Finally, participants were informed that their goal was to cross the intersection as they normally would if they encountered these traffic signs in the real world. They were told to examine the signs to see if they understood the information they provided and to use the information if they thought it was useful for crossing the intersection.

Participants then drove two trials with each sign. After each trial, the participant answered the NASA RTLX mental workload scale. After each trial set with one sign, the participant answered the post-condition questions related to the sign they had just interacted with. At the end of the post-condition questionnaire for each sign, participants were provided with a description of how each sign was intended to function. The description included a diagram of where the signs were positioned at the intersection and an explanation of what the messages displayed meant in relation to the presence or absence of traffic approaching the intersection. Once they had read this description of the sign's function, participants filled out the usability questionnaire.

After all five experimental sign conditions were completed drivers answered the sign-ranking and sign-state questionnaires. They were then debriefed in regard to the expected outcomes of the study and were allowed to ask questions. Finally, all participants were thanked for their time and compensated for participating.

Table 6.10. Order of simulation and questionnaire tasks for IDS evaluation.

Task Order	**Tasks**
1	Informed Consent
2	Demographic Questionnaire
3	Vision Testing
4	Practice Drives
5	Trial 1
6	NASA TLX
7	Trial 2
8	NASA TLX
9	Post-Condition Questions
10	Explanation of Sign's Function
11	Usability Questionnaire
12	Repeat Steps 5-8 for each Sign Condition (5 conditions total)
13	Sign Preference Ranking
14	Sign State Questionnaire
15	Debrief and Payment

7. Results

7.1. Data Screening

The data collected was analyzed for missing values and outliers using SPSS 13.0. Participants were excluded from an analysis of a variable if they were an extreme outlier in two or more of the sign conditions. Missing values were replaced using a method appropriate to the variable being analyzed.

Trial data for each sign condition was either averaged or summed together depending on the variable being analyzed. For example, because collisions and conflicts are individual events, they were summed across trials to give a frequency count. However, crossing-maneuver and gap-acceptance data were averaged across the two trials to give a single gap-acceptance value for each subject. Trial data was also subjected to testing (paired comparisons T-test) to determine if there were order effects between the first and second presentations of each four sign conditions. There were no significant order effects present for any of the variables.

For all the post-condition questionnaire data, there were only 33 missing values out of a possible 7,440 responses for all participants. Analyses for the questionnaire data were run with the values available; missing values were not replaced. One participant did not fill out the ranking or the sign-state questionnaire at the end of the study.

7.2. Data Analysis

The main analyses examined the interaction between sign, age and light conditions. The first level of analysis for continuous variables was a 2 (Age: young, older) x 2 (Light Condition: day, night) x 5 (Sign: Baseline, Hazard, Split-hybrid, Icon, VMS) mixed-model analysis of variance (ANOVA). *Post-hoc* analyses were conducted on the highest-level significant interaction to determine differences between signs, age groups and light conditions. For example, if a three-way interaction was significant, *post-hoc* analyses were not run on significant two-way interactions. However, because a main goal was to discover how the signs performed, all significant main effects of sign were subjected to *post-hoc* analyses. Results were considered significant if alpha was less than 0.05. However, trends are reported for age results approaching an alpha of 0.10. For all ANOVA analyses the more conservative Huynh-Feldt correction was used to account for violations of sphericity in the data. However, the degrees of freedom reported are for the unprotected test.

Non-parametric statistics were used for *post-hoc* tests because they are more conservative, thereby controlling for the family-wise error rate. The Mann-Whitney U (U_z) test for independent samples was used to analyze significant two-way interactions of sign by age or sign by light condition. The between-subjects variable (i.e., age or light condition) was the variable of interest in these follow ups. The main effects of sign were followed up using the Wilcoxon's signed ranks test (W_z) for paired samples. All smart-sign conditions were compared to Baseline initially (see Figure 7.1). The signs were then compared to each other to determine which sign resulted in the best performance for a variable (see Figure 7.2). Other appropriate non-parametric tests were used as required, such as chi-square for frequency variables.

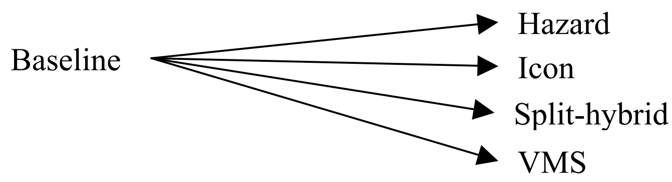


Figure 7.1. Baseline Comparisons. Each sign was compared to baseline to determine performance differences.

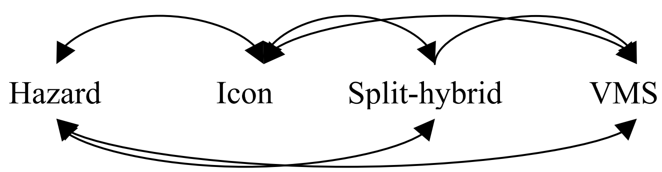


Figure 7.2. Sign Comparisons. Each smart sign was compared to the others to determine best performance among designs.

7.2.1. Crossing Maneuver Variables

7.2.1.1. Travel Time to Intersection (Covariate)

Travel time is the amount of time it takes from the start of the scenario to when the participant crosses into the intersection zone (see the Dependent Variables Section for a full description of all variables). The travel time measure was collected as a potential covariate for wait time and travel time. There was a possibility for travel time to affect both the total time spent waiting and crossing the intersection and the wait time before entering the intersection. Travel time to the intersection could potentially affect wait time at the intersection because drivers taking more time to get to the intersection would see larger gaps appear sooner, thus reducing their wait time compared to drivers who approached faster. This is because the traffic stream began as soon as the scenario started.

The travel time ANOVA results revealed no significant main effects or interactions for this, which indicates that travel time was similar between and within groups for each set of trials. Therefore, it is not necessary to co-vary it out of the analysis. This suggests that any significant differences in wait time at the intersection for different sign conditions is potentially due to drivers spending more time making a gap-acceptance decision or examining a sign, rather than simply because they arrived earlier at the intersection and had to wait longer for a sufficient gap. It may also indicate that some drivers who arrived early at the intersection possibly accepted smaller gaps rather than waiting for larger gaps; therefore, travel time had no affect on their wait time.

7.2.1.2. Wait Time at Stop Sign

Wait time is how long the drivers waited for a gap before they began the movement across the intersection. Wait time was calculated from when drivers entered the vicinity of the intersection (see Dependent Measures section) until the first time they depressed the accelerator and continued across the intersection. There was a significant main effect of sign condition for wait time [$F(4,176)=3.29$, $p=0.015$] (see Figure 7.3). *Post-hoc* tests for the main effect of sign revealed that wait times for Baseline (M=54.50 s) were significantly shorter than the Icon condition (M=70.85 s), [$W_z=-3.41$, $p=0.001$] and the Hazard condition (M=64.24 s) [Wz=-2.31, p=0.02]. Average wait times were also significantly shorter in the Hazard [Wz=-2.40, p=0.016] and VMS [Wz=-2.48, p=0.013] conditions when compared to the Icon condition. The Icon condition had the longest wait time.

Increases in wait time at the intersection suggest that drivers took more time to assess traffic at the intersection before crossing when using the Icon sign. This is also supported by the larger gap acceptance values for drivers using the Icon sign compared with the other signs (see Performance Variables below). Because gaps were available later in the traffic stream it is expected that drivers with larger gap acceptance would have both longer wait times and longer total times to cross the intersection.

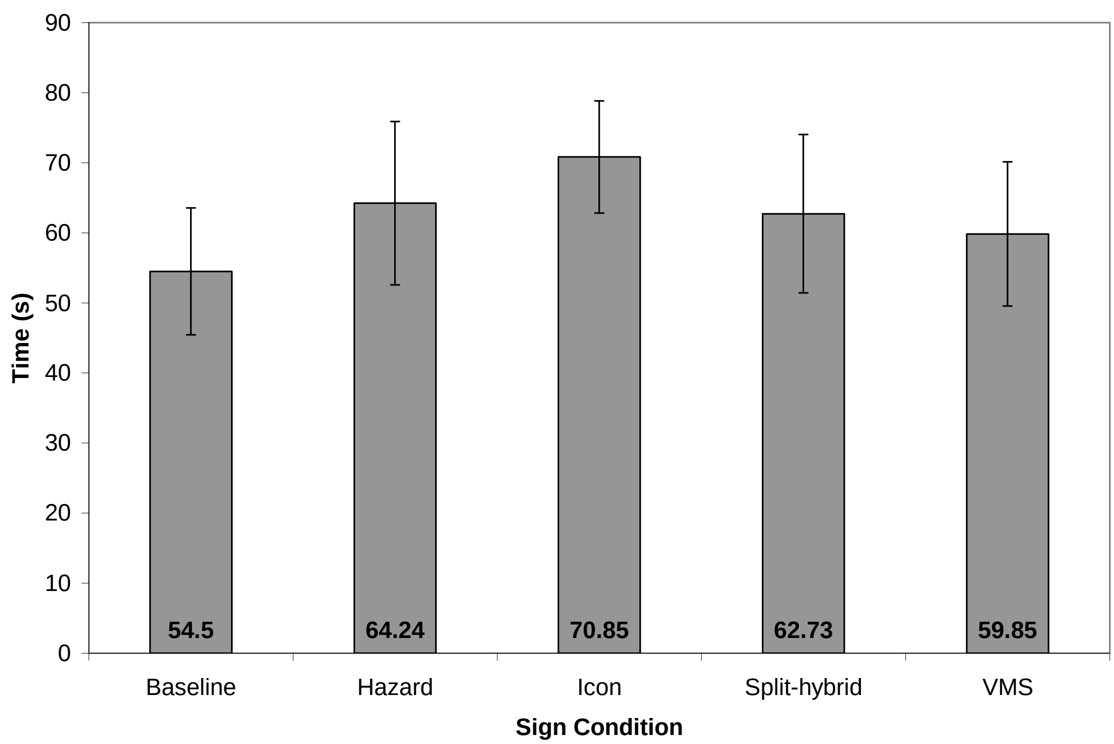


Figure 7.3. Main effect of sign condition for wait time.

7.2.1.3. Minimum Speed Through Median: One-stage versus Two-stage Strategies

The minimum speed through the median can help determine whether a driver performed a one-stage or two-stage strategy while crossing the intersection. A one-stage strategy is evidenced by a driver who does not stop or slow appreciably before entering the northbound lanes of traffic. Drivers passing through the median with speeds of less than 5 mph were considered to qualify as a two-stage strategy. Table 7.1 shows the number of one-stage and two-stage maneuvers by trial made during the day condition while Table 7.2 shows the same information for the night condition.

Table 7.1. Number of one-stage versus two-stage maneuvers for day condition by age, sign and trial.

	Young				**Older**			
Day	**Trial 1**		**Trial 2[a]**		**Trial 1**		**Trial 2[a]**	
	1-stage	**2-stage**	**1-stage**	**2-stage**	**1-stage**	**2-stage**	**1-stage**	**2-stage**
Baseline	0	12	0	11	0	12	0	11
Hazard	0	12	3	9	0	12	0	10
Icon	0	12	0	11	0	12	0	11
Split-hybrid	0	12	2	10	0	12	0	10
VMS	2	10	2	10	0	12	0	11

[a] Indicates a trial with missing data. N=12 per trial per sign condition. If condition does not equal 12, data is missing.

Table 7.2. Number of one-stage versus two-stage maneuvers for night condition by age, sign and trial.

	Young				**Older**			
Night	**Trial 1[a]**		**Trial 2**		**Trial 1**		**Trial 2**	
	1-stage	**2-stage**	**1-stage**	**2-stage**	**1-stage**	**2-stage**	**1-stage**	**2-stage**
Baseline	2	10	2	10	3	9	6	6
Hazard	2	10	3	9	5	7	4	8
Icon	2	9	1	11	3	9	4	8
Split-hybrid	2	10	4	8	4	8	4	8
VMS	2	9	4	8	3	9	3	9

[a] Indicates a trial with missing data. N=12 per trial per sign condition. If condition does not equal 12, data is missing.

Overall, these results suggest that drivers used a two-stage strategy more during the day than they did during the night. The larger number of one-stage strategies in the night condition is consistent with the shorter times spent in the median for the night condition. Table 7.3 shows the percentage of participants who used the same crossing strategy, whether it was a one-stage or two-stage maneuver, for both trials of a sign condition. Overall, drivers appeared to use the same strategy each time, although drivers at night appeared more likely to change their strategy than did drivers during the day. In both light conditions, young drivers more often switched to a one-stage strategy from a two-stage strategy in the second trial. Older drivers in the night condition more often switched to a two-stage strategy from a one-stage strategy in the second trial.

Table 7.3. Percentage of participants who used the same strategy (one-stage or two-stage) for crossing the intersection in both trials for each sign.

	Day		Night	
	Young	**Older**	**Young**	**Older**
Baseline	100	100	100	75
Hazard	75	100	91.67	91.67
Icon	100	100	91.67	91.67
Split-hybrid	83.33	100	83.33	100
VMS	100	100	83.33	100

7.2.1.4. Crossing Maneuver Summary

- The Icon sign produced the longest wait times at the STOP sign.
- The Baseline condition produced the shortest wait times at the STOP sign.
- Travel times to the intersection for each condition were similar. This potentially means that the larger wait times for the Icon sign and other smart signs at the intersection could be due to drivers looking at the signs and attempting to use them for their crossing decision.

7.2.2. Performance Variables

The majority of the performance variables focus on driver performance in the near-side (southbound) lanes of traffic. The data of interest was typically the near-side lane crossing from the STOP sign because the main gap acceptance scenario was dictated by the near-side traffic flow. Moreover, all signs had supporting functions for the near-side lanes. When appropriate, statistics for the northbound lanes are cited (e.g., collisions).

7.2.2.1. Accepted Gap

The accepted gap is the original size of the gap in traffic that the individual accepted as defined in the traffic model. An accepted gap can be measured for both the near-side and the far-side lanes. Gap sizes for the near-side ranged from 3-9 s, while gap sizes for the far-side ranged from 3-15 s. There was also an opportunity for drivers to wait until all the traffic had passed to cross. In these cases, a null value exists because there is no gap size. For the purposes of analysis, participants were assigned a gap size that was 1 SD above the largest gap size within the relevant experiment group (e.g., young day, older night).

7.2.2.1.1. Near-side Accepted Gap

There was a significant main effect of sign type for near-side accepted gap [$F(4,176)= 14.34$, $p<0.001$]. On average, young and older drivers in both the day and night conditions accepted significantly larger gaps for all the smart signs when compared to Baseline. Table 7.4 shows the results of the follow-up tests with the mean gap accepted by drivers for all sign conditions. Drivers also selected significantly larger gaps when the Icon sign was present versus the Hazard, Split-hybrid or VMS signs. There were no significant differences in accepted gap size among the Split-hybrid, VMS and Hazard signs. Figure 7.4 shows the main effect of sign condition when averaged across age and light conditions.

Table 7.4. Main effect of sign *post-hoc* comparisons for near-side accepted gap (Wilcoxon's).

Accepted Gap Comparisons	**Mean (s)**	**Wz**	**p**
Baseline	5.05		
Hazard	5.53	-2.67	0.01**
Icon	6.77	-5.08	<0.001**
Split-hybrid	5.70	-2.69	0.01**
VMS	5.63	-2.41	0.02*
Hazard	5.53		
Icon	6.77	-4.37	<0.001**
Split-hybrid	5.70	-0.73	0.47
VMS	5.63	-0.17	0.86
Icon	6.77		
Split-hybrid	5.70	-3.67	<0.001**
VMS	5.63	-3.44	<0.001**
Split-hybrid	5.70		
VMS	5.63	-0.05	0.96

* Significant at 0.05; **Significant at 0.01

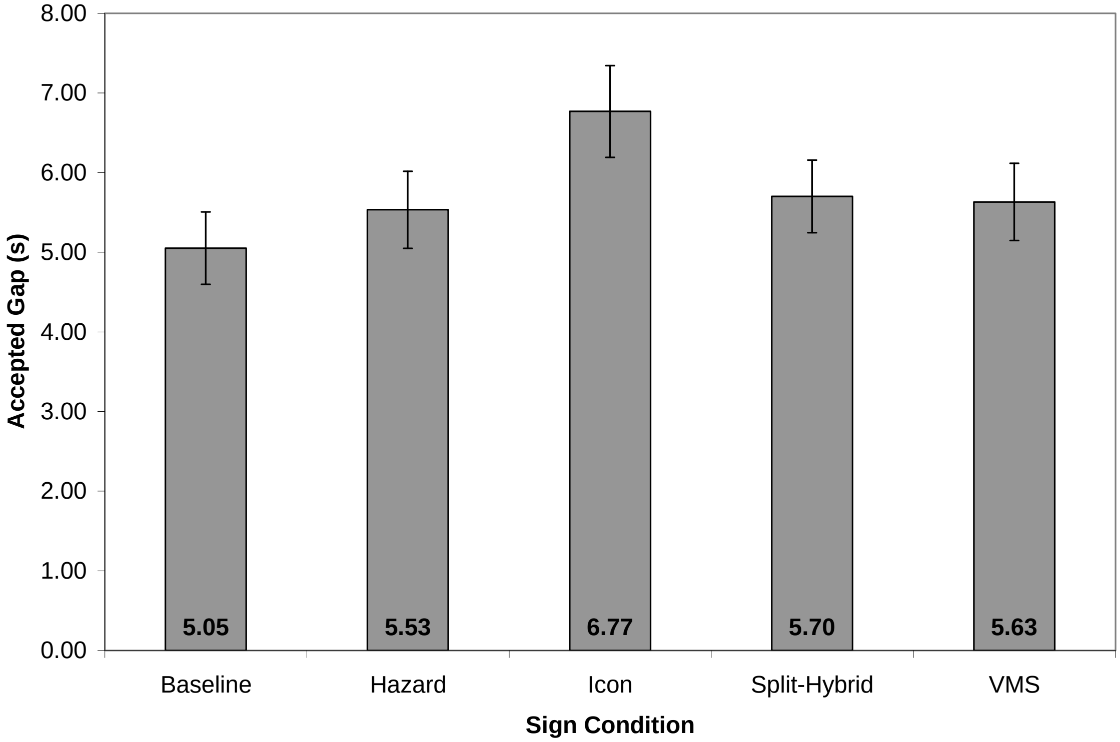


Figure 7.4. Main effect of sign condition for near-side accepted gap.

To examine the ratio of drivers above and below the 7.5 s safe gap threshold for the IDS designs, the cumulative percent of drivers accepting each gap size was plotted for the near-side lanes. Table 7.5 shows the percentage of participants above and below the threshold for night and day. Figure 7.5 shows cumulative percent of accepted gaps and Figure 7.6 shows cumulative percent of accepted gaps for night. Overall, a larger percentage of drivers in the night condition accepted gaps above the safe-gap threshold when compared to drivers in the day condition.

Table 7.5. Percentage of participants above and below the 7.5 s safe gap threshold for day and night driving for the near-side lanes.

	Day		**Night**	
	< 7.5 s threshold	**> 7.5 s threshold**	**< 7.5 s threshold**	**> 7.5 s threshold**
Baseline	100	0	91.67	8.33
Hazard	91.67	8.33	87.5	12.5
Icon	79.17	20.83	58.33	41.67
Split-hybrid	91.67	8.33	75	25
VMS	100	0	79.17	20.83

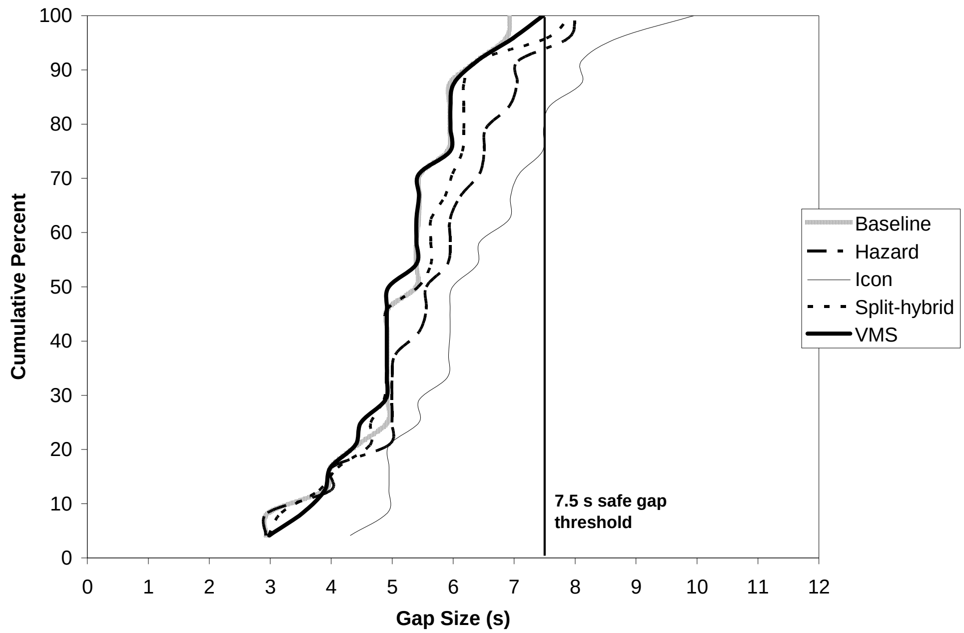


Figure 7.5. Cumulative percent for each accepted gap size value for day driving (N=24) in the near-side lanes.

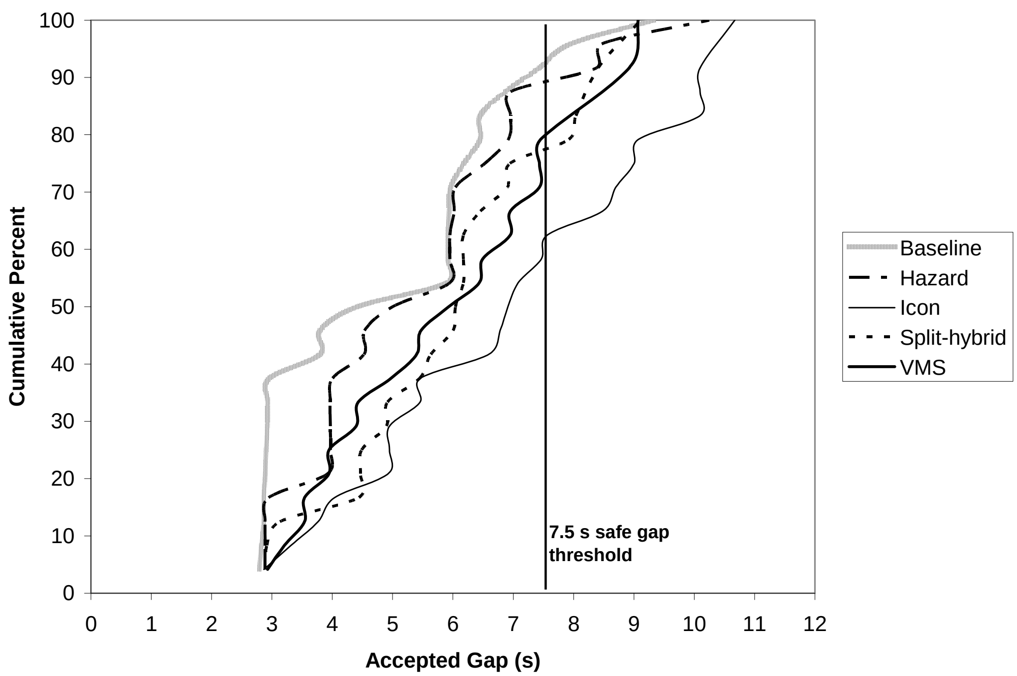


Figure 7.6. Cumulative percent for each accepted gap size value for night driving (N=24) in the near-side lanes.

7.2.2.1.2. Far-Side Accepted Gap

There were no significant interactions of sign by age or light condition (p's>0.05). There was a significant main effect of light condition, where drivers in the night condition (M=8.84 s) accepted significantly larger gaps than drivers in the day condition (M=7.65 s) [$F(1, 42)=16.13$, $p<0.001$). Far-side gap sizes were initially 10 s apart, then 3 s apart, with the first large gap after a series of 3 s gaps being 9 s. Because the gap pattern for the far lanes did not follow the linear increase in gap sizes observed in the near lanes, many drivers accepted a gap of 9 s or larger in the far lanes.

7.2.2.2. Initial Time-to-contact (TTC)

The initial TTC is the actual amount of time between the oncoming vehicle and the participant's vehicle when it first enters a set of lanes at the intersection. These values vary depending on how quickly a person begins to move into the intersection after deciding to accept one of the pre-determined gaps in the traffic pattern. An initial TTC was measured for when a driver entered the near-side lanes and for when a driver entered the far-side lanes.

7.2.2.2.1. Near-side Initial TTC

There was a significant main effect of sign type [$F(4,176)=10.89$, $p<0.001$] for initial TTC. The Icon sign (M=4.93 s) [$W_z=-4.65$, $p<0.001$] and the VMS sign (M=4.22 s) [$W_z=-1.99$, $p=0.047$] had significantly larger TTCs than Baseline (M=3.77 s) (see Figure 7.7; Table 7.6).

The Icon sign also had a significantly larger TTC than the Hazard sign [$W_z=-3.67$, $p<0.001$], the Split-hybrid sign [$W_z=-4.30$, $p<0.001$], and the VMS sign [$W_z=-2.77$, $p=0.006$]. The VMS sign also had a significantly larger TTC than the Split-hybrid sign [$W_z=-2.72$, $p=0.007$].

Table 7.6. Main effect of initial TTC for near-side lanes.

TTC Comparisons	Mean (s)	Wz	p
Baseline	3.77		
Hazard	3.97	-1.13	0.26
Icon	4.93	-4.65	<0.001**
Split-hybrid	3.68	-0.51	0.61
VMS	4.22	-1.99	0.047*
Hazard	3.97		
Icon	4.93	-3.67	<0.001**
Split-hybrid	3.68	-1.57	0.12
VMS	4.22	-0.63	0.53
Icon	4.93		
Split-hybrid	3.68	-4.30	<0.001**
VMS	4.22	-2.77	0.006**
Split-hybrid	3.68		
VMS	4.22	-2.72	0.007**

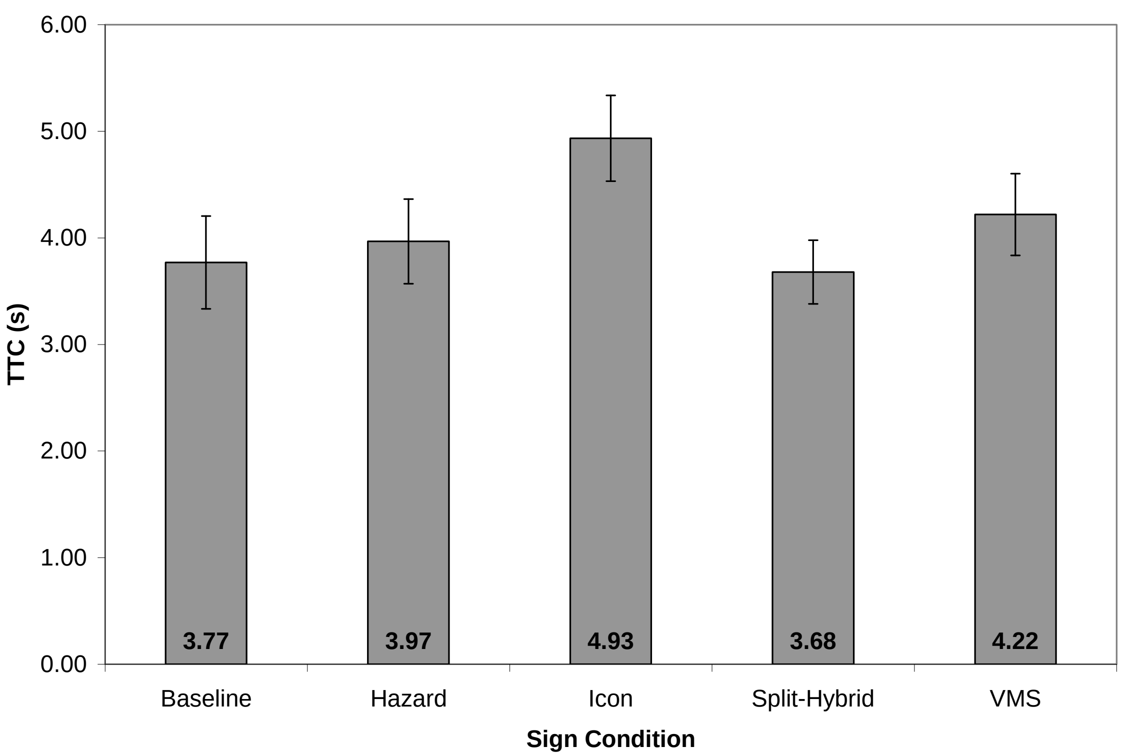


Figure 7.7. Main effect of sign for initial TTC for near-side lanes.

There was also a significant two-way interaction of sign and light condition [$F(4,176)=3.04$, $p=0.02$] and there was a significant two-way interaction of sign and age group [$F(4,176)=2.42$, $p=0.05$] for initial near-side TTC. However, the age by light by sign condition three-way interaction was also significant [$F(4,176)=3.72$, $p=0.02$]. Because there was a significant three-way interaction, the three-way was chosen for the follow-up analysis described below.

A 2 (Age: young, older) x 5 (Sign: Baseline, Hazard, Split-hybrid, Icon, VMS) mixed-model ANOVA was run separately for each of the day and night conditions to follow up the significant three-way interaction. There was no significant interaction between age and sign for the day condition [$F(4,88)=0.46$, $p=0.76$] (see Figure 7.8) but there was a significant simple main effect of sign condition for the day condition [$F(4,88)=7.34$, $p<0.001$]. Both the Hazard (M=4.61 s) [$W_z=-2.00$, $p = 0.045$] and the Icon (M=45.04 s) [$W_z=-3.94$, $p<0.001$] signs had significantly larger TTCs than the Baseline condition (M=4.17 s). The Hazard sign had a significantly larger TTC than the Split-hybrid sign (M=3.92 s) [$W_z=-2.43$, $p=0.015$] in the day condition. The Icon sign had a significantly larger TTC than the Split-hybrid [$W_z=-3.51$, $p<0.001$] and the VMS (M=4.12 s) [$W_z=-2.97$, $p=0.003$] in the day condition.

There was also a marginally significant simple main effect of age for the day condition [$F(1,22)=3.79$, $p=0.06$]. Older drivers had larger initial TTCs (M=4.66 s) than the young drivers (M=4.11 s) for the day condition when averaged across signs.

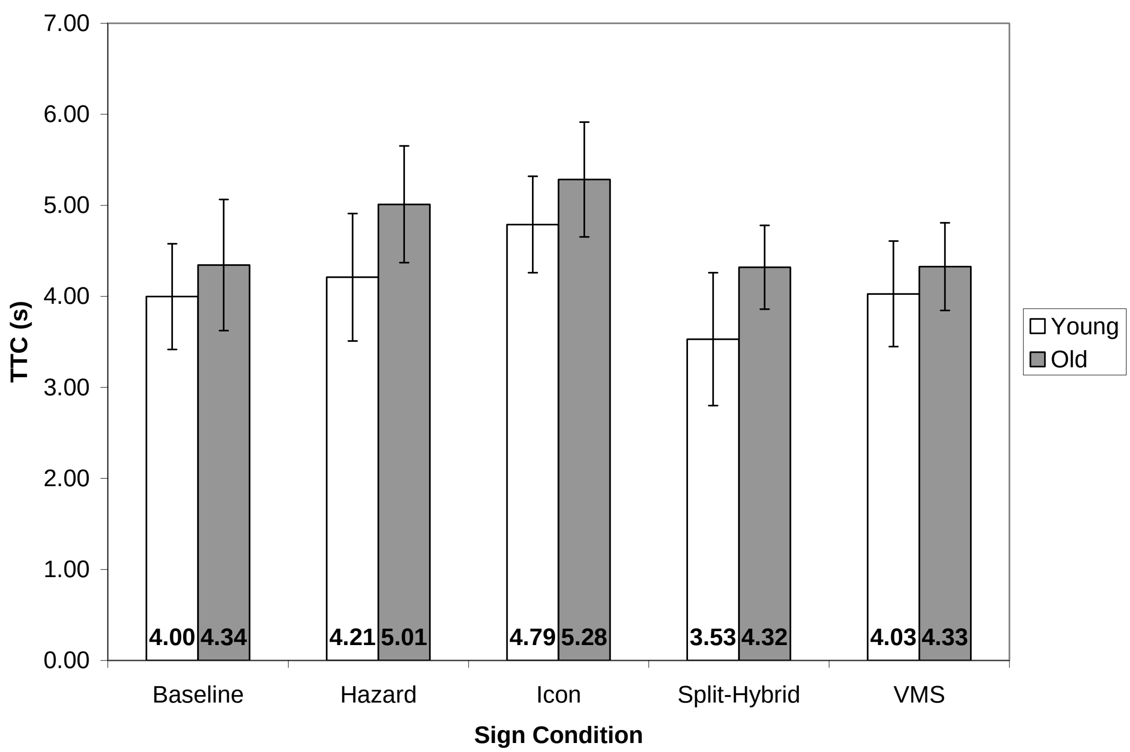


Figure 7.8. Interaction of age and sign condition for the day driving condition only for TTC for the near-side lanes.

In contrast to the day condition, there was a significant two-way interaction between age and sign condition for the night condition [$F(4,88)=3.79$, $p=0.007$] (see Figure 7.9). For the night condition, older drivers (M=4.15 s) had significantly larger initial TTCs for the Split-hybrid condition than did young drivers (M=2.72 s) [U_z=-3.00, p=0.002]. Older drivers (M=4.93 s) also had significantly larger initial TTCs for the VMS condition when compared with young drivers (M=3.59 s) [U_z=-2.02, p=0.04] in the night condition.

There was also a significant simple main effect of sign condition for the night driving [F(4,88)=7.34, p<0.001]. The Icon (M=4.83 s) [W_z=-3.00, p=0.003] and VMS (M=4.26 s) [W_z=-2.20, p=0.03] signs had significantly larger TTCs than Baseline (M=3.37 s) for the night condition. The Icon sign also had a significantly larger TTC than the Hazard (M=3.32 s) [W_z=-3.09, p=0.002] and the Split-hybrid (M3.44 s) [W_z=-2.80, p=0.005] signs. The VMS sign also had a significantly larger TTC than the Split-hybrid sign [W_z=-2.69, p=0.007].

Based on these separate analyses, the three-way interaction exists because older drivers had significantly larger initial TTCs in the Split-hybrid and VMS sign conditions than did younger drivers, but for the night driving condition only. The trend for both young (Day=4.99 s; Night=5.36 s) and older (Day=5.72 s; Night=6.72 s) drivers was an increase in accepted gap during the night condition.

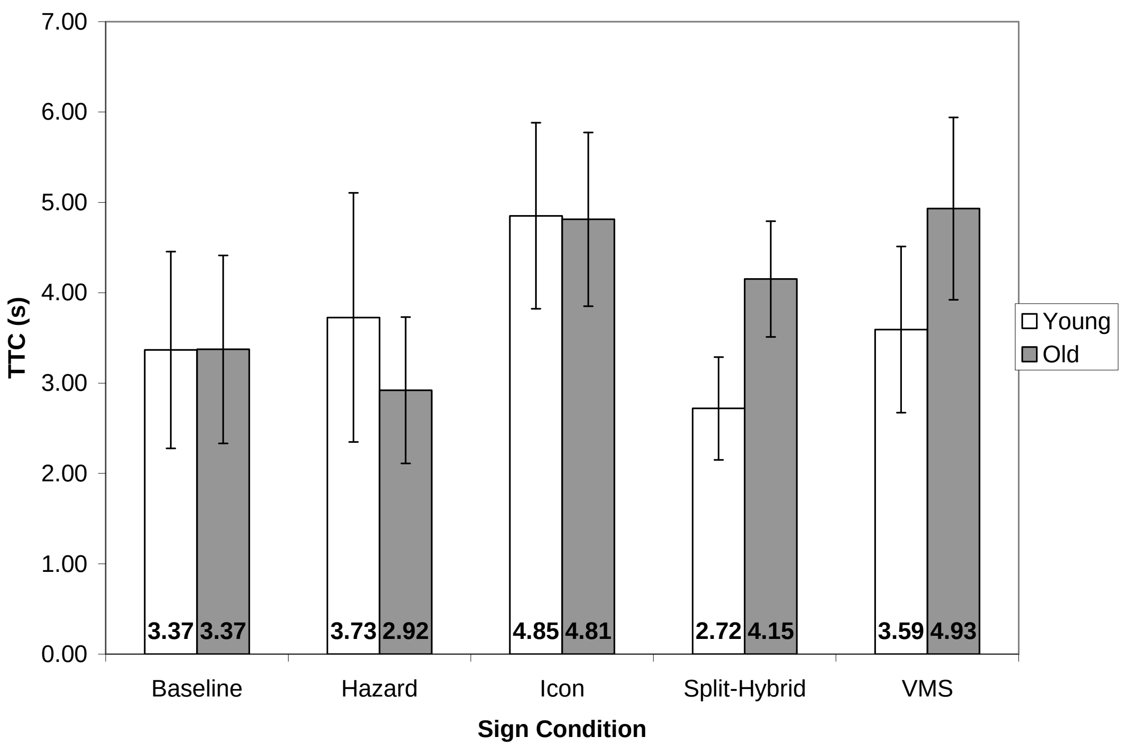


Figure 7.9. Interaction of age and sign condition for the night driving condition only for TTC for the near-side lanes.

7.2.2.2.2. *Far-Side Initial Time-To-Contact (TTC)*

There was a significant main effect of light condition for the far-side initial TTC [$F(1,42)=71.07$, $p<0.001$] (see Figure 7.10). On average, drivers in the day condition had significantly larger TTCs for the far lanes than drivers in the night condition.

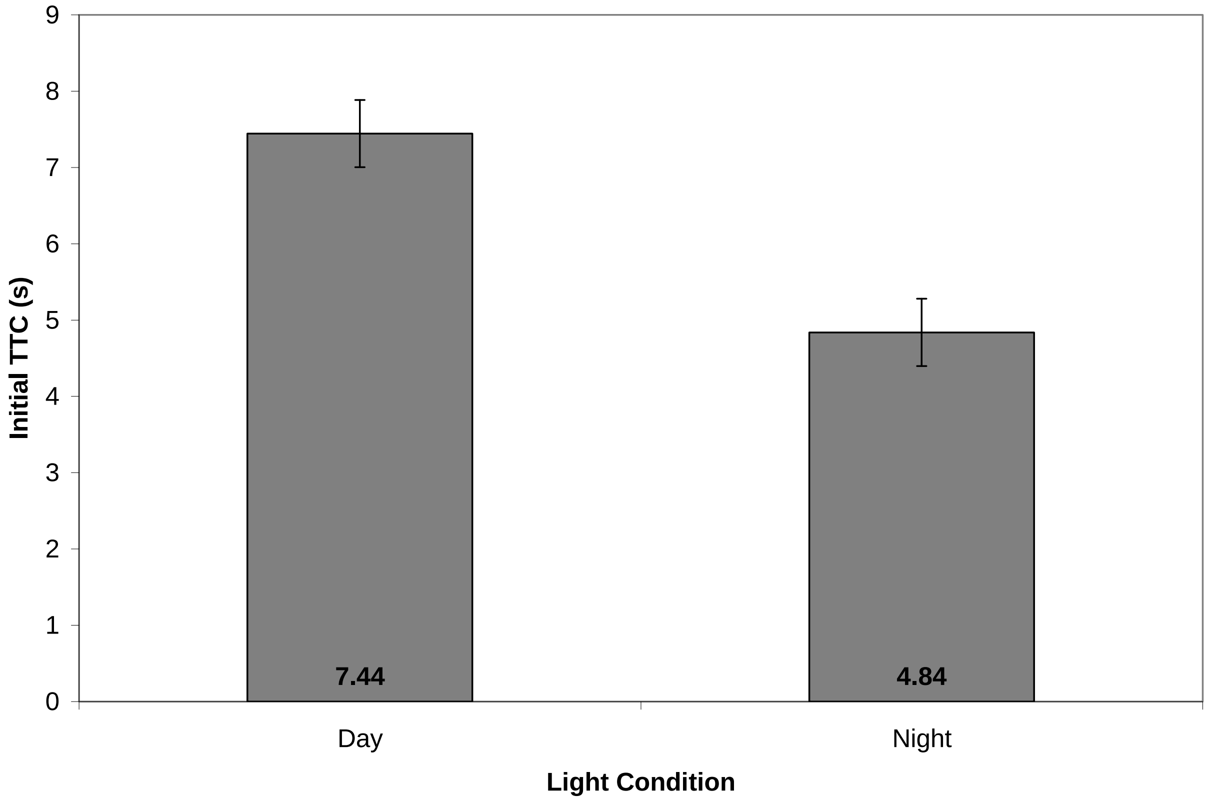


Figure 7.10 Main effect of light condition for far-side initial TTC.

7.2.2.3. Safety Margins

The safety margin is the TTC during each stage (near-side and far-side of the divided highway) of the crossing maneuver when the participant's vehicle is in the midpoint of the lanes it is crossing. This is the time from the oncoming vehicle to the participant's vehicle when the participant is at the midpoint of crossing the intersection. The safety margin depends on a number of factors. First, a driver may accept a reasonably sized gap, but may be slow to accelerate into and through the intersection, which means the oncoming vehicle is closer than it would be for someone who reacted faster. This is more likely to occur among older drivers who may have slower reaction times than younger drivers when entering the intersection after accepting a gap. Second, drivers may select a small gap, which means the oncoming vehicle was already close when the participant entered the gap. In most cases, the safety margins will be highly correlated with the accepted gap values. That is, the larger the gap size chosen, the larger the safety margin. Table 7.7 shows the Pearson r correlations between safety margin and accepted gap for the near-side lanes of traffic (initial crossing maneuver from STOP sign to median). All correlations were significant at p<0.001.

Table 7.7. Pearson r correlations for Accepted Gap and Safety Margin in the Southbound Lanes*

	Age Group	
Sign Condition	**Young**	**Older**
Baseline	0.94	0.67
Hazard	0.82	0.68
Icon	0.81	0.88
Split-hybrid	0.75	0.71
VMS	0.85	0.69

*All correlations were significant at p<0.001.

As Table 7.7 shows, safety margin was highly correlated with accepted gap in all cases. However, older drivers had slightly lower correlations in general, suggesting that older drivers may show more variability in how long it takes them to move into and through the intersection after a gap is accepted. Some older drivers will react more slowly or cross the intersection at slower speeds, thus reducing the safety margin regardless of gap size chosen. Therefore, older drivers' safety margins may be more variable depending on individual reaction times and how quickly a driver begins moving into and across the intersection after selecting a gap.

An examination of the speed values (mph) for older and young drivers at the midpoint of the southbound lanes indicates that older drivers had slightly slower speeds (M=18.44 mph) when crossing the intersection than young drivers (M=19.48 mph). Older drivers overall also had slower movement times (M=52.92 s) across the intersection compared with young drivers (44.96 s). Although neither of these differences was significant, the lower speeds and slower movement times would create overall smaller safety margins for the older drivers.

7.2.2.3.1. Near-Side Safety Margin

For the near-side safety margin, there was a significant main effect of sign condition [F(4,176)=11.68, p<0.001] (see Figure 7.11). The Icon sign (M=4.29 s) [Wz=-4.84, p<0.001] had a significantly larger safety margin than Baseline (M=3.26 s). The Icon sign also had a significantly larger safety margin than the Hazard sign [W_z=-3.69, p<0.001], the Split-hybrid sign (M=3.08 s) [W_z=-4.41, p<0.001], and the VMS sign (M=3.55) [W_z=-2.88, p=0.004]. The VMS sign also had a significantly larger safety margin than the Split-hybrid sign [W_z=-2.88, p=0.004]. The differences for signs between Baseline and the smart signs is the same as it was for initial TTC, with the Icon sign again showing the best performance and the Baseline showing the worst.

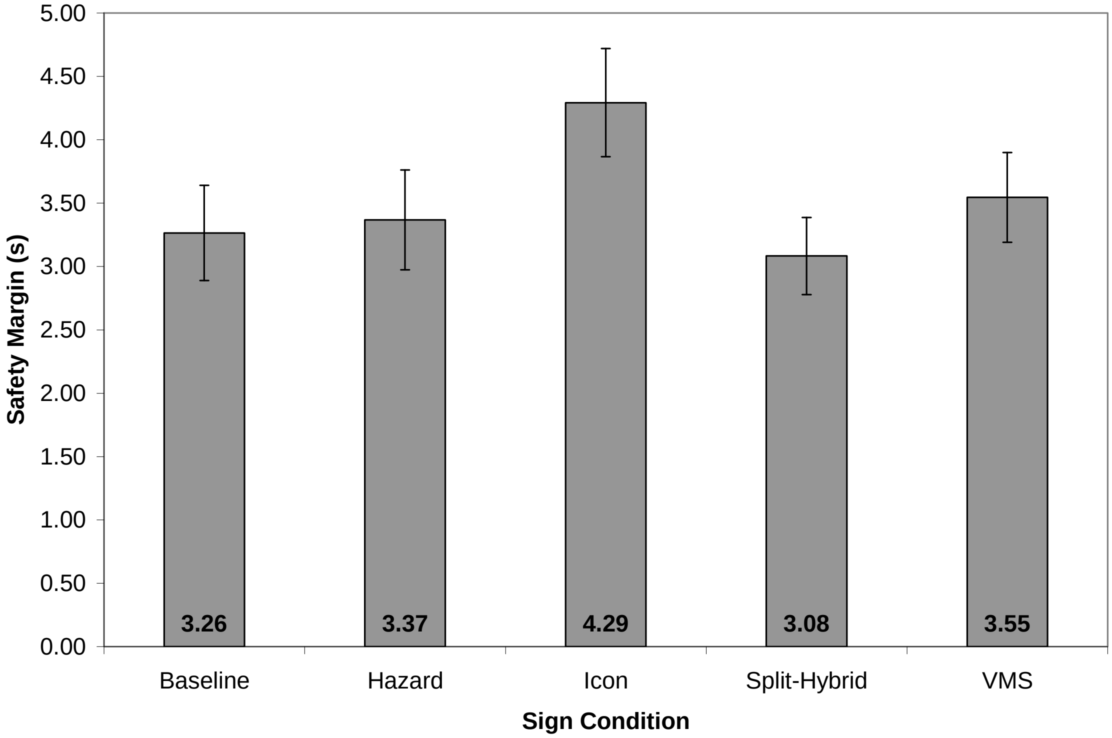


Figure 7.11. Main effect of sign for near-side safety margin.

There was a significant interaction between sign and light condition [F(4,176)=2.86, p=0.025]. The near-side safety margin was significantly greater in the day (M=3.92 s) versus the night (M=2.81 s) condition for the Hazard sign only.

There was also a significant interaction between sign and age [F(4,176)=2.77, p=0.03]. Young drivers (M=2.53 s) showed significantly smaller safety margins for the Split-hybrid sign than did older (M=3.64 s) drivers. As well, young drivers (M=3.08 s) showed significantly smaller safety margins for the VMS sign than did older drivers (M=4.00 s).

Finally, there was a also three-way interaction between age, light condition and sign condition [F(4,176)=3.06, p=0.018]. To follow up the interaction between age, light and sign conditions, two 2 (Age: young, older) x 5 (Sign: Baseline, Hazard, Split-hybrid, Icon, VMS) mixed-model ANOVAs were run separately for the day and night conditions.

There was no significant interaction between age and sign condition for the day driving condition [F(4,88)=0.42, p=0.77] (see Figure 7.12). However, there was a significant simple main effect of sign for the day condition [F(4,88)=7.35, p<0.001]. The Icon sign [W_z=-4.17, p<0.001] and the Hazard sign [W_z=-2.17, p=0.03] both had significantly larger safety margins than baseline. As well, the Icon sign had a significantly larger safety margin compared with the Split-hybrid [W_z=-3.57, p<0.001] and the VMS [Wz=-2.97, p=0.003] signs. The Hazard sign also had a significantly larger safety margin than the Split-hybrid sign [W_z=-2.23, p=0.026].

There was also a marginally significant simple main effect of age [F(1,22)=4.0, p=0.058. On average, young drivers (M=3.4 s) had smaller safety margins than older drivers (M=4.0 s) in the day condition.

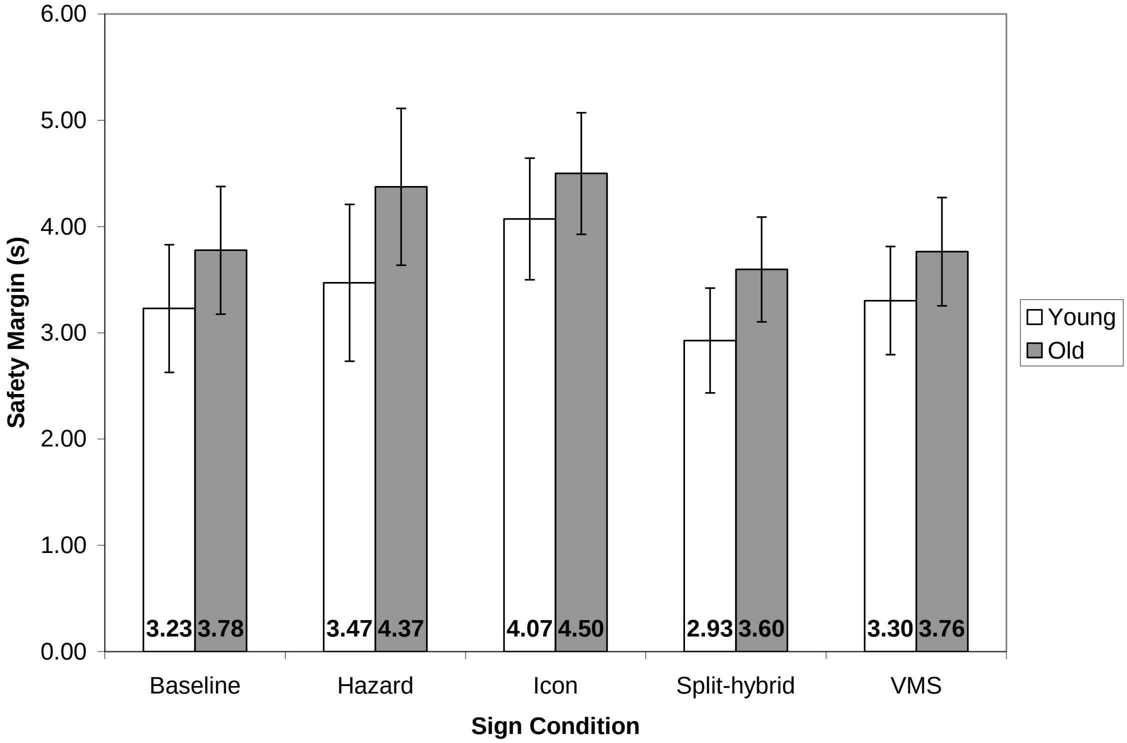


Figure 7.12. Interaction of age and sign condition for near-side safety margin in day condition only.

There was a significant interaction between age and sign condition for the night condition [F(4,88)=4.32, p=0.03] (see Figure 7.13). There was a significant difference in safety margin between the young (M=2.13 s) and older (M=3.67 s) drivers for the Split-hybrid condition [U_z=-2.71, p=0.006]. There was also a significant difference between young (M=2.87 s) and older drivers (M=4.25 s) for the VMS sign [U_z=-2.20, p=0.03].

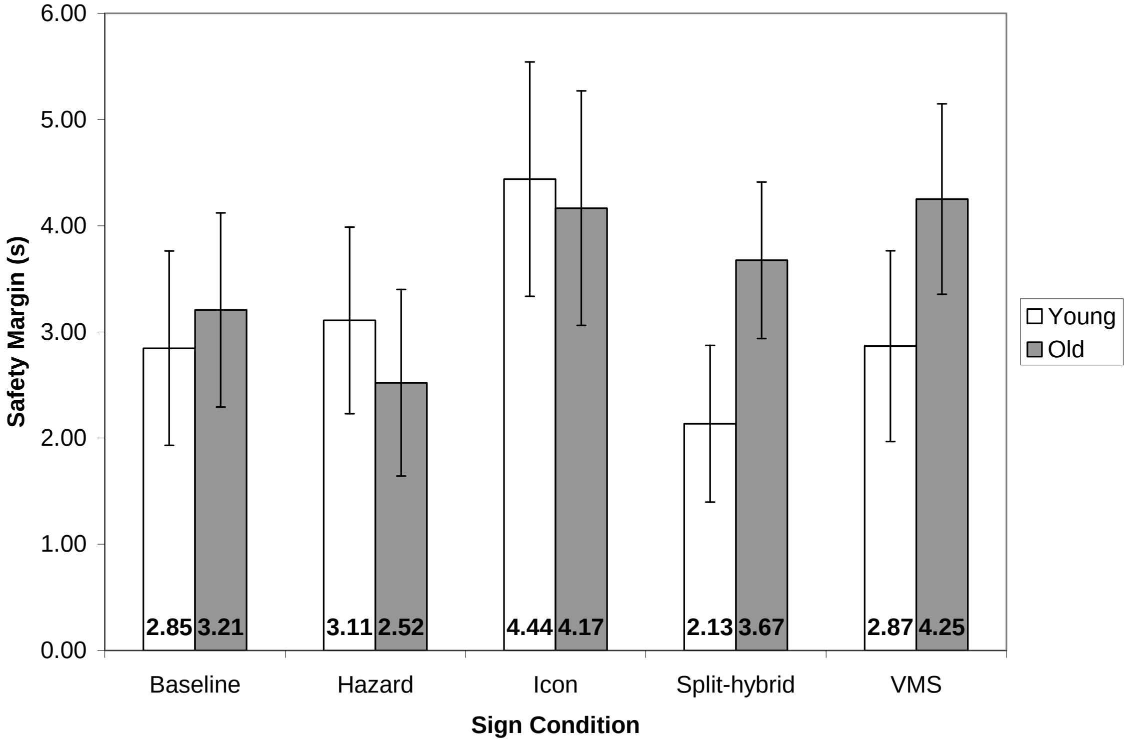


Figure 7.13. Interaction of age and sign condition for near-side safety margin in night only.

There was also a significant simple main effect of sign for the night condition [F(4,88)=7.24, p<0.001]. Again, the Icon (M=4.30s) sign had a significantly larger safety margin than Baseline (M=3.03 s) [W_z=-3.0, p=0.003], Hazard (M=2.81 s) [W_z=-3.20, p=0.001] and the Split-hybrid signs (M=2.90 s) [W_z=-2.83, p=0.005]. As with the day condition, the VMS sign (M=3.56 s) [$W_{z=}$-2.60, p=0.009] also had a larger safety margin than the Split-hybrid sign.

These supplemental analyses suggest the interaction of age, light and sign conditions exists because young drivers have a significantly lower safety margin than older drivers for the Split-hybrid and VMS signs, but in the night condition only.

7.2.2.3.2. Northbound Safety Margin

There was a significant main effect of light condition for the northbound safety margin [F(1,44)=92.85, p<0.001]. Overall, drivers in the day condition had significantly larger safety margins than drivers in the night condition (see Figure 7.14).

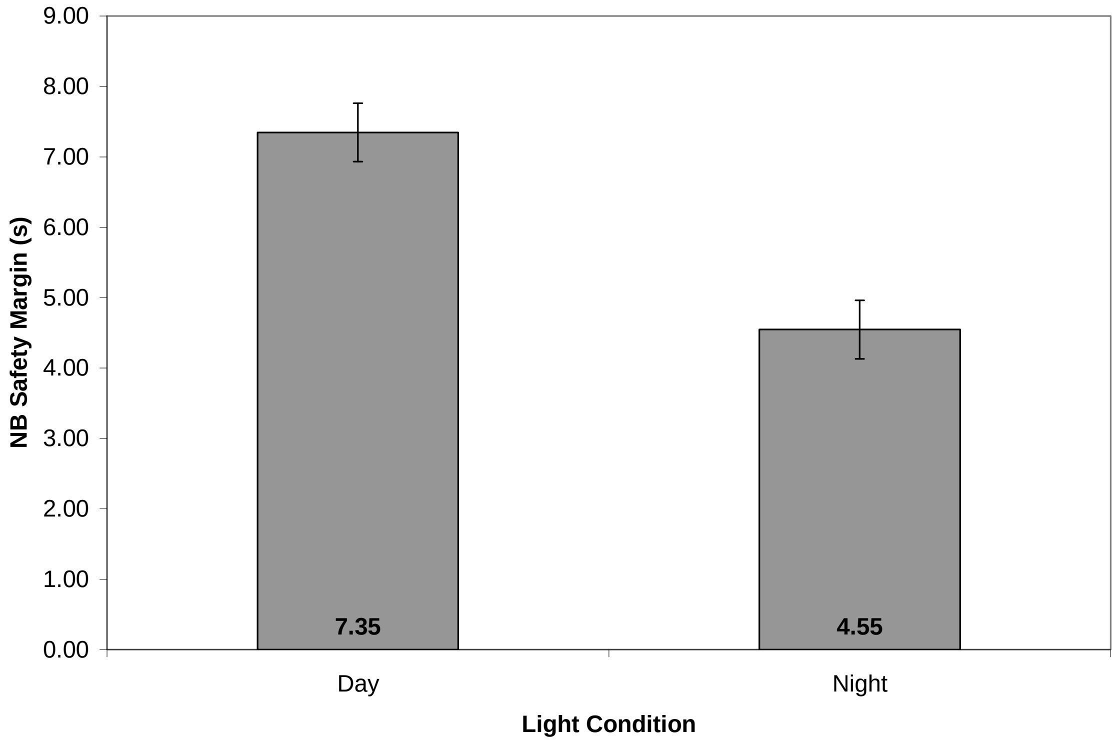


Figure 7.14. Main effect of light condition for northbound safety margins.

As with the near-side safety margins, the average far-side safety margin in day is higher for both young and older drivers for all sign conditions than it is during the night condition (see Table 7.8).

Table 7.8. Average far-side safety margin (s) by age and light condition for each sign.

	Day		Night	
Sign Condition	**Young**	**Older**	**Young**	**Older**
Baseline	7.31	7.93	4.92	5.09
Hazard	6.97	7.86	4.41	4.27
Icon	6.94	7.68	4.45	4.10
Split-hybrid	6.55	7.12	4.56	4.07
VMS	7.43	7.68	4.31	4.29

7.2.2.4. Collisions

Collisions were logged for the near-side and far-side lanes. There were no collisions for either young or older drivers in the day condition. There were a total of 22 collisions in the night condition. Young drivers experienced a total of six collisions, while older drivers experienced a total of 16 collisions. Table 7.9 shows the number of collisions for the night condition only for young and older drivers, and for each set of lanes. Thirteen participants (5 young; 8 older) accounted for all the collisions in this study. Two older participants accounted for 43.75% of all older driver collisions.

Two older participants experienced multiple collisions in the near-side lane for a single trial, while two other older participants experienced multiple collisions in the northbound lanes for a single trial. These participants misjudged the location of the lane boundary at the STOP sign or in the median; therefore, they were sitting waiting for an acceptable gap while a part of their vehicle was in the intersection and several vehicles passed by (collided). This collision data is not included in this analysis, as it would over represent the number of collisions among older participants for gap acceptance. However, this problem demonstrates the older drivers' difficulty with the night driving condition.

Table 7.9. Number of collisions in night condition for near-side and far-side lanes by age.

	Near-Side Lanes		**Far-Side Lanes**	
Sign Condition	**Young**	**Older**	**Young**	**Older**
Baseline	1	0	1	1
Hazard	1	0	0	2
Icon	1	2	0	4
Split-hybrid	0	1	1	1
VMS	1	2*	0	4*
Total	4	5	2	11

*One participant contributed 3 of the 6 VMS collisions.

Older drivers had a similar number of collisions for the near-side lanes as the young drivers. However, in the far-side lanes they had 11 collisions compared to only two for the young drivers. This difficulty in the far-side lanes is similar to the findings by Preston and Storm (2003a) that suggest the majority of accidents occur in the far lanes for this intersection.

However, when the older driver collision data was examined it was discovered that four of the eight drivers who experienced a collision actually experienced more than one collision during the study (see Table 7.10). One older participant actually had four collisions for the study, while another had three, and two others had two collisions each. The fact that two participants alone contributed almost half (7/16) of the collisions made by older drivers suggests that these two participants may have had difficulty with the simulated scenarios in general. Therefore, the collision data for older drivers should be examined cautiously. With these two drivers removed, the number of collisions for older drivers drops to nine in comparison to the six experienced by young drivers. For the young drivers, only one participant who contributed to the total number of collisions experienced more than one collision in the study. This participant experienced two collisions.

Table 7.10. Number of collisions experienced by young and older drivers.

Number of Collisions	Young	Older
1	4	4
2	1	2
3	0	1
4	0	1

The Icon sign and the VMS sign conditions had the most collisions for older drivers. However, a single older participant contributed three of the six collisions for the VMS condition, suggesting that the larger number of collisions for this sign may not be due to the sign but to one particular driver. The remaining two VMS collisions by older drivers occurred with drivers who completed a one-stage maneuver. In contrast, six different older participants experienced collisions while using the Icon sign, and four of these collisions were in the northbound lanes. Of these six older drivers, three completed a one-stage maneuver. It is not entirely clear why older drivers had more collisions with the Icon sign in the far-side lanes. However, four of the six older driver collisions with the Icon sign occurred with drivers who saw the Icon condition first in the study. The increase in crashes for this sign could be due to drivers experiencing the most complex of the IDS signs on their first trials.

Overall, 42.86% of the collisions occurred among drivers who used a one-stage crossing strategy at the intersection (see Table 7.11). Of the older drivers in the night condition who had collisions, six of the 16 crashes (37.5%) were for drivers who completed a one-stage strategy. Three of the young driver crashes (50%) were for drivers who completed a one-stage strategy.

Table 7.11. Percentage of collisions for each sign type that occurred for drivers executing a one or two-stage crossing strategy.

	Strategy Type	
Sign Condition	**One-stage**	**Two-stage**
Baseline	0	100
Hazard	100*	0
Icon	42.9	57.1
Split-hybrid	33.3	66.7
VMS	50	50**

*One collision was missing data. Value is for two of three collisions.
**The 3 2-stage strategy collisions for VMS were all the same driver. The 3 1-stage strategy collisions were separate participants.

7.2.2.5. Conflict Count

Conflicts occur when the safety margin (TTC) with the nearest major-road vehicle is less than 1.5 s (see Carsten & Tate, 1999). The maximum number of conflicts a participant could experience per trial was two, one for the near-side lane crossing and one for the far-side lane crossing. Conflicts were summed across the two trials for each sign condition.

7.2.2.5.1. Total Conflicts

Because there were so few conflicts during the day, a statistical analysis could not be run on the conflict data to compare night and day. However, chi-square analyses were conducted for the night condition only to compare young and older conflicts for each sign condition (see Table 7.13). Table 7.12 shows the total number of near-side and far-side conflicts for each condition.

Table 7.12. Total conflicts for each sign by age and light conditions.

	Day		**Night**	
	Young	**Older**	**Young**	**Older**
Baseline	0	0	8	6
Hazard	2	1	7	13
Icon	0	0	4	7
Split-hybrid	2	1	11	8
VMS	1	0	7	10

7.2.2.5.2. Near-side Conflicts

For the night condition, young drivers experienced a total of 25 conflicts while older drivers experienced 21 conflicts. During the Hazard sign condition, older drivers had significantly more conflicts (8) than the young drivers (3). Older drivers showed the smallest accepted gap for the hazard sign which would explain the increased number of conflicts in this group. In contrast, young drivers showed the second largest accepted gap for the Hazard sign, which would result in fewer conflicts. Table 7.13 shows the night conflicts and the chi-square results for comparison between young and older drivers for each sign condition.

Table 7.13. Near-side conflict frequencies during the night condition for each sign by age.

	Young	**Older**	χ^2	**p-value**
Baseline	6	4	0.30	0.59
Hazard	3	8	4.02	0.05*
Icon	3	2	0.31	0.58
Split-hybrid	8	5	0.24	0.62
VMS	5	2	1.74	0.19

* = significant at p<.05

7.2.2.5.3. Far-side Conflicts

Both older and young drivers experienced a similar number of conflicts for the night condition.

Table 7.14 shows the night conflicts and the chi-square results for comparison between young and older drivers for each sign condition.

Table 7.14. Far-side conflict frequencies during the night condition for each sign by age.

	Young	Older	χ^2	p-value
Baseline	2	2	0.00	1.00
Hazard	4	5	0.44	0.56
Icon	1	5	2.28	0.13
Split-hybrid	3	3	0.00	1.00
VMS	2	8	3.27	0.07

7.2.2.6. Sign State for Near-side Crossing Maneuver

Table 7.15 shows the percentage of participants who moved into the intersection while the indicated sign state was present for the first and second crossing trials for each sign. This data represents movement from the STOP sign and the crossing of the near-side lanes. It does not include median data.

There were two potential states for the Hazard sign, either "on" (unsafe gap detected) or "off" (no unsafe gap detected). Because this sign flashed off and on, it is hard to know whether participants had fully waited for a safe gap or whether the sign state was captured as "off" as part of the flashing phase. Based on the average gap size for all groups and the percentage of drivers above and below the safe-gap threshold, it seems that the percentages more likely represent the Hazard sign's flashing, rather than a true choice to wait for it to stop flashing before beginning the maneuver. This seems to be the case as the percentage of participants who said they used the Hazard sign to help them make their decision to cross was less than 50% for all age groups and conditions (see Table 7.23 under Questionnaire Data).

For the Icon sign, there were three possible states for the portion of the sign that indicated conditions for the near-side lanes: DO NOT ENTER (unsafe gap detected), "yellow icon" (vehicle within 12.5 s but not within 7.5 s) and "cross/turn right" (no unsafe gap detected for near lanes). More drivers entered the near-side lanes with a yellow icon or a cross/turn right during the night condition. However, there was no appreciable increase in the percentage of people who reported using the sign to help them make their crossing decision between the day and night conditions.

For the Split-hybrid (icon portion) and the VMS signs, there were three possible states for the sign while stopped at the STOP sign: DO NOT ENTER (unsafe gap detected), "no left turn/cross" (no unsafe gap detected for southbound lanes), and CAUTION (no unsafe gap detected in southbound or northbound lanes). Although the Split-hybrid results show a very small percentage of participants entering the intersection on a "no left turn/do not cross" or "caution icon" for the night condition, 91.7% of young and 100% of older night drivers said they used the sign to help them make their crossing decision. It is possible that even though drivers at night may have crossed while an unsafe gap was detected, they still may have found the countdown timer (which is not reported here) useful for their decisions.

The VMS results do not show a real difference in sign state between night and day. As well, on average, fewer than 50% of participants said they used the sign to help them make a decision to cross.

The results of self-reported sign use are located in Table 7.23 in the Questionnaire Results.

Table 7.15. Percentage of participants who began moving into intersection from STOP sign when sign was in indicated state.

	Trial 1				Trial 2			
	Day		Night		Day		Night	
	Young	Older	Young	Older	Young	Older	Young	Older
Hazard								
Off	66.7	41.7	25	58.3	63.6	80	58.3	50
On	33.3	58.3	75	41.7	36.4	20	41.7	50
Icon								
Do not enter	100	83.3	63.6	83.3	100	90.9	50	58.3
Yellow icon	0	8.3	18.2	0	0	0	25	25
Cross/turn right	0	8.3	18.2	16.7	0	9.1	25	16.7
Split-hybrid								
Do not enter	91.7	100	83.3	79.2	91.7	100	83.3	83.3
No left turn/cross	8.3	0	16.7	16.7	8.3	0	16.7	8.3
Caution	0	0	0	4.2	0	0	0	8.3
VMS								
Do not enter	100	100	83.3	50	100	100	83.3	75
No left turn/cross	0	0	16.7	41.7	0	0	8.3	16.7
Caution	0	0	0	8.3	0	0	8.3	8.3

7.2.2.7. Performance Variable Summary

- On average, all four smart signs (Hazard, Icon, Split-hybrid, VMS) showed significantly larger accepted gaps for the near-side lanes when compared to Baseline.
- On average, the Icon sign condition produced the largest accepted gaps for the near-side lanes. These gaps were also significantly larger than the Hazard, Split-hybrid and VMS sign conditions.
- Overall, drivers in the night condition showed an increase in near-side accepted gaps compared to drivers in the day condition for the Icon, Split-hybrid and VMS signs, particularly the older drivers. However, the Baseline and Hazard sign conditions showed a decrease in accepted gap sizes at night when compared to day.
- A larger percentage of drivers at night accepted near-side gaps over the 7.5 s threshold compared with day drivers.
- On average, the Icon and VMS signs showed significantly larger near-side initial TTCs compared with Baseline.

- The Icon sign also showed a significantly larger near-side initial TTC compared with the Hazard, Split-hybrid and VMS sign conditions.
- A significant three-way interaction of sign, age and light conditions for near-side initial TTC existed because the young drivers in the night condition showed a significantly smaller initial TTC compared with older drivers in the night condition for the Split-hybrid sign only. There was no difference in near-side initial TTC for the Split-hybrid sign for young and older drivers during the day condition.
- For the near-side safety margin, the Icon and VMS signs showed significantly larger safety margins compared with Baseline. This result is similar to those found for both near-side initial TTC and accepted gap.
- The Icon sign also showed the largest safety margin over Baseline as well as the Hazard, Split-hybrid and VMS signs. The VMS sign also showed a significantly larger safety margin than the Baseline condition.
- There were 22 collisions in the night condition compared with none for the day condition.
- Older drivers in the night condition experienced the most collisions overall, although two participants alone contributed 43.75% of these older driver collisions. This suggests a performance problem with these two drivers, rather than an overall significant difference in collisions between the young and older drivers at night. In particular, participants who experienced the Icon sign on their first set of trials experienced more collisions than participants who experienced the Icon sign later in the experiment.
- In general, drivers began their movements into the intersection while the majority of the signs were indicating an unsafe gap.

7.2.3. Questionnaire Data

7.2.3.1. Mental Workload Ratings

7.2.3.1.1. NASA RTLX Subscales

The individual subscales of the NASA RTLX workload scale (mental demand, physical demand, time pressure, performance, effort, frustration) were analyzed to determine how participants experienced each sign condition by age and light condition. There were significant main effects of age group for four of the TLX subscales (see Table 7.16). On average, older drivers found the intersection scenarios to be more mentally and physically demanding than young drivers. They also rated themselves as feeling under time pressure to complete the crossing scenarios and as having worse performance in completing the scenarios than young drivers.

Table 7.16. Main effect of age group For TLX subscales. Note: Larger TLX values indicate increasing difficulty in performing the task along a subscale dimension.

	Young (M)	Older (M)	F	p-value
Mental Demand	47.75	59.18	5.41	0.025*
Physical Demand	26.30	39.43	5.52	0.023*
Time Pressure	28.28	45.57	12.24	0.001**
Performance	33.95	45.14	7.286	0.01**
Effort	35.18	45.53	3.615	0.064
Frustration	37.79	48.28	3.87	0.055

* Significant at p<0.05; ** Significant at p<0.01

There was a two-way interaction of age group and light condition for the time pressure subscale [F(1,44)=5.26, p=0.027] (see Figure 7.15) and the effort subscale [F(1,44)=4.62, p=0.037] (see Figure 7.16). Older drivers (M=56.71) expressed a significantly greater feeling of time pressure in the night condition when compared with young drivers (M=28.08) [U_z=-3.23, p=0.001], whereas there was no difference between older (M=34.43) and young (M=28.48) drivers during the day. Older drivers also reported requiring significantly more effort to complete the scenarios (M=59.28) than young drivers (M=37.21) in the night condition [U_z=-2.48, p=0.013]. There were no differences in perceived effort between older (M=31.79) and young (M=37.21) drivers during the day.

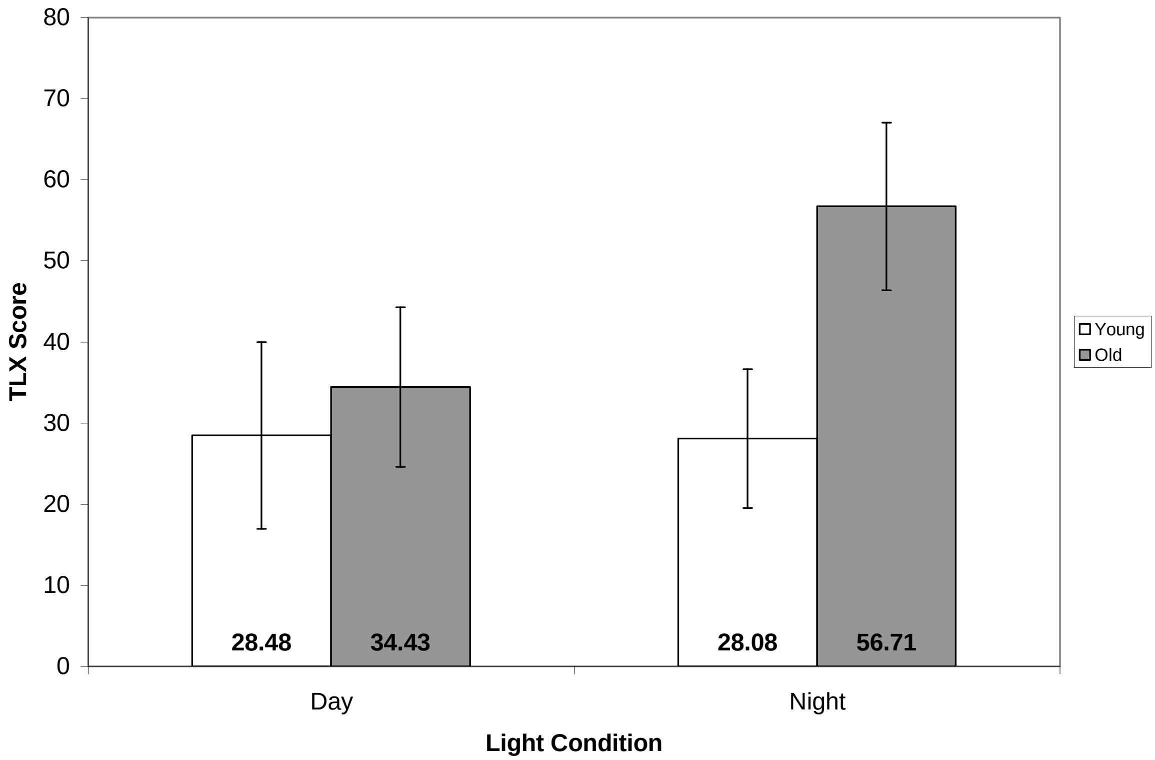


Figure 7.15. Interaction of age by light condition for time pressure TLX subscale.

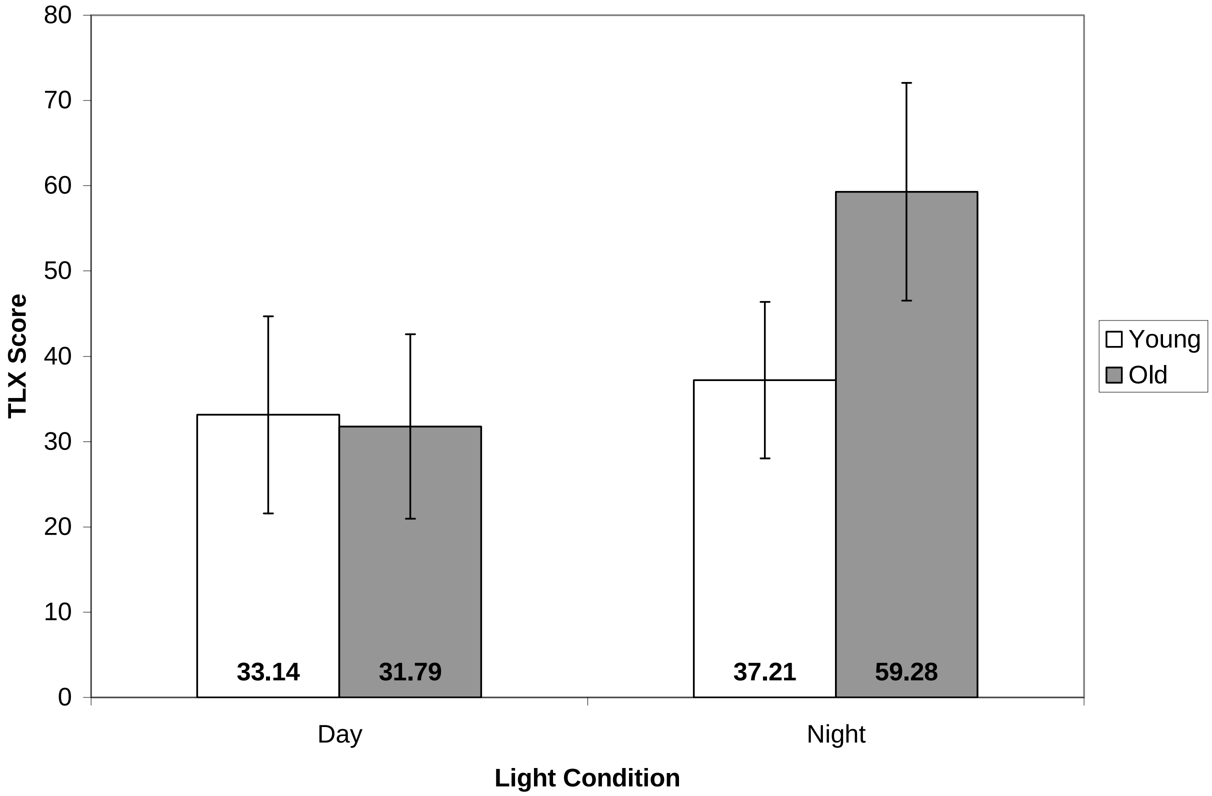


Figure 7.16. Interaction of age by light condition for effort TLX Subscale.

There was also a main effect of light condition for all six of the TLX subscales (see Table 7.17). Drivers at night, regardless of age, felt that the scenarios were significantly more mentally and physically demanding than drivers during the day. Drivers in the night condition also reported significantly more time pressure, effort and frustration across scenarios compared with day-condition drivers. Finally, drivers in the night condition rated their performance to complete the scenarios significantly poorer than did drivers during the day.

Table 7.17.Main effect of light condition results. Note: Larger TLX values indicate increasing difficulty in performing the task along a subscale dimension.

	Day	Night	F	p-value
Mental	45.31	61.62	11.00	<0.001**
Physical	24.57	41.16	8.80	0.01**
Time	31.45	42.40	4.92	0.03*
Performance	34.00	45.09	7.16	0.10
Effort	32.47	48.24	8.38	0.01**
Frustration	36.18	49.89	6.59	0.01**

* Significant at 0.05; ** Significant at 0.01

7.2.3.1.2. Total NASA RTLX

The NASA TLX scores were also averaged across the six subscales to provide an overall assessment of workload while completing the driving scenarios. As with the subscales, there were significant main effects of age [$F(1,44)=11.6$, $p=0.001$] and light condition [$F(1,44)=15.14$, $p<0.001$]. However, there was also a significant interaction of age by light condition for overall workload [$F(1,44)=4.92$, $p=0.032$] (see Figure 7.17).

Follow-up tests of the significant interaction revealed that older drivers (M=58.24) reported significantly higher workload assessments compared to young drivers (M=37.90) in the night condition [$U_z=-3.18$, $p=0.001$]. There were no differences between older (M=36.14) and young (M=31.85) drivers during the day.

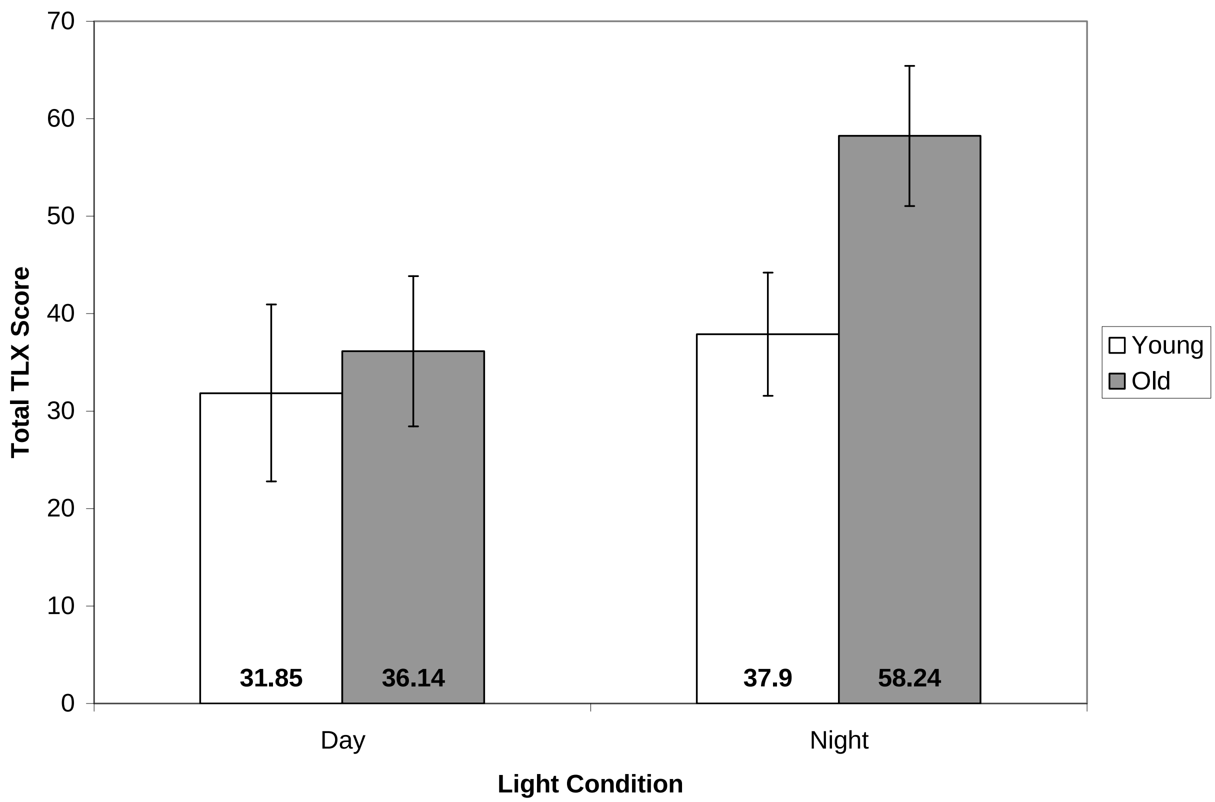


Figure 7.17. Interaction of age and light condition for NASA TLX workload scale. Ninety-five percent confidence intervals shown.
Note: Larger values indicate higher perceived workload.

7.2.3.2. Post-Condition Questions

These post-condition questions asked participants to rate their opinion (1= strongly disagree; 5 = strongly agree) of certain sign characteristics. Separate ANOVAs were run on each question in this set to determine differences between signs. All 10 questions resulted in a significant outcome. In most of the analyses the smart signs differed significantly from baseline. Because the STOP sign was familiar to all drivers, many drivers rated its functionality as a STOP sign and not as a decision support sign. Comparisons of the smart signs that aid with decision making to the STOP sign alone that does not provide decision support do not yield useful information about how the smart signs performed. Instead, the comparisons across the smart signs better explain drivers' perceptions and preferences between the smart signs. Therefore, the questionnaire data presented here focuses on differences between the smart signs and does not include the baseline comparisons.

7.2.3.2.1. Question 1: I felt confident using this sign

There was a significant interaction between sign and light condition for question 1 [F(3,138)=3.57, p=0.019) (see Figure 7.18). Overall, participants in the night condition rated themselves as feeling less confident using the Hazard sign [U_z=-2.13, p=0.033] and the VMS sign [U_z=-1.97, p=0.048] than participants did during the day. In contrast, participants in the night condition reported feeling more confident using the Split-hybrid sign than did participants in the day condition [U_z=-2.19, p=0.03]. Overall, drivers in the night condition showed the more confidence using the Split-hybrid and the Icon signs compared with drivers in the day condition.

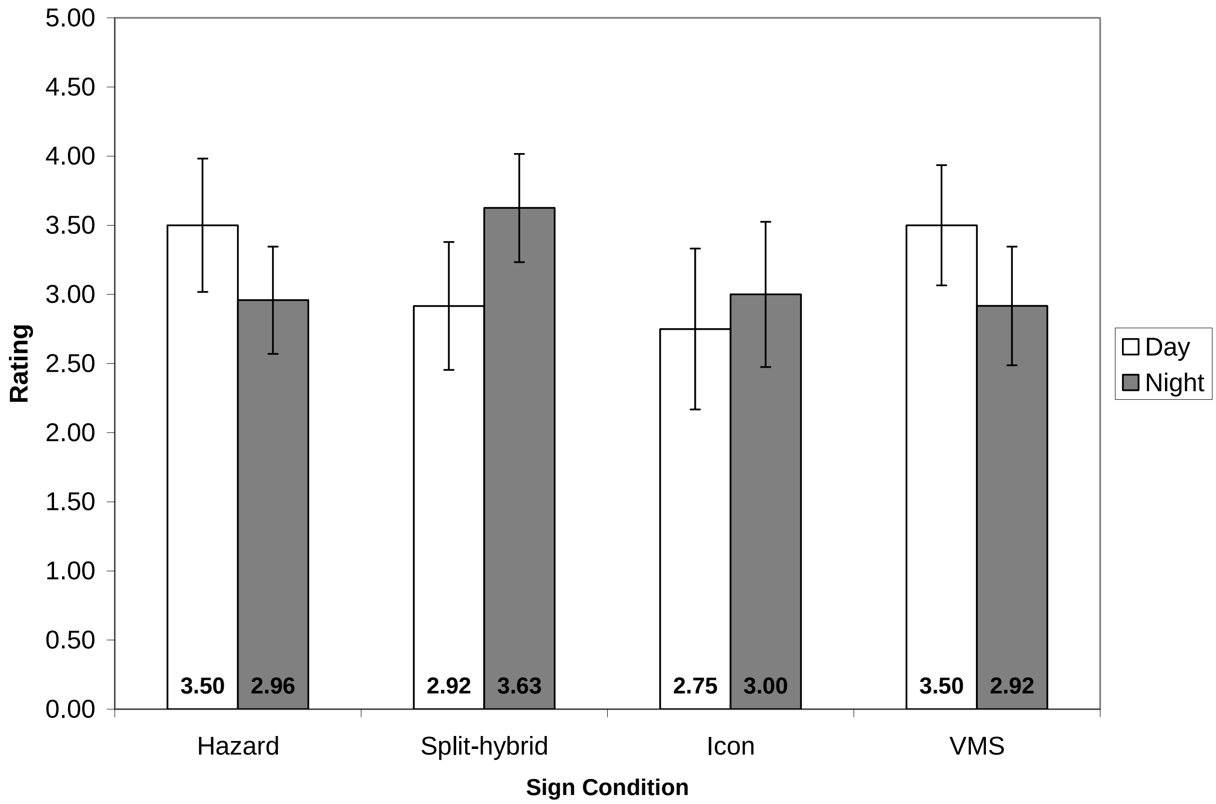


Figure 7.18. Sign by light condition interaction for Question 1 "I felt confident using this sign".

7.2.3.2.2. Question 2: I felt this sign was confusing to use

There was a significant main effect of sign for the question "I felt this sign was confusing to use" [F(3,132)=4.18, p=0.01] (see). Overall, the Icon sign (M=3.19) was rated significantly more confusing to use than Hazard sign (M=2.46) [Wz=-2.56, p=0.01] and the Split-hybrid sign (M=2.58) [Wz=-3.04, p=0.002]. There was also a significant main effect of age [F(1,44)=9.58, p=0.03]. On average, older drivers rated the IDS signs significantly more confusing to use (M=2.99) than young drivers (M=2.5) (see Figure 7.19).

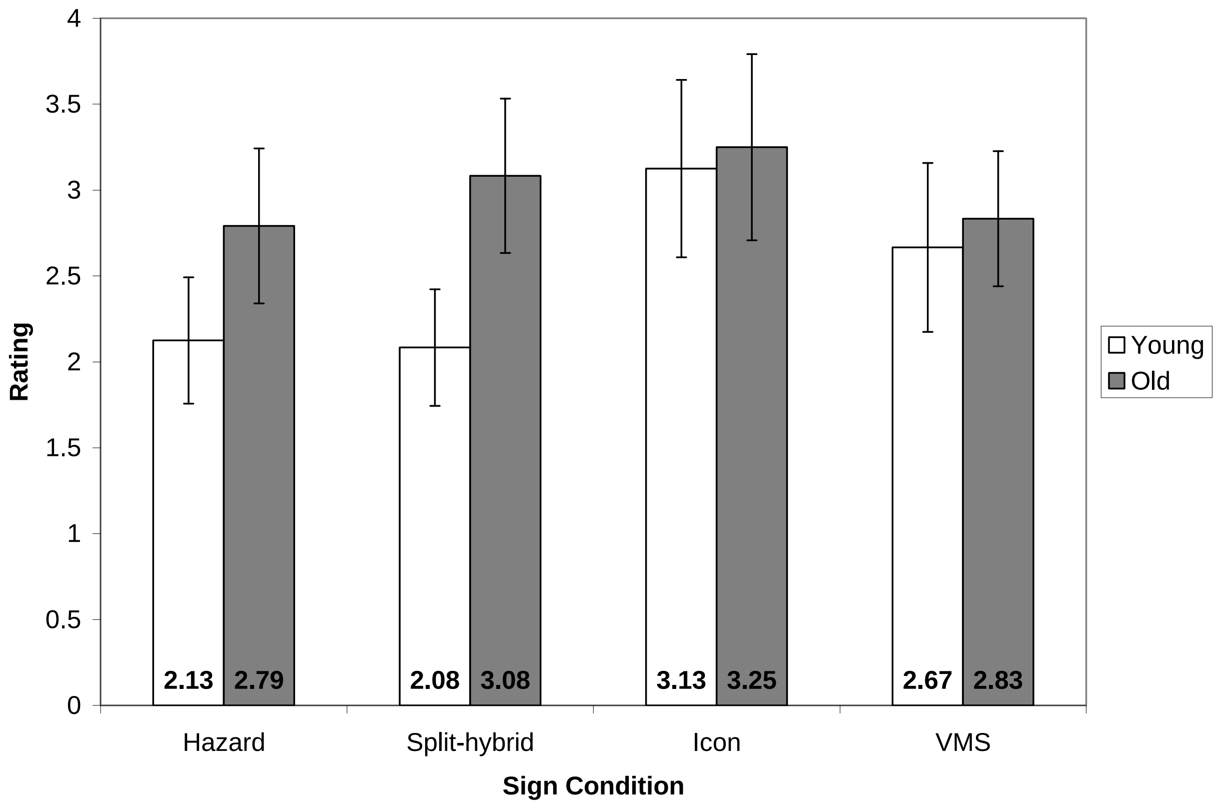


Figure 7.19. Interaction of sign and age condition for Question 2, "I found this sign confusing to use.

7.2.3.2.3. Question 3: Using this sign made me feel safer

There was a significant main effect of sign for question 3 [F(3,138)=2.97, p=0.038]. The Split-hybrid (M=3.33) was rated significantly higher (safer) than the Hazard sign (M=2.81) [W_z=-2.16, p =0.03], and the Icon sign (M=2.75) [W_z=-2.79, p=0.005] for making drivers feel safer. Overall, the Split-hybrid received the highest rating for making participants feel safer. There was also a significant interaction of sign by light condition [F(3,132)=4.71, p=0.005] (see Figure 7.20). On average, drivers in the night condition rated the Split-hybrid sign [Uz=-2.22, p=0.03] and the Icon sign [Uz=-2.02, p=0.04] as making them feel safer compared to drivers in the day condition.

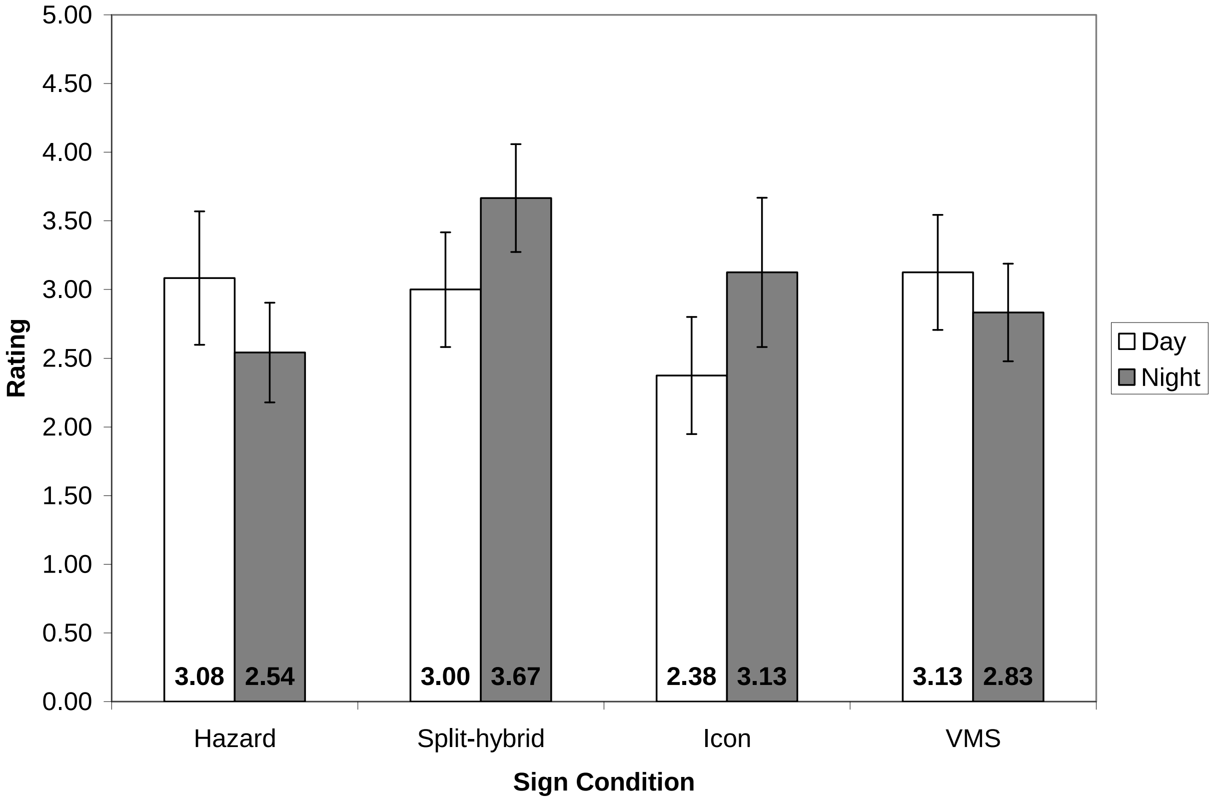


Figure 7.20. Sign by light condition interaction for question 3 "Using this sign made me feel safer".

7.2.3.2.4. Question 4: I trusted the information provided by the sign

There were no significant main effects or interactions for question 4.

7.2.3.2.5. Question 5: I like this sign

There was a significant interaction of sign by light condition for Question 5 [F(3,138)=3.86, p=0.01] (see Figure 7.21). Participants in the day condition liked the Split-hybrid sign less than participants in the night condition [U_z=-2.06, p=0.04]. Overall, the Split-hybrid sign was most liked in the night condition.

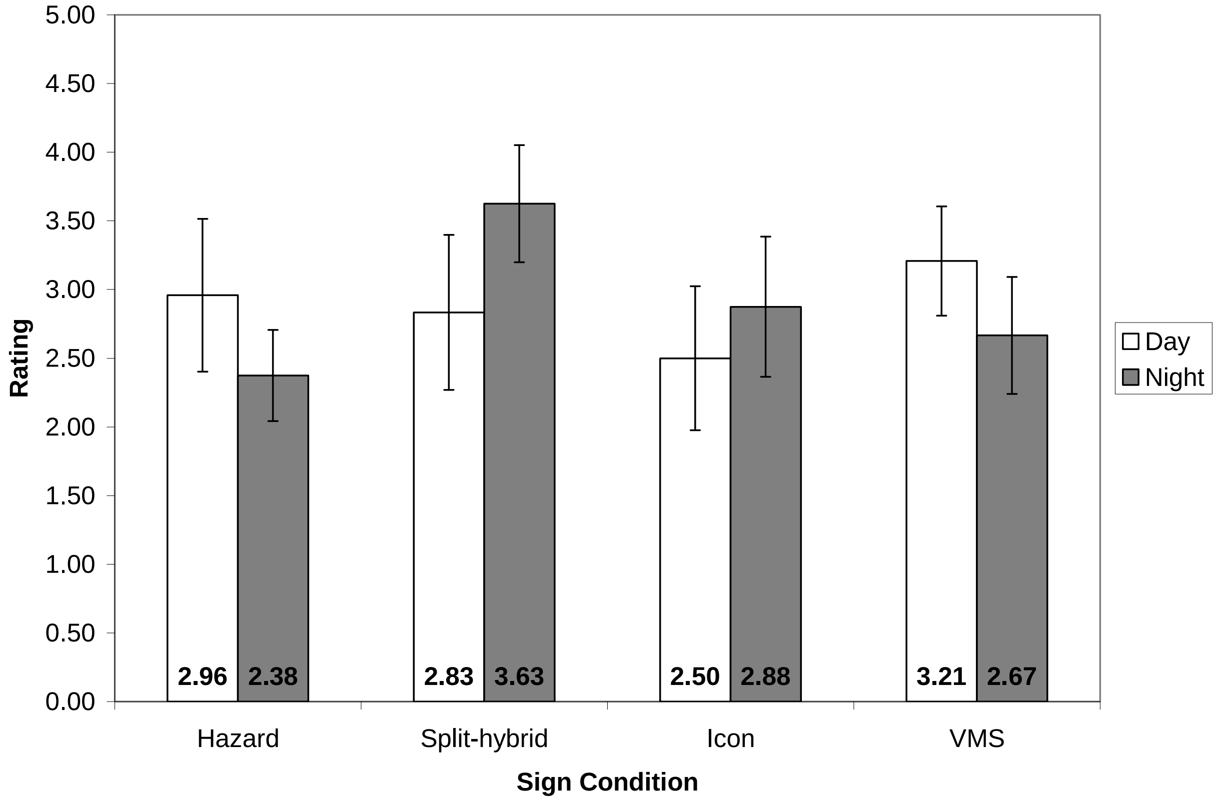


Figure 7.21. Interaction of sign by light condition for Question 5 “I like this sign”.

7.2.3.2.6. Question 6: The sign was reliable

There were no significant main effects or interactions for question 6.

7.2.3.2.7. Question 7: I felt this sign was easy to understand

There was a significant main effect of sign for Question 7 [F(3,141)=3.79, p=0.012] (see Figure 7.22). Within the smart signs, the Split-hybrid sign was rated the easiest to understand and it was rated significantly higher than the Icon sign [W_z=-3.47, p=0.001] and the VMS sign [W_z=-2.13, p=0.03].

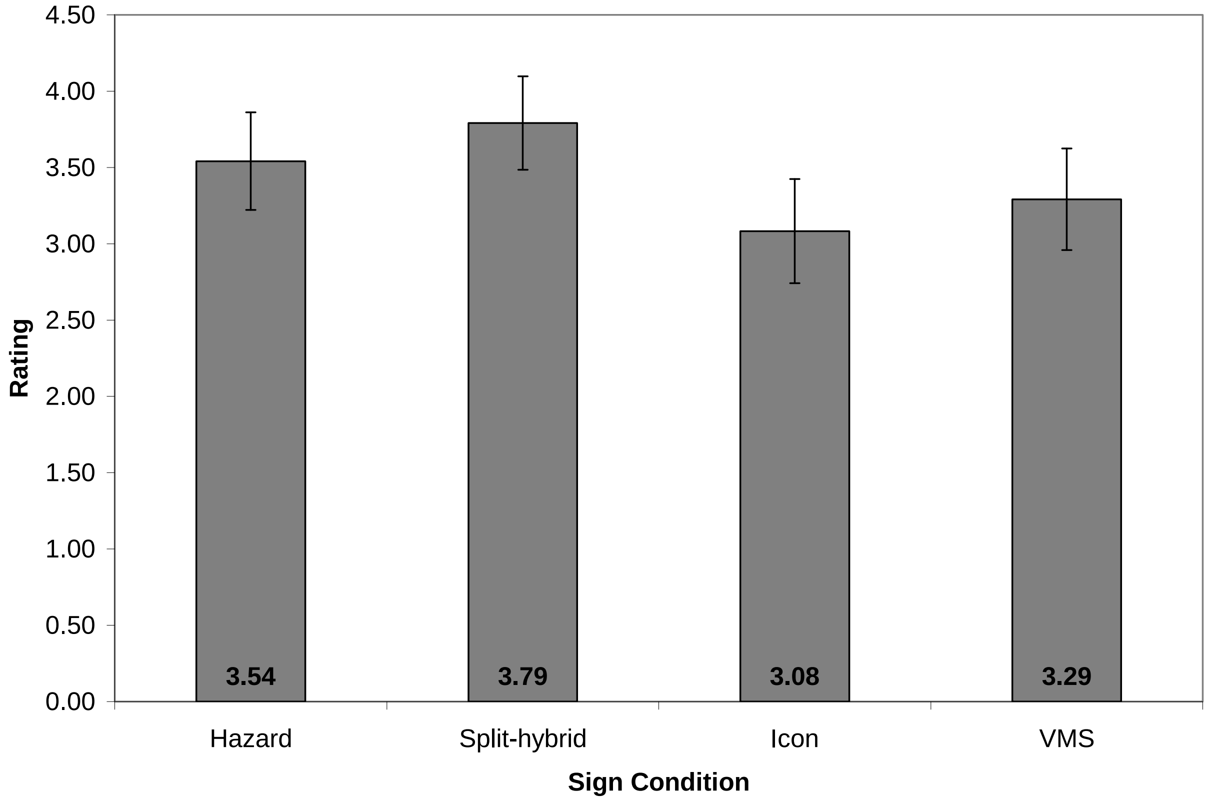


Figure 7.22. Main effect of sign for Question 7 “I felt this sign was easy to understand”.

7.2.3.2.8. Question 8: The sign’s information was believable (credible)

There were no significant main effects or interactions for question 6.

7.2.3.2.9. Question 9: This sign was useful

There was a significant interaction of sign by light condition for question 9 [F(3,138)=6.27, p=0.001] (see Figure 7.23). Participants in the day condition found the Hazard sign to be significantly more useful than did participants in the night condition [Uz=-2.19, p=0.03]. Participants in the night condition found both the Split-hybrid sign [Uz=-1.96, p=0.05] and the Icon sign [Uz=-2.33, p=0.02] more useful than participants in the day condition. Overall, the Split-hybrid sign was rated most useful at night, whereas the Hazard sign was rated most useful during the day condition.

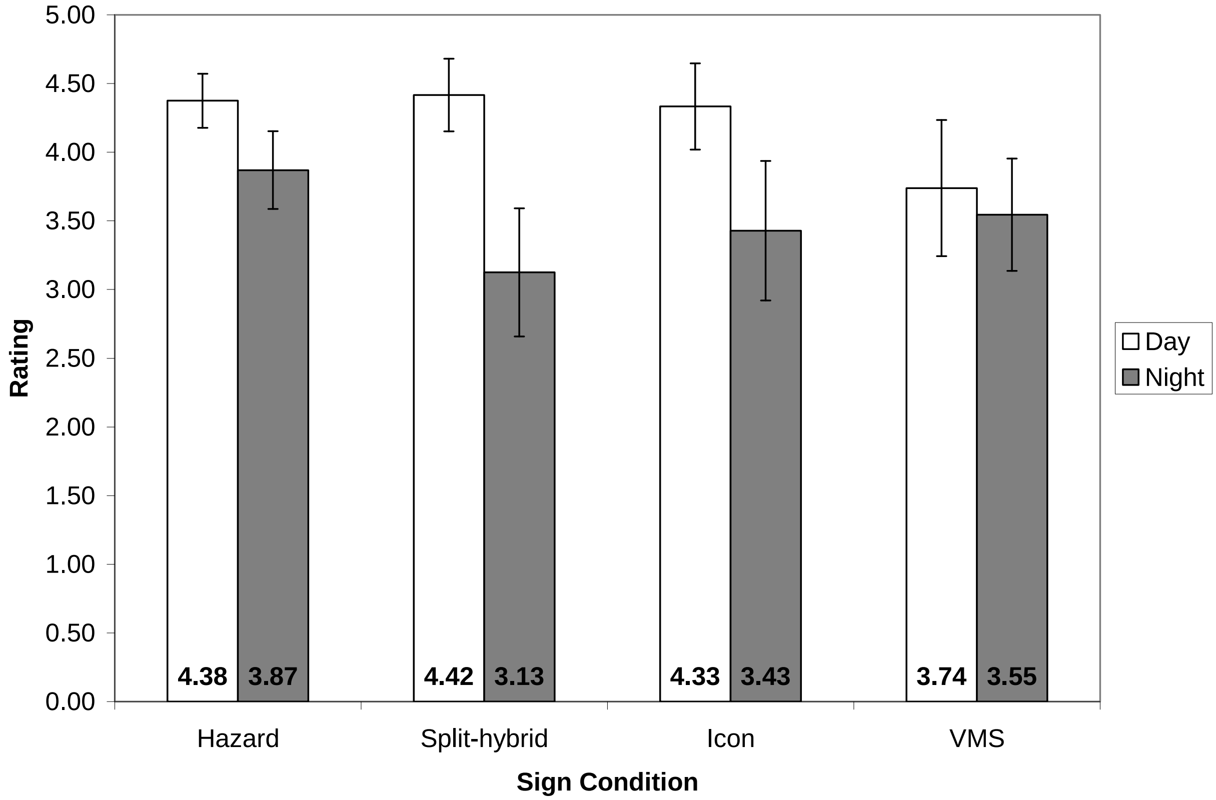


Figure 7.23. Interaction of sign by light condition for question 9 “This sign was useful”.

7.2.3.2.10. Question 10: I could complete this maneuver the same without using the sign

There was a significant interaction of sign by light condition for question 10 [F(3,138)=2.87, p=0.046] (see Figure 7.24). Participants in the night condition showed significantly lower agreement with this statement compared to participants in the day condition for the Hazard sign [Uz=-2.63, p=0.004], the Split-hybrid [Uz=-3.98, p<0.001] and the Icon sign [Uz=-2.58, p=0.01].

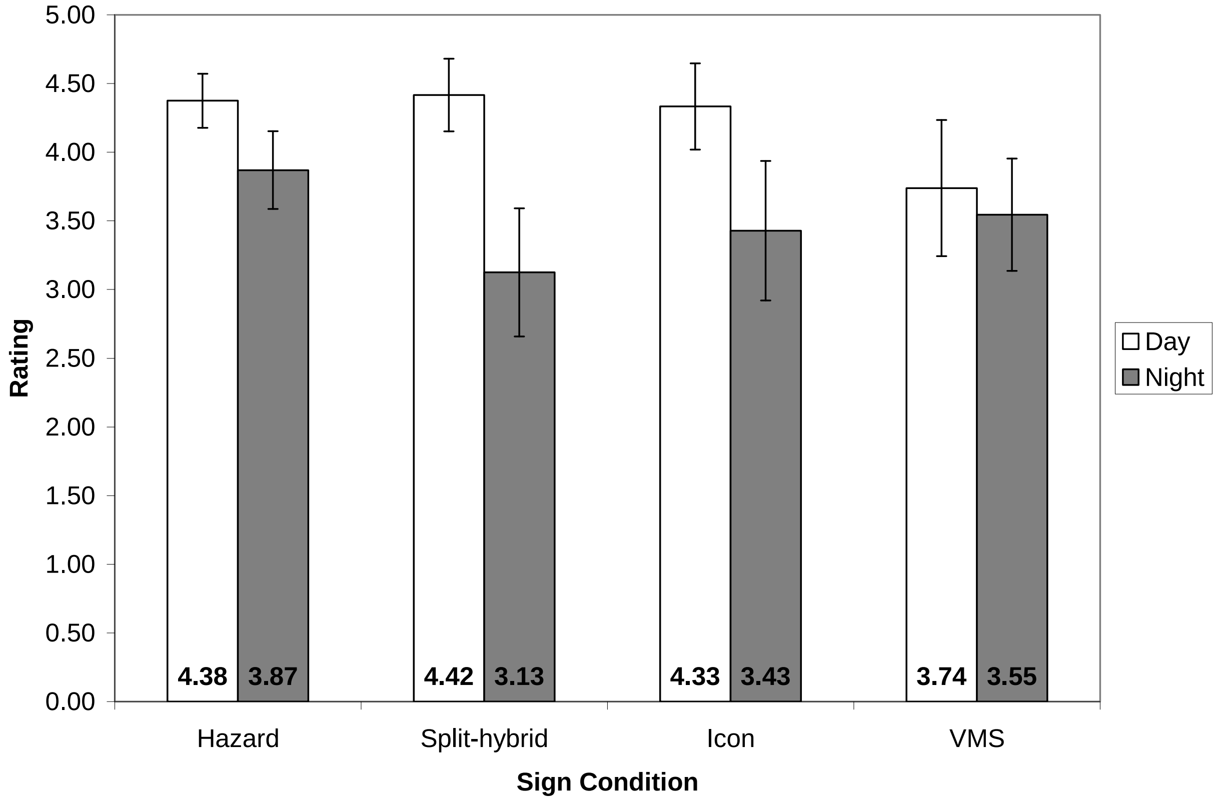


Figure 7.24. Interaction of sign by light condition for Question 10 "I could complete the maneuver the same without using the sign".

7.2.3.3. TLX and Usability Questions Summary

- Overall, older drivers rated the driving scenarios to be more mentally and physically demanding than did young drivers. They also had higher ratings of time pressure, effort and frustration, and rated their performance as significantly worse than young drivers.

- In particular, older drivers perceived the night scenarios to be considerably more demanding in terms of workload than did young drivers and than all drivers did in the day condition.

- Overall, drivers in the night condition showed the more confidence using the Split-hybrid and the Icon signs compared with drivers in the day condition. In the night condition, participants rated themselves as feeling most confident using the Split-hybrid sign (Q1).

- Overall, all drivers found the Icon sign to be the most confusing sign to use. Overall, older drivers found the IDS sign significantly more confusing to use than young drivers (Q2).

- Overall, the Split-hybrid received the highest rating for making participants feel safer and it was rated as making drivers feel significantly safer than the Hazard sign and the Icon sign. Drivers in the night condition felt safer using the Split-hybrid and Icons signs compared with drivers in the day condition (Q3).

- Participants in the night condition liked the Split-hybrid sign significantly more than drivers in the day condition (Q5).
- The Split-hybrid was rated easiest to understand. It was rated significantly easier to understand than the Icon or VMS signs (Q7).
- The Split-hybrid and Icon signs were rated significantly more useful by drivers in the night condition compared with drivers in the day condition. The Hazard sign was rated significantly more useful by drivers in the day condition when compared with drivers in the night condition (Q9).
- The presence of the Split-hybrid and the VMS signs were considered more necessary to complete the crossing maneuver than was the Hazard sign (Q10).

7.2.4. Sign Comprehension

Before the study, drivers were told that the signs were "smart" signs that monitored the crossing traffic at the intersection to detect safe gaps. Therefore, drivers were already aware of the basic function of the signs, but not the more specific information provided by each design concept. For each sign, participants were asked the following question: "Please describe in your own words how this sign worked. What information does it provide?" They were then also asked to describe what certain indicated features on each sign meant. The responses for each sign were categorized in order to determine how well participants understood the information provided on the signs. One researcher created a set of categories for each response set for each sign and then assigned each participant's response to a category. A second researcher also independently assigned participant responses to the categories. Inter-rater reliability was high (0.82). Differences in categorization were reviewed by both researchers and a consensus reached on which category applied for a response. In some cases, drivers provided an answer that did not relate to the question or (such as comments, rather than a response), could not be interpreted by the researchers or was sufficiently different from all other participants that it could not be grouped into a category. In these cases, the response was placed in the "other category". Participants who said they did not know the answer or provided no answer at all were placed in the "Don't know/No answer" category. Otherwise, the creation of categories attempted to account for most answers and provide an understanding of how drivers viewed the signs' information.

7.2.4.1. Hazard Sign

Figure 7.25 shows the Hazard sign and the two features drivers were required to describe after driving with this sign present at the intersection. Table 7.18 shows the categories of responses for the Hazard sign. An asterisk (*) denotes the category (or categories) that best represents the function of the sign. Overall, drivers did not fully grasp that the sign would stop flashing when no unsafe gaps were detected in both sets of lanes. However, most indicated that it was an "alert" sign indicating they should take caution while crossing the intersection and that heavy or dangerous traffic was present. The alerting function of the sign was a primary function of the sign. .

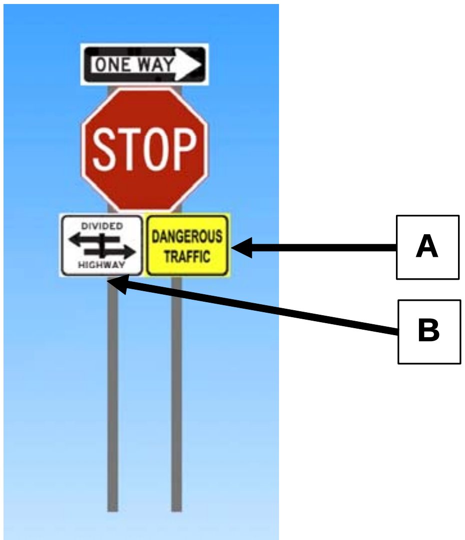


Figure 7.25. Hazard sign. A: Dangerous traffic flasher. B: Divided highway sign.

Only one driver out of 48 answered correctly that the sign stopped flashing when there was no traffic detected ("When the dangerous traffic sign is on, it's not ok to enter the intersection"). This case exemplifies the need for drivers to experience and be cognizant of all states of a sign in order to discern its functionality. The driver who answered correctly had waited until all the traffic had passed and saw the sign stop flashing. This was further supported by their responses to Feature A, the Dangerous Traffic Flasher, where the majority of responses included descriptions of heavy or fast traffic at the intersection. Most drivers understood the meaning of the Divided Highway sign.

Table 7.18. Hazard Sign: percentage of participant responses for each response category.

How does this sign work?	**Day**		**Night**	
	Young	**Older**	**Young**	**Older**
Dangerous traffic/Dangerous intersection	58.3	33.3	25	25
Indicates heavy traffic or fast traffic flow	16.7	25	16.7	25
Use caution while crossing*	16.7	-	-	-
Caution/be careful/alert	-	8.3	8.3	-
When "dangerous traffic" sign is on, it is not ok to enter the intersection*	-	-	-	8.3
Dangerous to enter intersection/cross	-	8.3	8.3	8.3
Traffic approaching	8.3		16.7	
Don't know/No answer	-	8.3	16.7	16.7
Other	-	16.7	8.3	16.7
A: Dangerous traffic flasher	**Day**		**Night**	
	Young	**Older**	**Young**	**Older**
Dangerous traffic/conditions/intersection	16.7	-	25	25
Indicates heavy traffic or fast traffic flow	33.3	50	41.7	33.3
Use caution while crossing*	16.7	8.3		
Caution/be careful/alert	16.7	8.3	8.3	8.3
Dangerous to enter intersection/dangerous to cross	8.3	-	8.3	25
Traffic approaching	8.3	8.3	8.3	-
Don't know/No answer	-	8.3	-	8.3
Other	-	16.7	8.3	-
B: Divided Highway	**Day**		**Night**	
	Young	**Older**	**Young**	**Older**
Divided highway*	83.3	50	91.7	75
More than one lane of traffic to cross	16.7	8.3	8.3	-
Traffic from two directions	-	16.7	-	25
Other	-	25	-	-

* indicates category derived from responses that best reflects actual function of sign/feature.

7.2.4.2. *Icon Sign*

Figure 7.26 shows the features for which a response was requested and shows the response categories and percentage of participant responses for each. The majority of drivers in all conditions indicated that the Icon sign's main function was to tell the driver when they were able to cross or turn at the intersection. Several drivers indicated this function as well as indicating that the sign provided information about the presence of traffic. Older drivers in the day condition had the fewest responses (50%) indicating the general function of the sign, while young drivers in the day condition had the most responses for this function (with or without comments about traffic) (100%). Both young and older drivers in the night condition showed similar percentages of responses for this type of function, with or without a mention of traffic (young = 66.7%; older = 58.4%).

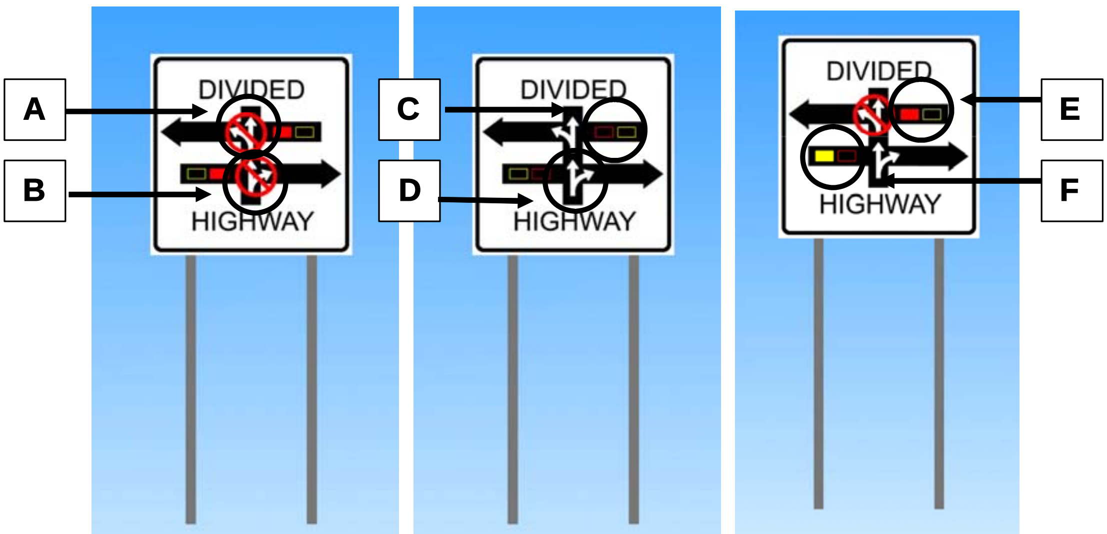


Figure 7.26. Icon Sign. A: Do not cross or turn left (far lanes). B: Do not cross or turn right (near lanes). C: No traffic detected (from right). D: Right turn or cross to median. E: Vehicle within safe gap. F: Vehicle approaching; cross or turn right but watch for traffic.

Feature A showed the prohibitive slash and circle over the far lanes left turn or cross path indicator. This means drivers should not attempt to cross or turn left into the far lanes of traffic because traffic is within the safe gap. This prohibitive message can be displayed even if it is safe to cross the near lanes, therefore, a good response would have included a reference to the far lanes of traffic. However, although the majority of participants answered "do not cross or turn left", only one participant (older night) mentioned the far lanes in their response.

Feature B is the turn right or cross path indicator with the prohibitive circle and slash present. This feature indicates it is not safe to cross to the median or turn right because vehicles are within the safe gap. The majority of drivers said "do not cross or turn right" when describing what Feature B meant. Compared with Feature A (far lanes) more drivers mentioned that Feature B was related to the near lanes specifically, as opposed to only one who mentioned the far lanes in association with Feature A. Mentioning the median or near lanes shows a greater awareness of Feature B's relationship to the near lanes only. However, because the information on the entire sign indicates that it is not safe to cross or turn into either set of lanes it is possible that participants provided the more general “do not cross or turn” response based on the entire sign rather than the Feature B alone.

Feature C shows the traffic warning icons in their “off” state (far lanes). This feature’s main function is to indicate that no traffic is detected within 12.5 s or 7.5 s of the intersection (from the right). The young drivers in the night condition had the most correct responses (50%) for this feature. The remaining responses mostly related to drivers who indicated that Feature C meant it was all right to cross or to turn left. Although not specific about the traffic, these responses are correct as the prohibitive circle and slash will not be illuminated when no vehicles are detected, thus showing to drivers that it may be safe to cross the lanes indicated.

Feature D shows the path indicator for turning right or proceeding to the median across the near lanes without the prohibitive circle and slash present. This indicates that drivers may be able to cross to the median or turn right. As with Feature B, few drivers mentioned that it related to the near lanes. However, the majority of drivers did indicate that it meant they could cross or turn right. Because the entire sign indicates that no traffic is detected in either direction, drivers who simply answered that Feature D meant it was safe to cross or turn without specifically applying it the near lanes, may have based their answer on the entire sign rather than the single Feature indicated.

Feature E shows the red traffic warning icon in its “on” state (far lanes). This feature’s main function is to indicate that traffic is detected within the same gap. It is presented in conjunction with the prohibitive slash and circle over the path indicator for the lanes. Few drivers responded that it meant traffic was close to the intersection; however, the majority responded that they could not cross or turn left. The responses for vehicle warning icons suggest that drivers interpreted the combination of information presented for a set of lanes rather than individual Features in isolation.

Feature F shows the yellow traffic warning icon in its “on” state (near lanes). This feature’s main function is to indicate that traffic is approaching the intersection (within 12.5 s), but is not yet within the safe gap threshold. Therefore, drivers may be able to cross, but the icon is intended to alert them to the presence of traffic before they decide to cross or turn. For this feature, more young drivers in both the day (50%) and night (58.3%) conditions made reference to traffic approaching than did older drivers in the day and night (33% for both groups).

Table 7.19. Icon sign: percentage of participant responses for each response category.

How does this sign work?	Day		Night	
	Young	Older	Young	Older
Indicates when to cross or turn	75	50	50	41.7
Indicates how far away traffic is and if it is safe to cross/turn	25	-	16.7	16.7
Proceed with caution	-	8.3	-	-
Indicates traffic flow/direction of traffic	-	8.3	8.3	8.3
Don't know/No answer	-	8.3	8.3	16.7
Other	-	25	16.7	16.7
A: Do not turn left or cross (far lanes)	**Day**		**Night**	
	Young	**Older**	**Young**	**Older**
Do not turn left or cross*	66.7	25	66.7	41.7
Do not turn left and/or cross; traffic approaching*		41.7	-	33.3
Do not cross/go	33.3		25	8.3
No left turn	-	16.7	-	-
Don't know/No answer	-	8.3	-	-
Other	-	8.3	8.3	16.7
B: Do not turn right or cross to median	**Day**		**Night**	
	Young	**Older**	**Young**	**Older**
Do not cross or turn right	41.7	16.7	58.3	33.3
Do not cross or turn right; traffic approaching	-	33.3	-	41.7
Do not cross to median and/or turn right*	50	16.7	16.7	-
Do not cross/go	-	8.3	16.7	8.3
No right turn	8.3	16.7	-	-
Other	-	8.3	8.3	16.7

Table 7.19. Icon sign: percentage of participant responses for each response category (continued from previous page.

C: No traffic detected (far lanes)	Day		Night	
	Young	Older	Young	Older
No traffic approaching*	8.3	16.7	50	8.3
Cross or turn left	41.7	16.7	8.3	33.3
Cross or turn; traffic is far enough away	8.3	25	8.3	33.3
Cross/go	25	8.3	16.7	8.3
Don't know/No answer	-	8.3	16.7	16.7
Other	16.7	25		
D: Right turn or cross to median	**Day**		**Night**	
	Young	**Older**	**Young**	**Older**
Cross to median or turn right*	33.3	16.7	8.3	25
Cross or turn right	50	33.3	50	16.7
Cross/go	-	16.7	16.7	8.3
Cross or turn, but vehicles might be approaching	8.3	8.3	-	8.3
Cross or turn right; traffic is far enough away	8.3	8.3	-	16.7
No traffic approaching	-	-	25	8.3
Don't know/No answer	-	-	-	16.7
Other	-	16.7	-	-
E: Vehicle within safe gap	**Day**		**Night**	
	Young	**Older**	**Young**	**Older**
Traffic approaching*	-	8.3	25	8.3
Do not cross or turn left	25	8.3	8.3	33.3
Do not cross/go	8.3	8.3	25	8.3
Do not cross or turn; traffic is too close	41.7	41.7	25	33.3
Don’t know/No answer	8.3	16.7	8.3	-
Other	16.7	16.7	8.3	16.7

*indicates category derived from responses that best reflects actual function of sign/feature.

Table 7.19. Icon sign: percentage of participant responses for each response category (continued from previous page.

F: Vehicle approaching; possible to cross but watch for traffic	Day		Night	
	Young	Older	Young	Older
Cross/go but vehicle is approaching; caution*	25	-	33.3	8.3
Vehicle approaching*	16.7	25	25	8.3
Safe to cross or turn right because traffic is far enough away	8.3	8.3	-	16.7
Cross near lanes only/go to median or turn right	25	33.3	-	25
Cross/go and/or turn right	8.3	8.3	25	8.3
Don't know/No answer	8.3	16.7	8.3	25
Other	8.3	8.3	8.3	8.3

*indicates category derived from responses that best reflects actual function of sign/feature.

7.2.4.3. Split-hybrid Sign

Figure 7.27 shows the Split-hybrid sign and the features for which drivers provided a response. Table 7.20 shows the percentage of participant responses for each response category. The Split-hybrid sign indicates the time to arrival of vehicles and also provides information about prohibited actions, such as when it is not safe to enter the intersection. The majority of participants in all groups responded that this sign indicated the time to arrival of vehicles at the intersection. Young drivers overall and older drivers in the night condition had more responses that also related to the sign's function of providing information about when it is unsafe to enter the intersection.

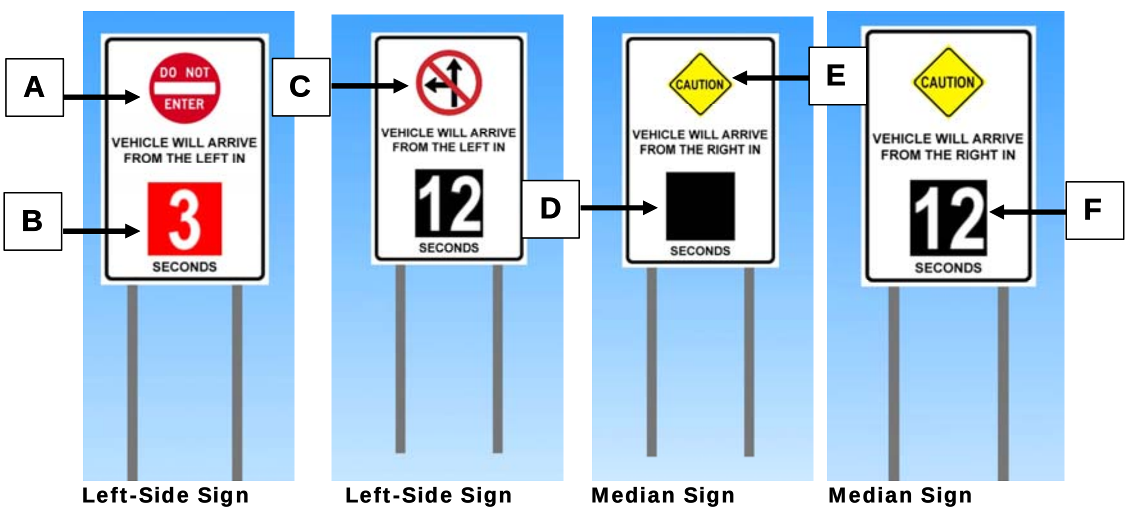


Figure 7.27. Split-Hybrid. A: Do not enter icon. B: Time countdown, vehicle within safe gap. C: Do not cross or turn left (may proceed to median). D: No vehicle detected. E: Caution icon; possible to cross. F: Time countdown, vehicle approaching but not in safe gap.

Feature A is the DO NOT ENTER icon. For this particular sign, this icon indicated that it was not safe to cross the intersection because vehicles were detected within the safe gap. Twenty-five percent of all young drivers and 25% of older drivers in the day condition indicated that the icon meant they could not cross the intersection. Older drivers in the night condition mostly responded that the icon meant they could not enter the one-way traffic lane (58%), whereas only 20.8% of young drivers and 16.7% of older drivers in the day said it meant they could not enter the one way lanes. For the "unsafe to enter" and the "do not enter/do not proceed" categories it is not possible to infer whether drivers thought they could not proceed or enter the one-way lanes or that they could not cross the intersection.

Feature B shows a 3 s timer countdown with a red background. This indicates that a vehicle will arrive at the intersection in 3 s and the red background means it is not enough time to cross the lanes safely. Only two young participants defined both the time element and the color element of the timer countdown. The majority of participants (75%) responded specifically that it meant a vehicle was arriving in 3 s or, more generally, that it indicated the time until the next vehicle would arrive at the intersection.

Feature C shows the DO NOT CROSS OR TURN LEFT icon that is presented on the near-side sign only, when a driver is waiting at the STOP sign. This icon is always accompanied by the timer countdown with a black (with or without a time value) because it indicates that traffic is not detected in the safe gap of the near lanes, but that traffic is detected within the safe gap of the far lanes. Drivers must infer that it means it could be safe to proceed to the median. The majority of drivers simply responded "Do not cross or turn left" without making any mention of other possible maneuvers. However, 25% of young drivers in the day condition did respond that it meant "Do not cross or turn left; can go to median or turn right". The main function of the Split-hybrid sign is to indicate to drivers what actions are prohibited. It is ultimately the driver's responsibility to determine what conditions they consider safe for crossing or turning.

Feature D shows a blank, black timer background. This indicates that no vehicles are detected within the safe gap for the lanes indicated by the sign (i.e., near or far). Although the majority of drivers correctly identified the function of Feature D, a proportion of older drivers in the day (25%) and night (16.7%) conditions, and young drivers in the night condition (25%) thought it meant the sign was broken. In actuality, if the sign were not functioning properly, a question mark (?) would appear in the timer box to indicate a problem.

Feature E is the caution icon. This icon is presented on the near-side sign while at the STOP sign when no traffic is detected within the safe gaps of both the near and far lanes. It also appears on the far-side sign in the median to indicate that no traffic is detected within the safe gap for the far lanes. In each group, 25% of drivers indicated they could cross the intersection, and that they should use caution. An additional 25% of young drivers in both light conditions and 16.7% of older drivers in both light conditions indicated simply that they could "proceed with caution". These are desirable responses. Because the IDS signs are prohibitive in nature, it is important that when vehicles are not detected within the safe gaps drivers do not automatically assume it is safe to go. Instead they should infer that it clear to go, but that they must still be cautious and check for traffic. This icon also elicited responses such as "be careful" or "pay attention", without reference to crossing the intersection.

Feature F is the timer countdown with a 12 s time and a black background. This indicates that a vehicle is detected near the intersection, but that it is not within the safe gap. Again, the driver must decide if the condition is safe for them to proceed. The majority of drivers in all groups simply responded that it was the time to arrival of the next vehicle.

Table 7.20. Split-Hybrid: Percentage of responses for each response category.

How does this sign work?	**Day**		**Night**	
	Young	**Older**	**Young**	**Older**
When cars will arrive at intersection and whether it is safe to cross or enter the intersection*	25		16.7	16.7
Indicates when it is safe to cross			8.3	8.3
Time to arrival of vehicle	33.3	58.3	50	16.7
Sign changed based on traffic conditions	8.3			
How much time there is to cross the intersection	16.7	16.7	8.3	16.7
How much time until can cross intersection	8.3			
Don't know/No answer		16.7	8.3	16.7
Other	8.3	8.3	8.3	25
A: Do not enter icon	**Day**		**Night**	
	Young	**Older**	**Young**	**Older**
Do not enter one-way lanes	25	16.7	16.7	58.3
Do not enter/Do not proceed	33.3	41.7	41.7	8.3
Unsafe to enter*	8.3	8.3	8.3	25
Do not enter; wait for sign to indicate it is safe to cross*		8.3		
Do not cross intersection*	25	25	25	
Don't know/No answer				
Other	8.3		8.3	8.3

* indicates category derived from responses that best reflects actual function of sign/feature.

Table 7.20. Split-Hybrid: Percentage of responses for each response category (continued from previous page).

B: 3 s with red background	**Day**		**Night**	
	Young	**Older**	**Young**	**Older**
3 s to cross	8.3			16.7
Vehicle approaching in 3 s/time until vehicle arrives	75	75	75	75
Vehicle approaching; vehicle close to intersection			8.3	
Time until vehicle arrives and red background means do not cross*	8.3		8.3	
Not enough time to cross				8.3
Don't know/No answer				
Other	8.3	25	8.3	
C: Do not turn left or cross	**Day**		**Night**	
	Young	**Older**	**Young**	**Older**
Do not turn left or cross	58.3	66.7	83.3	50
Do not turn left or cross; can cross to median (or turn right)*	25		8.3	8.3
Do not cross until time interval is safe		8.3		
Do not proceed		8.3		
No left turn		8.3		8.3
Can turn right				8.3
Must turn right	8.3	8.3		
Don't know/No answer	8.3		8.3	8.3
Other				16.7

* indicates category derived from responses that best reflects actual function of sign/feature.

Table 7.20. Split-Hybrid: Percentage of responses for each response category (continued from previous page).

D: Blank timer (black background)	Day		Night	
	Young	Older	Young	Older
No traffic detected*	66.7	33.3	41.7	58.3
Sign is broken/off		25	25	16.7
Time until next vehicle arrives		8.3		
Safe to cross; use caution	8.3			8.3
Do not enter/go				8.3
No time available to cross		8.3		
Don't know/No answer		25	25	
Other	25		8.3	8.3
E: Caution icon	**Day**		**Night**	
	Young	**Older**	**Young**	**Older**
Cross intersection with caution*	25	25	25	25
Proceed with caution	25	16.7	25	16.7
Safe to cross				
Caution/be careful/alert	41.7	58.3	33.3	25
Watch for traffic	8.3		8.3	16.7
Do not cross				8.3
Don't know/No answer				8.3
Other			8.3	
F: 12 s timer with black background	**Day**		**Night**	
	Young	**Older**	**Young**	**Older**
12 s until next vehicle arrives and it is safe to cross	8.3	8.3	16.7	16.7
12 s until next vehicle arrives/Time until next vehicle arrives*	58.3	66.7	75	50
12 s available to cross intersection*	33.3			16.7
Enough time to cross/safe to cross		16.7	8.3	8.3
Don't know/No answer				8.3
Other		8.3		

* indicates category derived from responses that best reflects actual function of sign/feature.

7.2.4.4. *VMS Sign*

Young drivers in the night condition provided the most correct responses for this sign (41.7%) by indicating that the sign told them when it was safe to cross or enter the intersection. However, a significant proportion of drivers responded that they did not know the answer, provided no answer, or provided an answer that could not be adequately categorized when asked to describe how the VMS sign worked. Overall, comprehension of the VMS sign's function was low.

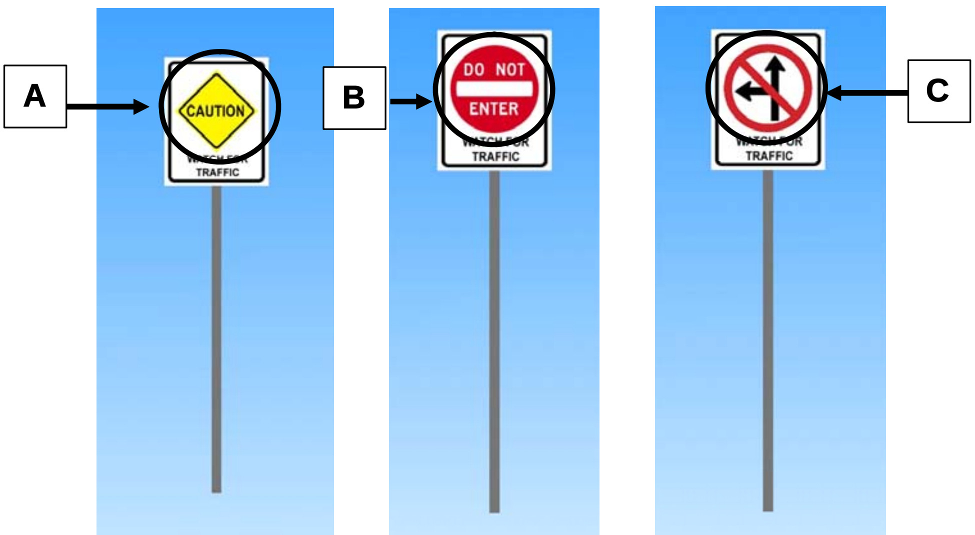


Figure 7.28. VMS. A: Caution icon. B: Do not enter icon. C: Do not turn left or cross icon.

Feature A was the same caution icon used for the Split-hybrid sign and was presented based on the same control logic. Only two participants provided an answer that most closely resembled the intended meaning of the icon (Cross but watch for traffic/be cautious). In addition, 16.7% of young drivers in the day, 25% of young drivers at night, and 33.3% of older drivers at night responded with "proceed with caution". Again, the function of the caution icon is to convey to the driver that it may be safe to cross, but that they are ultimately responsible for determining whether it is safe to cross and that caution is warranted. The majority of participants answered with general comments such as "be cautious" or "caution" or "watch for traffic".

Feature B was the same DO NOT ENTER icon presented on the Split-hybrid sign. This icon meant it was not safe to enter the intersection because vehicles were detected within the safe gap. Participants appeared to mistake the DO NOT ENTER portion of the sign as meaning they could not turn into the one-way lanes of traffic. Young and older drivers in the night condition were less likely to make this mistake compared with young and older drivers in the day condition. This could be because the drivers in the night condition accepted more gaps above the 7.5 s threshold and thus, potentially saw the sign changing. In the day condition, no drivers accepted gaps above the 7.5 s threshold and would, therefore, have only seen the DO NOT ENTER icon. This emphasizes the point that drivers may need exposure to the full range of functions in order to comprehend the sign's function.

Feature C was also the DO NOT TURN LEFT OR CROSS icon used on the Split-hybrid sign. The majority of drivers stated simply that the sign meant "do not cross or turn left". Several also mentioned the possibility of crossing to the median or turning right. More drivers in the VMS condition responded that they did not know the answer or provided a response that could not be categorized compared with the Split-hybrid condition.

Table 7.21. VMS percentage of participant responses per response category.

How does this sign work?	Day		Night	
	Young	Older	Young	Older
Tells when it is safe to enter/cross*	8.3		41.7	8.3
Do not enter one-way lanes	25			
Watch for traffic/There is oncoming traffic	16.7	8.3	8.3	8.3
Warning/cautionary sign	16.7	8.3	8.3	
Proceed with caution	8.3	8.3		
Don't know/No answer	16.7	33.3	16.7	66.7
Other	8.3	41.7	25	16.7
A: Caution Icon	**Day**		**Night**	
	Young	**Older**	**Young**	**Older**
Caution/be careful/alert	33.3	41.7	16.7	33.3
Watch for traffic/There is oncoming traffic	41.7	33.3	41.7	25
Cross but watch for traffic/be cautious*	8.3	8.3		
Proceed with caution*	16.7		25	33.3
Cross			8.3	8.3
Other		16.7	8.3	
B: Do not enter icon	**Day**		**Night**	
	Young	**Older**	**Young**	**Older**
Do not enter one-way traffic	50	58.3	16.7	33.3
Do not enter – unsafe or vehicle approaching*	8.3	8.3	16.7	8.3
Do not enter/cross intersection*	16.7		16.7	8.3
Do not enter/do not proceed		16.7	41.7	33.3
Don't know/No answer			8.3	8.3
Other	25	16.7		8.3

* indicates category derived from responses that best reflects actual function of sign/feature.

Table 7.21. VMS percentage of participant responses per response category (continued from previous page).

C: Do not turn left or cross	Day		Night	
	Young	Older	Young	Older
Do not turn left or cross	41.7	50	66.7	50
Do not turn left or cross; can turn right/cross to median	25		16.7	8.3
Don't know/No answer	8.3	33.3	8.3	25
Other	25	16.7	8.3	16.7

* indicates category derived from responses that best reflects actual function of sign/feature.

7.2.5. Comprehension of Different Sign States

At the end of the study drivers were presented with a questionnaire that showed the signs they had viewed in each of two or three states that could occur while stopped at the STOP sign (see the Sign State Questionnaire in Appendix D. The states corresponded to one of the following meanings:

- Stop and wait
- Proceed to median and wait
- Cross entire intersection

The Hazard sign only has two states: stop and wait or cross entire intersection, while the Split-hybrid, Icon and VMS signs can show all of the three states listed above. Table 7.22 shows the percentage of participants who answered each question of the quiz correctly.

Table 7.22. Percentage of participants who answered correctly for each sign state question by sign, age and light condition.

	Day		Night	
	Young	Older	Young	Older
Hazard				
Stop and wait	91.7	75	100	54.5
Cross entire intersection	16.70	0.00	33.30	45.50
Icon				
Stop and wait	100.00	100.00	91.70	100.00
Proceed to median	91.70	75.00	91.70	90.90
Cross entire intersection	75.00	50.00	83.30	72.70
Split-hybrid				
Stop and wait	91.70	91.70	100.00	100.00
Proceed to median	100.00	75.00	58.30	81.80
Cross entire intersection	16.70	8.30	16.70	0.00
VMS				
Stop and wait	91.70	83.30	91.70	54.50
Proceed to median	33.30	8.30	8.30	18.20
Cross entire intersection	8.30	0.00	25.00	27.30

Overall, most drivers best comprehended the information on most signs that corresponded to the action “stop and wait”. However, older drivers in the night condition had lower comprehension than other drivers of the “stop and wait” state for the Hazard and VMS signs. In the Icon and Split-hybrid sign conditions, drivers also had fairly high comprehension rates for the prohibitive NO LEFT TURN OR CROSS icon. The high comprehension of most of the unsafe prohibitive states is important because a key design goal was for drivers to understand the information indicating it was not safe to enter the intersection. In particular, the Icon and Split-hybrid signs’ prohibitive information was best understood overall.

The implied safe state indicated by the CAUTION icon in the Split-hybrid and VMS sign conditions was least understood. When the CAUTION icon is presented on these signs it means no vehicles are detected on either side of the intersection within the safe gap thresholds. This suggests that drivers do not automatically assume it is safe to cross the intersection when the CAUTION icon is present compared with the more prohibitive icons. In fact, many drivers indicated that the sign meant “caution” or “proceed with caution” in their written responses of what the icon meant. Thus, although the drivers felt that it may be clear to enter the intersection, they still understood that caution was warranted when crossing.

The results for each of the three states were also summed for each participant and divided by the appropriate number of questions (i.e., Hazard = 2 state questions; Icon, Split-hybrid, VMS = 3 state questions) to get a percentage score for each participant per sign. These results were analyzed using a mixed-model ANOVA for sign, age and light condition.

There was a significant main effect of sign condition for the results of the state questions [F(3,123)=45.5, p<0.001] (see Figure 7.29). Overall, the Icon sign showed the best comprehension for the quiz (M=88.15) when compared to the Hazard sign (M=51.11) [Wz=-5.23, p<0.001], the Split-hybrid sign (M=64.44) [Wz=-4.46, p<0.001], and the VMS sign (M=39.26) [Wz=-5.43, p<0.001]. Overall, the VMS sign showed the worst comprehension for the quiz when compared to the Split-hybrid [Wz=-4.15, p<0.001] and the Hazard signs [Wz=-3.21, p=0.001]. There were no significant differences in comprehension of sign between night and day for the interaction of sign and light condition (p's>0.05).

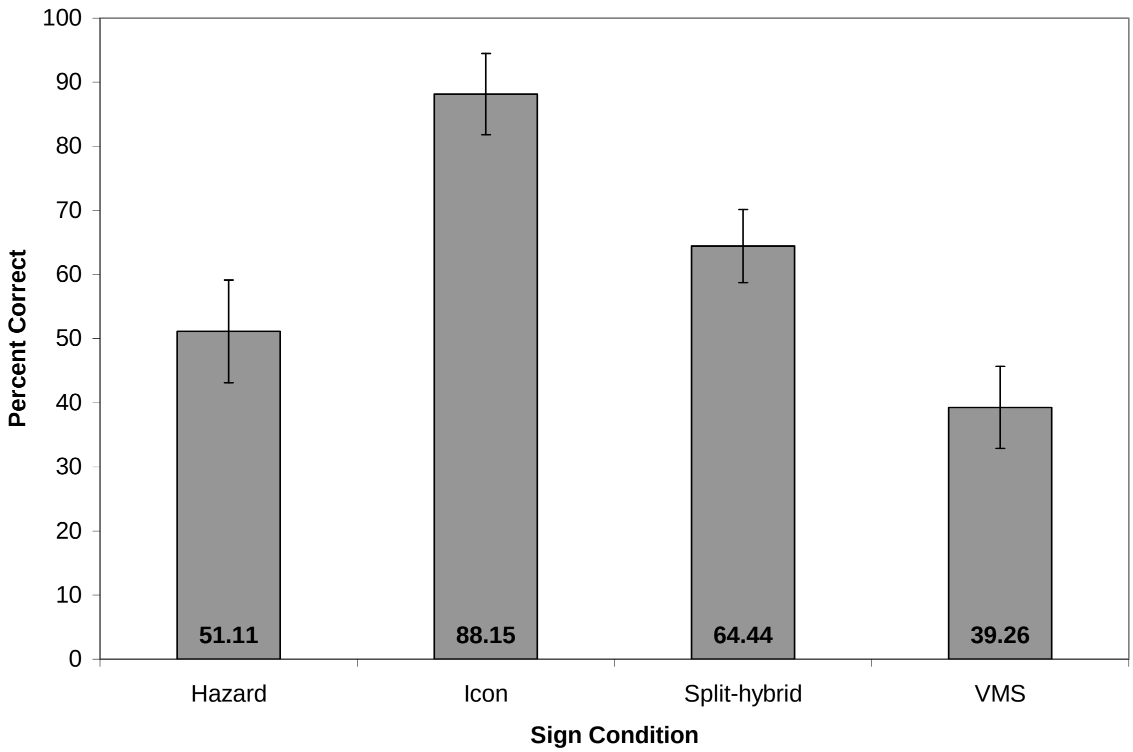


Figure 7.29. Main effect of sign for sign state questions.

There was also a significant main effect of age for comprehension of the sign states [F (1,41)=6.88, p=0.012]. On average, sign state comprehension was significantly higher for young drivers (M=64.1%) than for older drivers (54.2%). This result is similar to the comprehension shown when drivers were asked to describe the function of the signs where young drivers had the highest comprehension in all sign conditions except the Hazard sign.

7.2.6. Self-Reported Sign Use

Question 13 asked participants to answer "yes" or "no" to the following question: "Did you use information provided by the sign to help make your decision during the crossing maneuver?" Table 7.23 shows the percentage of people who responded "yes" that they used some piece of information from the sign to help them make their crossing decision. More older drivers in the night condition said they used the Icon, Split-hybrid and VMS signs when compared to older drivers in the day condition. The Split-hybrid sign showed the highest percentage of use for both the day and night driving condition by young and older drivers.

Table 7.23. Percentage of participants by age and light condition who answered yes or no to the question “Did you use this sign to help you make your crossing decisions?”

	Day		**Night**	
	Young	**Older**	**Young**	**Older**
Hazard				
No	58.3	50.0	91.7	66.7
Yes	41.7	50.0	8.3	33.3
Icon				
No	41.7	75.0	41.7	50.0
Yes	58.3	25.0	58.3	50.0
Split-hybrid				
No	33.3	50.0	0	0
Yes	66.7	50.0	100	100
VMS				
No	45.5	66.7	75	58.3
Yes	54.5	33.3	25	41.7

7.2.7. Preference Rankings

Participants were asked to rank the signs based on both their preference and how helpful they felt each sign was for making the crossing maneuver. A rank of 1 indicated that a sign was most preferred by the participant whereas a rank of 5 indicated that a sign was least preferred. Many of the analyses were marginally significant ($p<0.1$) and are discussed below to determine the differences in perceptions between the young and older drivers regarding the IDS signs. There was a marginally significant main effect of sign [$F(3,138)=2.36$, $p=0.078$]. On average, drivers ranked the Split-hybrid sign (M=2.62) significantly higher than the Icon sign (M=3.40) [$Wz=-2.55$, $p=0.01$]. The Split-hybrid sign was also ranked the highest in all groups except by older drivers in the day condition.

There was also a marginally significant interaction of sign and light condition [$F(3,141)=2.27$, $p=0.087$]. Drivers in the night condition (M=2.09) preferred the Split-hybrid significantly more than did drivers in the day condition (M=3.13) [$U_z=-2.16$, $p=0.031$].

There was also a marginally significant interaction of sign by age condition [$F(3,135)=2.17$, $p=0.098$]. Young drivers ranked the Split-hybrid sign significantly higher (M=2.13) than older drivers (M=3.10) [$Uz=-2.31$, $p=0.02$].

In addition to the above interactions, there was also a marginally significant main effect of light condition [$F(1,43)=3.69$, $p=0.06$], where drivers in the day condition showed lower preferences overall for the IDS signs (M=3.18) compared with drivers in the night condition (M=2.93).

In general, older drivers in the night condition preferred the signs in the following order from most preferred to least preferred: Split-hybrid, Icon, VMS, Hazard, and Baseline. In contrast, the older drivers in the day condition ranked the signs from most preferred to least preferred in the following order: Baseline, Hazard, VMS, Split-hybrid and Icon. It appears that the older drivers at night preferred signs with more specific gap information than did the older drivers in the day. The reasons for this are examined in more detail in the Discussion section below. Young drivers in both the day and night conditions preferred the Split-hybrid sign most (see Figure 7.30 and Figure 7.31).

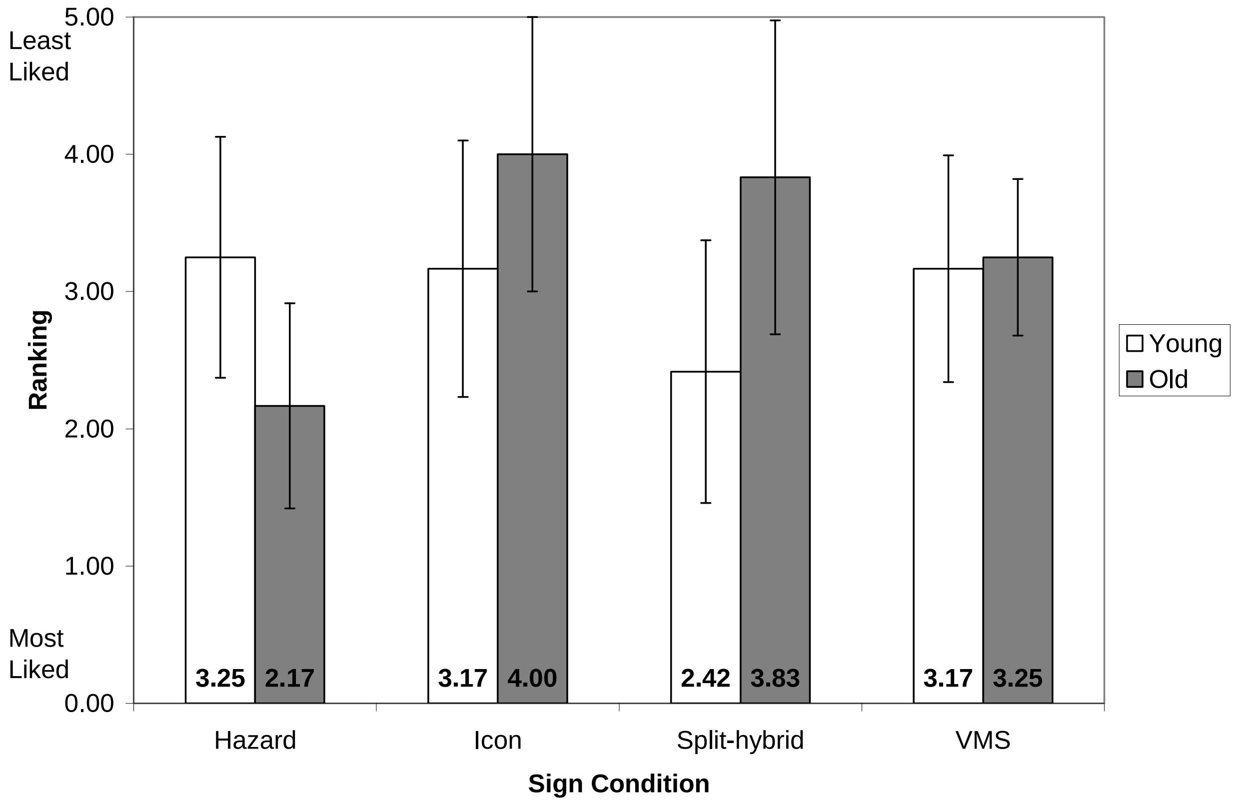


Figure 7.30. Interaction of sign by age group for preference rankings for the day condition only.

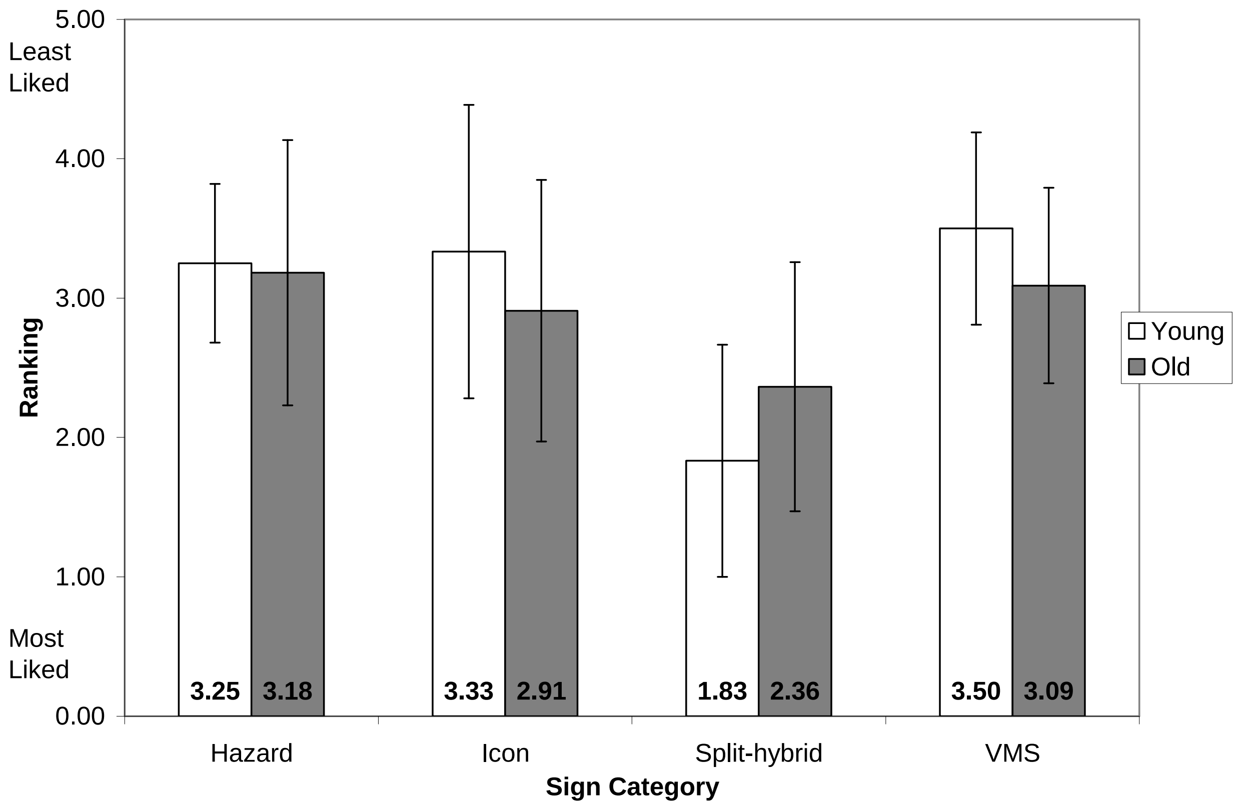


Figure 7.31. Interaction of sign by age group for preference ranking for the night condition only.

7.2.8. Usability Questionnaire

Drivers filled out the Usability Questionnaire after they were provided with a description and diagram for each sign outlining its main functions and operating logic. The nine usability questions make up two dimensions of usability: usefulness and satisfying. Results are plotted on these two dimensions to see where they fall in comparison to each other (see Van der Lann et al., 1997). Therefore, the Usability Questionnaire provides a measure of how driver's felt about the signs after driving with them and after learning the full functionality. This provides data that can be compared to the usability question data (see Usability Questions 1-10 above) collected after participants drove with the system, but before they were fully apprised of the signs' full functionality.

Figure 7.32 shows where the five signs placed in comparison to each other when the usefulness and usability scales were calculated for all drivers. The Split-hybrid sign was rated the most useful and satisfying of the IDS concept interfaces. The Icon, Hazard and VMS signs were clustered near the zero axis of the satisfying scale and had relatively low usefulness ratings.

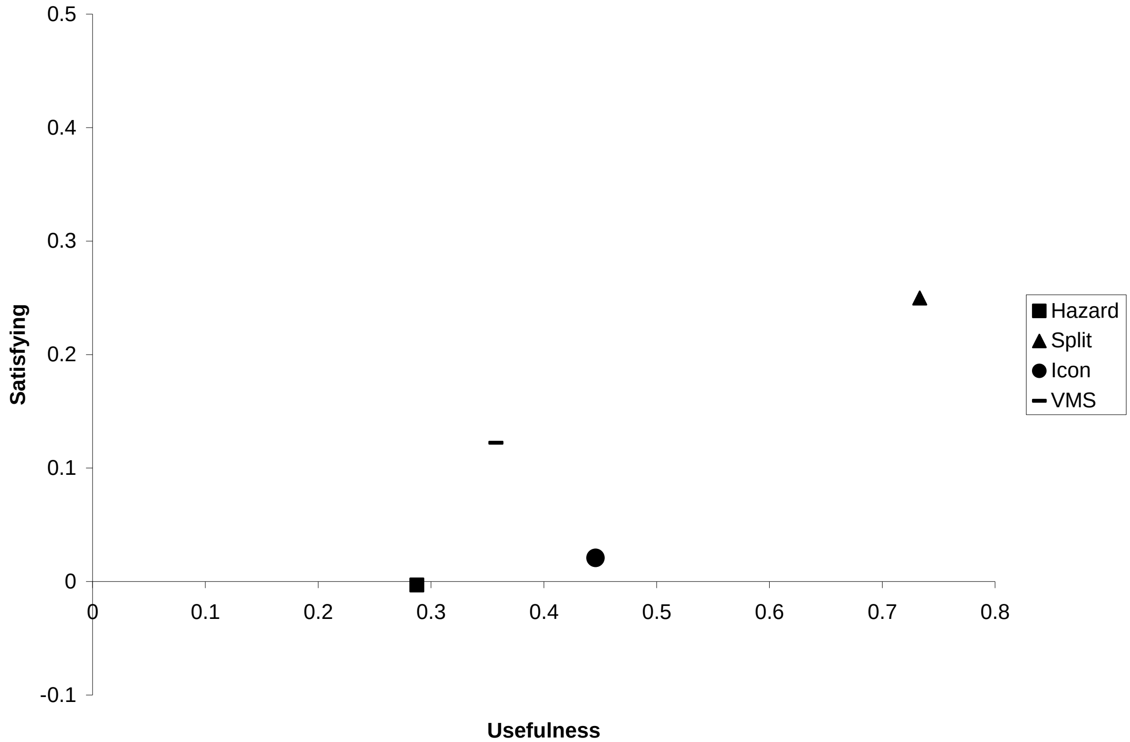


Figure 7.32. Location of signs along each dimension of the usability scale: satisfying and usefulness.

Usability values along the usefulness and satisfying dimensions were also plotted for night and day for young drivers as well as night and day for older drivers to determine if differences in ratings occurred among the groups.

Figure 7.33 shows how young drivers rated the usability of each sign during the day and night conditions. For the smart signs, young drivers rated the Split-Hybrid as the most satisfying and useful for making a crossing decision during both daytime and nighttime conditions. Young drivers also found the Icon sign to be useful, but felt it was much more satisfying to use during the day than in night conditions. These results match the previous usability questions and young drivers' preference for the Split-hybrid sign.

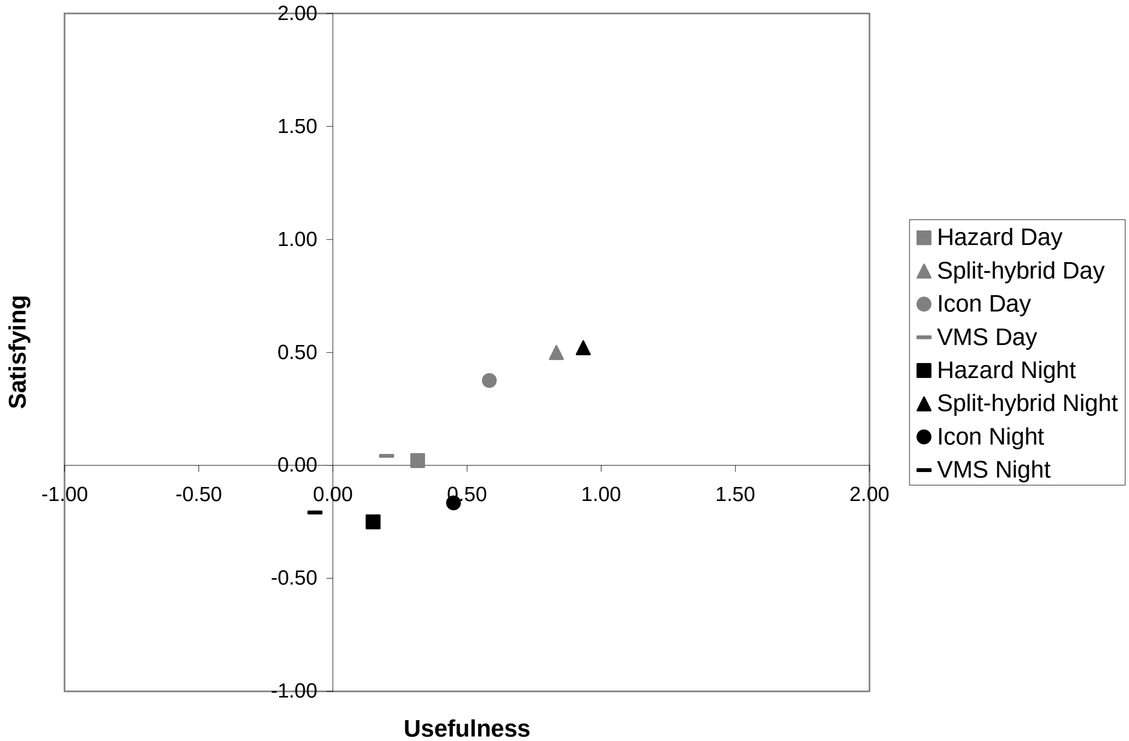


Figure 7.33. Young driver usability ratings comparing day to night conditions.

Figure 7.34 shows how older drivers rated the usability of each sign during the day and night. Older drivers in the day condition rated the VMS sign as the most satisfying and useful of the smart signs, but older drivers in the night condition found it much less useful and satisfying. Older drivers in the night condition found the Split-hybrid and Icon signs to be similarly useful and satisfying. Older drivers in the day condition found the Split-hybrid and Icon signs to be much less useful and satisfying than older drivers in the night condition. Overall, there was a large difference in how older drivers in the night condition rated the signs compared to older drivers in the day condition. This difference is also reflected in the preference ranking scores and suggests that older drivers in the night condition regarded the smart signs differently for some reason compared with the older drivers in the day condition. This difference is examined in more detail in the Discussion section.

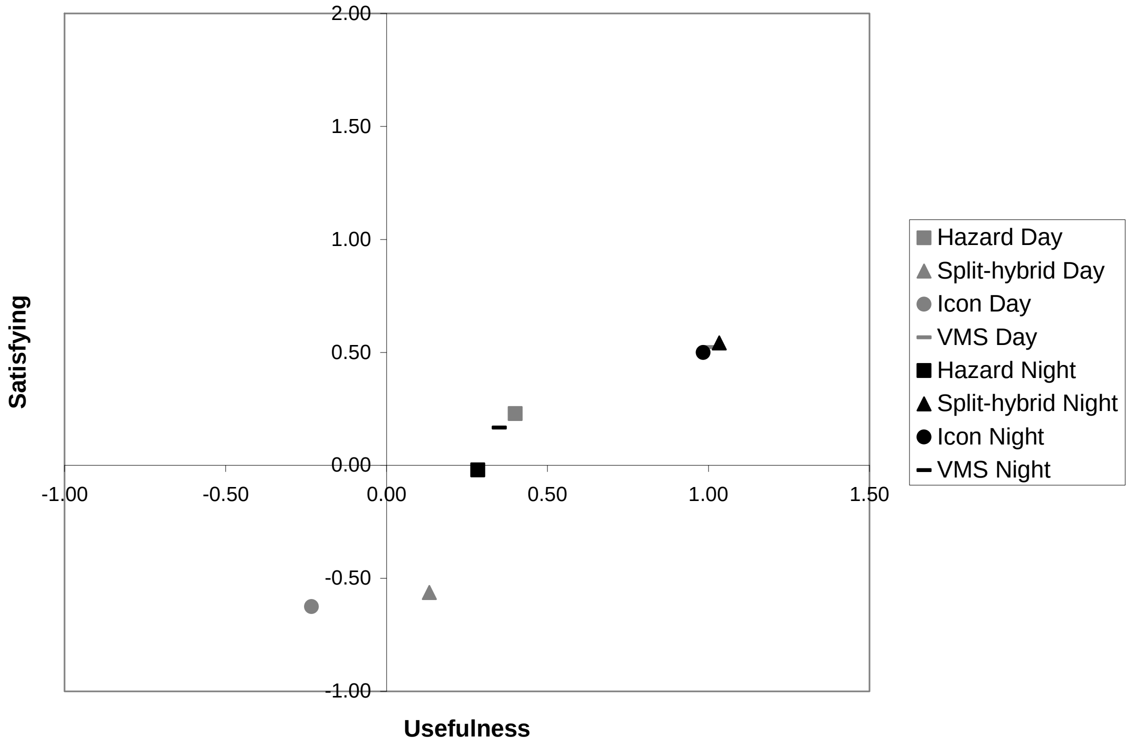


Figure 7.34. Older driver usability ratings comparing day to night conditions.

7.2.8.1. Sign Comprehension, Use, Preference and Usability Summary

- Overall, drivers' were best able to describe the function of the Icon and Split-hybrid signs versus the Hazard and the VMS signs when drivers were asked to describe the signs' functions.
- For the Icon sign, older drivers in the day condition had lower comprehension (50%) than young drivers in the day condition (100%).
- For the Icon sign, older (58.4%) and young drivers in the night condition had similar comprehension (66.7%) of the sign's function.
- For the Split-hybrid sign, a majority of drivers comprehended the time to arrival information (54.2%). Nine drivers (18.75%) said the sign told them when it was safe to cross, either with or without a mention of the time-to-arrival information.
- Overall, drivers reported the highest sign use for the Split-hybrid sign. In particular, 100% of young and older drivers at night reported using the sign to help them make their crossing decision.
- At night, both older and young drivers preferred the Split-hybrid sign over the other signs.

- For sign state comprehension, drivers had the best comprehension for the states of the Icon sign (88.15%). The Split-hybrid sign had the next best comprehension (64.44%).
- On average, sign state comprehension was significantly higher for young drivers (M=64.1%) than for older drivers (54.2%).
- For usability, drivers rated the STOP sign as the most useful and satisfying.
- The Split-hybrid sign was rated the most useful and satisfying for all drivers, particularly the young drivers.
- Young drivers found the Split-hybrid the most satisfying and useful of all the smart signs during both daytime and nighttime conditions.
- Older drivers in the day condition found the VMS sign to be the most useful and satisfying of all the smart signs and rated the Split-hybrid and Icon signs low on the usability scales.
- Older drivers in the night condition found the Icon and Split-hybrid signs to be more useful and satisfying.

7.3. Results Summary

The tables on the following pages (see Tables 7.24-7.31) show a subset of the variables to summarize overall performance and subjective preference for individual signs in each condition. The signs are arranged in increasing order of performance and preference from left to right. Signs on the left showed the lowest performance or had the worst subjective ratings while signs on the right had better performance and higher subjective rating of preference. The following performance variables are shown for comparison:

- Accepted Gap (near-side)
- Initial TTC (near-side)
- Safety Margin (near-side)
- Collisions
- Conflict Count

In addition, the following questionnaire variables are summarized below:

- Comprehension
- Confusion
- Self-reported Sign Use
- Preference
- Usability: Usefulness
- Usability: Satisfying

Although the signs are shown from lower performance/rating to better performance/rating based on the absolute values obtained for each group, the differences between signs are not necessarily statistically significant.

7.3.1. Young Drivers in the Day Condition

Table 7.24 Young Drivers, Day Condition: Performance Variable Summary

Lower Performance/Rating		⟵		⟶			Better Performance/Rating
Wait Time	Short						Long
Accepted Gap	Small						Large
Initial TTC	Small						Large
Safety Margin	Small						Large
Collisions	More	-	-	-	-	-	Less
Conflict Count	More						Less

Table 7.25 Young Drivers, Day Condition Questionnaire Results Summary

Lower Performance/Rating		⟵	⟶			Better Performance/Rating
Compre-hension	Low					High
Confusion	High					Low
Self-reported Use	Low					High
Preference Rank	Low					High
Usability: Usefulness	Low					High
Usability: Satisfying	Low					High

7.3.2. Young Drivers in the Night Condition

Table 7.26. Young Drivers, Night Condition: Performance Results Summary

Lower Performance/Rating ⟷							Better Performance/Rating
Wait Time	Short						Long
Accepted Gap	Small						Large
Initial TTC	Small						Large
Safety Margin	Small						Large
Collisions	More						Less
Conflict Count	More						Less

Table 7.27 Young Drivers, Night Condition: Questionnaire Variables Summary

Lower Performance/Rating		⟷			Better Performance/Rating	
Compre-hension	Low					High
Confusion	High					Low
Self-reported Use	Low					High
Preference Rank	Low					High
Usability: Usefulnes s	Low					High
Usability: Satisfying	Low					High

7.3.3. Old drivers in the Day Condition

Table 7.28. Old Drivers, Day Condition: Performance Variables Summary

Lower Performance/Rating			←→				Better Performance/Rating
Wait Time	Short						Long
Accepted Gap	Small						Large
Initial TTC	Small						Large
Safety Margin	Small						Large
Collisions	More	-	-	-	-	-	Less
Conflict Count	More						Less

Table 7.29. Old Drivers, Day Condition: Questionnaire Variables Summary

Lower Performance/Rating		⟷			Better Performance/Rating	
Compre-hension	Low					High
Confusion	High					Low
Self-reported Use	Low					High
Preference Rank	Low					High
Usability: Usefulness	Low					High
Usability: Satisfying	Low					High

7.3.4. Old Drivers in the Night Condition

Table 7.30. Old Drivers, Night Condition: Performance Variable Summary

Lower Performance/Rating		⟵		⟶			Better Performance/Rating
Wait Time	Short						Long
Accepted Gap	Small						Large
Initial TTC	Small						Large
Safety Margin	Small						Large
Collisions	More						Less
Conflict Count	More						Less

Table 7.31. Old Drivers, Night Condition: Questionnaire Variable Summary

Lower Performance/Rating		⟷				Better Performance/Rating
Compre-hension	Low					High
Confusion	High					Low
Preference Rank	Low					Most Liked
Self-reported Use	Low					More
Usability: Usefulness	Low					More
Usability: Satisfying	Low					More

8. Discussion

The goal of this study was to evaluate concepts for signage to be used in an infrastructure-based Intersection Decision Support (IDS) system to assist drivers to safely cross a thru-stop intersection. The function and content of these sign concepts were derived from a cognitive task analysis of the driving task at rural thru-stop highways. The evaluation of these concepts used a sample of older drivers to represent the high-risk demographic group in comparison to a younger sample. The sign concepts were evaluated in a driving simulator under daytime and nighttime lighting conditions to examine the effect of the sign functions under conditions of high and low information available in the driving environment.

An examination of the crossing maneuver variables, performance variables, and the subjective responses of participants provided information about how the IDS sign concepts were interpreted and impacted driving behaviors. The analyses presented for review in the discussion best describe an examination of the near-side safe gap threshold as derived from the AASHTO (2001) standards for crossing lanes of traffic from a STOP sign, rather than making a left turn either using a one-stage or two-stage crossing strategy. The need to standardize the traffic model to determine minimum gap acceptance from the STOP sign limited the ability to test the far-side thresholds. Thus, the usefulness of the one-stage 12.5 s threshold and the two-stage 8.0 s threshold for a left turn/crossing maneuver was not fully evaluated. However, the near-side performance results in combination with the subjective measures provided good information about how drivers perceived the near-side safe gap threshold both with and without the IDS signs present. Overall, the results discuss the impact of age and light condition on threshold acceptance as derived from the AASHTO (2001) standards for crossing a set of traffic lanes from a STOP sign. These results can be applied to both the near-side and far-side thresholds in future IDS evaluations.

In this discussion, general conclusions will made regarding which sign concepts offer the most potential for future IDS applications. This will include consideration of potential limitations imposed by the simulator methodology and conceptual issues regarding the information presented to drivers. Finally, a number of future research needs will be identified to support future IDS development. Each sign will be discussed in terms of performance on the following objective and subjective variables:

- Accepted gap (near-side)
- Percentage of drivers who accepted gaps over the safe gap threshold (near-side)
- Safety margin (near-side)
- Collisions and conflicts
- Comprehension of sign's function
- Comprehension of sign's states
- How confusing drivers found the sign to use

- Preference for the sign
- Usability evaluation of the sign
- Self-reported sign usage
- Self-reported workload (NASA TLX)

Certain performance variables are excluded from the discussion such as wait time and initial time-to-contact because they are highly correlated with the accepted gap and safety margin variables and, thus, provide redundant information.

8.1. Baseline

The existing STOP sign for this type of intersection provided a baseline condition without decision support to compare with the IDS signs. Overall, all the IDS signs resulted in better gap acceptance performance by drivers when compared with the baseline condition (i.e., no decision support), particularly in the night driving condition. The baseline had a similar mean safety margins compared with the Split-hybrid, VMS and Hazard signs. Only the Icon sign had a significantly larger safety margin compared to baseline. The IDS signs also resulted in longer wait times compared with the baseline condition, with the VMS sign having the shortest and the Icon sign having the longest.

However, the larger mean accepted gap values for the IDS signs compared to the baseline may be an artifact of drivers waiting longer at the intersection to interpret the IDS signs. The traffic stream on the mainline was deliberately scripted to have a linear increase in gap size over time in order to systematically examine one and two-stage maneuver options. Thus, the larger accepted gaps with the IDS signs may have resulted from the correlation between wait time and the incremental size in gaps within the traffic stream. That is, drivers did not decide to take a longer gap with the IDS. Rather, they had to wait longer because there was more information to interpret, and by the time they comprehended the information, larger gaps were available. Of course, this does not preclude the possibility that the larger gaps were in fact the result of safer decisions made by drivers informed by the signs. However, the accepted gap results alone do not yield a clear understanding of whether drivers used the signs to help them make a crossing decision. Therefore, conclusions about the IDS performance should also be based on performance data, crossing maneuver data and the subjective responses provided by the participants.

8.1.1. Older Drivers

8.1.1.1. Day

Older drivers in the day condition showed a smaller mean accepted gap in the baseline condition, compared with the Hazard, Icon and Split-hybrid signs. This mean gap was significantly smaller than those for the Hazard and Icon sign conditions. The mean accepted gap for baseline was similar to that of the VMS sign with the VMS sign showing only a 0.06 s smaller mean accepted gap size that was not significant. Overall, no drivers in this condition accepted a gap larger than the safe gap threshold. There were no collisions or conflicts for this group in the day condition.

Comprehension of the STOP sign's function was high, as would be expected for a sign that drivers interact with on a regular basis. Overall, drivers did not appear to rate the STOP sign as a condition with decision support absent but instead rated it based on its function as a STOP sign. In general, the older drivers in the day condition appeared to have a different perspective about the utility of the smart signs when compared to the older drivers in the night condition and young drivers in both lighting conditions. Older drivers in the day frequently commented that they did not think they needed a decision aid for making their crossing decisions. Consequently, this group ranked the STOP sign that did not provide decision support as their most preferred sign, and this ranking occurred even after drivers were given full descriptions of how the smart signs worked. Ultimately, the lack of a perceived need for such a decision support due to their faith in their own abilities to make decisions while driving indicates that the older drivers in this group did not perceive the potential risks they actually face in these crossing situations. This finding suggests that it is not really relevant to compare the subjective responses of the drivers toward the STOP sign with the other IDS signs because the function of a STOP sign is very different from the IDS signs.

In fact, all four groups of drivers rated the STOP sign as highly useful and satisfying on the usability scale. The usability scale requires drivers to rate the sign based on its function as a marker for the intersection and stop control device. Therefore, it is not surprising that all drivers rated the STOP sign as highly useful and satisfying because its function is well understood and is necessary for knowing that one must stop at the intersection. Again, comprehension of the STOP sign's function was high.

8.1.1.2. Night

Older drivers in the night condition showed a significantly smaller mean accepted gap in the baseline condition compared to the Icon, Split-hybrid and VMS conditions. The Hazard condition had the smallest mean accepted gap for this group. Two drivers in this condition accepted a gap above the safe gap threshold around which the smart signs were designed. This suggests that in lower visibility conditions, some older drivers may wait for a larger gap even without the presence of decision support. This group experienced one collision and six conflicts in this condition. The number of conflicts in this condition was similar to the Icon and Split-hybrid signs, but less than for the Hazard and VMS signs for this group.

In contrast to the older drivers in the day condition, the older drivers in the night condition did not consider the STOP sign alone to be sufficient for making their crossing decision when the option of an available decision aid existed. This most likely occurred because the older drivers in the night condition perceived the driving scenarios to be significantly more demanding and requiring higher workload than did young drivers at night, or all drivers during the day. Therefore, decision making at night was perceived by this group to be more difficult and potentially motivated a need for help with decision making while crossing. Older drivers often report that night driving is more difficult for them than day driving (e.g., Holland & Rabbit, 1992), so the finding that drivers found these scenarios to be significantly more demanding than during the day supports the need to test these decision support signs at night.

Overall, the group of older drivers in the night condition completed 1-stage maneuvers more often than young drivers in the day and night conditions, and older drivers in the day condition. The greater frequency of 1-stage maneuvers at night for the older drivers suggests that they found the driving demands difficult which impaired their motivation or awareness to search and detect for traffic in the far lane. Specifically, the design of this intersection makes it inherently difficult to see approaching traffic in the far lanes while stopped at the STOP sign. Research on older drivers often shows that when mental demand increases during a maneuver, these drivers will spend less time evaluating the situation and will make poorer decisions (Delorme & Marin-Lamellet, 1998, Guerrier et al., 1999).

These findings for the older drivers at night are in contrast to all the drivers in the day condition and most of the young drivers at night that made mostly two-stage maneuvers on both trials. In the day condition, the presence of multiple vehicles might have been easier to see in the far lanes from the STOP sign. That is, during day conditions all the drivers could "see" that there was a far lane with potential traffic hazards. Moreover, based on workload measures, it is also possible that the older drivers in the day condition used more time and effort to evaluate the situation because they felt less pressure to complete the maneuvers.

Because older drivers in the night condition perceived difficulty with their decision making for the scenarios, the STOP sign alone did not provide them with same confidence as it did for the older day drivers. In fact, compared to older drivers in the day condition, the older drivers at night showed a trend towards larger gap acceptance and safety margins with the Icon, Split-hybrid and VMS signs, while showing a decrease in mean gap size and safety margins for the baseline condition and the Hazard sign, which provides the least decision support information. Also, whereas the older drivers ranked the STOP sign favorably in the daytime condition, they ranked the STOP sign (baseline) as their least preferred sign for helping with the crossing decision at night, behind all the decision support signs.

8.1.2. Young Drivers

8.1.2.1. Day

Young drivers in the day condition had the smallest mean accepted gap for the baseline condition, but it was not significantly smaller than the Hazard, Split-hybrid or VMS conditions. It was significantly smaller than the mean accepted gap for the Icon sign for this group. Like the older drivers in the day condition, no young drivers in the day accepted a gap larger than the safe gap threshold around which the smart signs were designed. Accepting gaps smaller than the threshold when no decision support is available suggests that these drivers found smaller gaps more acceptable and were potentially not willing to wait for a larger gap.

Young drivers in this group also showed a high comprehension for the STOP sign's function, and, similar to the older drivers in both light conditions, it was rated as highly usable based on its function as a STOP sign. The STOP sign was ranked similarly to Hazard, Icon and VMS signs by this group. Overall, the Split-hybrid stood out significantly as the top-ranked sign for young drivers in the day and night condition. Young drivers appeared to better understand the goals of the smart sign designs and were more favorable towards evaluating their designs.

8.1.2.2. Night

Similar to the young drivers in the day, young drivers at night conditions had the smallest mean accepted gap for the baseline condition. Unlike the young drivers in the day condition, this gap was not only significantly smaller than the Icon condition, but was also significantly smaller for the VMS, Hazard and Split-hybrid signs. Only one young driver in the night condition accepted a gap larger than the safe gap threshold around which the smart signs were designed.

Like the older drivers in the night condition, young drivers in the night condition made more 1-stage maneuvers than young drivers in the day. Like the older drivers, the young drivers also made about the same number of 1-stage versus 2-stage maneuvers for each trial in the night condition, suggesting that fewer young drivers changed their crossing strategy from trial 1 to trial 2 at night. The number of 1-stage maneuvers did not change from trial 1 to trial 2 for baseline for the young drivers in the night condition, in contrast to the results for the older drivers in the night condition.

8.1.3. Summary

Research shows that older drivers tend to be unaware of the errors they make while driving (Holland & Rabbit, 1994) and are often unaware of visual and cognitive declines that occur with age (Holland & Rabbitt, 1992). However, research has shown that when older drivers are made aware of their cognitive limitations when driving, they often adopt new safety behaviors to compensate (e.g., Holland & Rabbitt, 1992). In this study, the night driving scenarios made the older drivers aware of their limitations in terms of judging and accepting gaps at night, while the day scenario did not. Thus, the smart signs were considered useful. This suggests that the IDS signs may be most useful for the "worst case scenario" for older drivers when they are most at risk. Moreover, older driver education that outlines the risks to drivers at intersections in both day and night driving may better prepare older drivers to accept decision support technology.

Overall, the STOP sign alone does not meet any of the desired decision support criteria for thru-STOP intersections. In particular, very few drivers accepted a gap above the safe gap threshold. No young or older drivers in the day condition accepted a gap above the threshold, while only one young driver and two older drivers at night accepted a gap above the threshold.

The results for older drivers, who may be more resistant to new technology and less aware of their potential decision making limitations, indicate that using the STOP sign alone is not a good comparison for smart signs because the function of the STOP sign is significantly different from that of the smart signs. However, the STOP sign alone provided good information about how drivers make their crossing decisions and how drivers might perceive the technology when the decision-making situation is made more difficult. That is, young drivers in general, and older drivers in a situation perceived to be difficult, were more accepting of the decision support provided by the smart signs compared with baseline.

8.2. Hazard Sign

The Hazard sign's primary function is to alert drivers to the presence of traffic on the highway. It flashes the "dangerous traffic" message when a vehicle is detected in either of the safe gaps for the near and far lanes. If no traffic is present in either direction within the safe gap, the sign will stop flashing the message. Overall, the sign does not provide specific information about the size of gaps and does not advise drivers of prohibited actions. Because of this functionality, the Hazard sign is most like the baseline condition, but also provides a "caution" message to drivers about traffic on the roadway.

Overall, the majority of both young and older drivers perceived the Hazard sign to be a "cautionary" sign only that alerted them to take care while crossing rather than a decision support sign in relation to traffic. Because very few drivers saw the sign stop flashing, many were unaware that it would stop flashing the "dangerous traffic" message when no unsafe gaps were detected in both the near and far lanes. Overall, the sign has the potential to prevent collisions or conflicts at the intersection by encouraging drivers to be more cautious of the traffic present on the roadway.

Overall, the Hazard sign produced a significantly larger mean accepted gap compared with the baseline condition. However, this gap was significantly smaller than the mean accepted gap for the Icon sign, and was similar to the mean gaps for the Split-hybrid and VMS signs. This sign was rated as the second easiest smart sign to understand and the second most reliable smart sign. It came second the Split-hybrid sign in both cases. It was also rated as more trustworthy than the Icon sign, but similar to the VMS and Split-hybrid signs.

8.2.1. Older Drivers

8.2.1.1. Day

The older drivers in the day condition had their second largest mean accepted gap while using the Hazard sign. This gap was significantly larger than the baseline condition, but was significantly smaller than the Icon condition. Overall, it was similar to the Split-hybrid and VMS signs. Only one driver in this group accepted a gap larger than the safe gap threshold for the near lanes. There were no collisions and only one conflict for the drivers in this group with this sign.

The older drivers in the day condition perceived the Hazard sign to be the least complicated of the smart signs. A frequent comment made by drivers for this sign is that it made them "more cautious" in their decision making. In particular, 50% of drivers said they used the information provided by the sign in their crossing decision, such as by being more cautious. This could be why the Hazard sign showed a larger mean accepted gap compared to baseline, but similar mean accepted gaps as the Split-hybrid and the VMS signs. Drivers accepted larger gaps on account of being more cautious, but did not use the Hazard sign as a decision support system in terms of waiting for a safe gap in both lanes before proceeding into the intersection. Ultimately, the goal of shifting gap acceptance towards a safe threshold occurred in this group presumably by increasing driver attention to potential crash risks.

In terms of comprehension, most drivers understood the alerting portion of the sign, but none realized that the sign would stop flashing if no unsafe gaps were detected in either direction. Even after the sign's function was described to them, 75% of drivers in this group correctly understood the flashing 'dangerous traffic" message, but none understood what it meant when the sign stopped flashing. Only 25% of drivers in this group felt the sign was confusing to use. This is a smaller percentage than for the Icon or the Split-hybrid signs.

Older drivers in the day condition ranked the Hazard sign as their second most preferred sign, just behind the STOP sign alone. This may be expected in that the appearance and functionality of the Hazard sign was most like the baseline condition (STOP sign). Older drivers in this group also rated the Hazard sign as the third most useful and satisfying sign overall after its full function was explained to them. This most likely occurred because these drivers appeared to not perceive a need for a decision aid but did perceive some value for such a system that only provides an alert signal regarding the potential presence of traffic hazards at the intersection. Overall, the larger mean accepted gap with the Hazard sign, compared to baseline, may have occurred for this group because it made them more cautious at the intersection.

8.2.1.2. Night

At night, viewing conditions were more difficult in terms of perceiving the intersection lanes, median, and approaching traffic. In contrast to the results for the older drivers in the day condition, older drivers in the night condition had the smallest mean accepted gap for the Hazard sign. This gap value was also smaller than mean accepted gap for the Hazard sign for the older drivers in the day condition. Similar to the day condition, only one driver accepted a gap larger than the safe gap threshold. This driver also waited for a safe gap in the far lanes while waiting at the STOP sign and, thus, saw that the sign stopped flashing when no traffic was present within the safe gap threshold for either direction. This driver was able to describe the full function of the Hazard sign after driving with it.

The smaller mean accepted gap for the older drivers in the night condition compared to other signs and to the day condition indicates that the Hazard's cautionary flasher alone was not sufficient to aid drivers in the night condition with their gap acceptance decisions. Older drivers in the day condition accepted larger gaps with the Hazard sign and indicated that it made them more cautious. They may have been able to exercise more caution and accept larger gaps because they had good visibility of the traffic flow and better cues about the size of available gaps in the day condition. However, the drivers in the night condition found the crossing scenarios to be mentally demanding and the reduced visibility potentially impaired their ability to judge the size of gaps in the traffic flow. Therefore, the cautionary sign alone may not have been sufficient to aid them in their gap acceptance because they required more detailed information about the nature of the gaps available, as provided by the other smart signs.

Comprehension of the sign states after the functionality of the sign was described to these drivers was lower for the flashing "dangerous traffic" state (54.5%) compared with the older drivers in the day condition. However, the night driver's comprehension of the sign's state when the "dangerous traffic" message was not present was much higher (45.5%). The same percentage of older drivers at night rated the Hazard sign confusing to use (25%), but fewer drivers in this condition said they used the sign (33.3%) to help them with their crossing maneuver compared with the older drivers in the day condition.

Older drivers at night ranked the Hazard sign as their fourth most preferred sign, just ahead of the STOP sign alone and it was considered the least useful and satisfying in terms of usability when compared to the other smart signs. This potentially occurred because these drivers saw the Hazard sign as providing limited gap information compared with the other smart signs during the difficult viewing conditions at night. Older drivers at night were significantly less confident using the Hazard sign than were older drivers in the day and also had significantly more conflicts with this sign than did young drivers at night. The older drivers in the night condition also experienced two collisions in the northbound lanes while using this sign.

Although other drivers accepted gaps above the safe threshold for the near lanes, the presence of traffic in the far lane safe gap meant they did not see the sign stop flashing. Therefore, it was perceived primarily as an alerting sign by most of the older drivers in both the day and night conditions.

8.2.2. Young Drivers

8.2.2.1. Day

Young drivers in the day condition showed a similar, relative pattern of gap acceptance for the Hazard sign when compared to the other signs. It showed the second largest mean accepted gap for this group, but was significantly smaller than the Icon sign. However, unlike the day drivers, the mean accepted gap for Hazard was not significantly larger than baseline. Similar to the older drivers in the day and night conditions, only one driver in this group accepted a gap larger than the safe gap threshold for the near lanes of traffic with this sign.

Overall, young drivers also interpreted the Hazard sign as an alerting sign only. During the day, the Hazard sign had the lowest mean ranking of the smart signs but it was not ranked significantly differently than the Icon, VMS or STOP signs. Comprehension was similar to that of the older drivers in the day condition, with high comprehension for the flashing “dangerous traffic” state, but low for when the sign stopped flashing. The Hazard sign was considered to be somewhat useful, but not very satisfying when compared to the other smart signs for this group after its functionality was explained. It was rated similarly to the VMS sign, but much lower than the Icon or Split-hybrid sign by this group for usability. Few drivers in this group found this sign confusing to use (16.7%) and only 41.7% said they used the sign to help them make their crossing decision.

8.2.2.2. Night

In the night condition, young drivers showed similar mean accepted gaps compared with the young day drivers with the Hazard sign. It had a significantly larger mean accepted gap than baseline, but was similar gap acceptance for the Split-hybrid and VMS signs at night. The Hazard sign had a significantly smaller accepted gap compared with the Icon sign for this group. Unlike the other groups, two drivers in this group accepted gaps larger than the safe gap threshold.

Young drivers at night showed the best comprehension (100%) for the flashing “dangerous traffic” state, and showed similar comprehension to the older drivers at night of the non-flashing sign state (33.3%). Only one driver in this group rated this sign as confusing to use. Unlike drivers in the other conditions, only one young driver (8.3%) in the night condition said they used the sign to help them make their crossing decision.

The low use of this sign for decision making is also reflected in by the ranking of this sign as the least preferred of all the smart signs by this group. Like young drivers in the day condition, this sign was rated somewhat useful, but not very satisfying on the usability scale. Overall, the Hazard sign was not perceived to be a useful decision support sign by young drivers, most likely because the simple (one-stage maneuver) logic and conservative gap thresholds resulted in a perpetual “caution” state.

8.2.3. Summary

Overall, the Hazard sign met its objective of indicating the presence of traffic and alerting drivers to that traffic, but it does not provide additional information about the size of the gap or advice for prohibited behaviors when an unsafe gap is detected. For the Hazard sign, only one young driver and one older driver in the day condition accepted a gap above the safe gap threshold, while two young drivers and one older driver accepted gaps above the threshold for the night condition. There was no real difference in gap acceptance between young and older drivers in either light condition regarding the safe gap threshold for this sign.

Most likely, drivers perceived the function of this sign to be limited and conservative because it only provided information about the presence of unsafe gaps for an assumed one-stage maneuver. This may not have been consistent with the intended crossing strategies of the drivers. In fact, with the exception of older drivers at night, the majority of drivers made two-stage maneuvers. For the older drivers at night, the Hazard sign did not encourage a change in strategy to a two-stage maneuver for those drivers who made a one-stage maneuver in the first trial. This observation suggests a need for IDS support systems to operate for two-stage maneuvers, possibly in combination with one-stage maneuvers. However, the data from the driver responses to the hazard sign does demonstrate some utility from a simple function that alerts to the driver to the presence of a traffic hazard at an intersection by instilling a greater level of attention and caution in crossing behavior. Moreover, a Hazard sign could be placed at the STOP sign and in the median, such as with the other IDS signs, which would support both one and two-stage crossing strategies.

8.3. Icon Sign

The Icon sign was designed to simultaneously support both one and two-stage maneuvers because of its independent representation of traffic in both sets of lanes on a single display at the STOP sign and in the median. The functionality of this sign was to provide information about the size of gaps and the presence of oncoming traffic using the yellow (<12.5 s gap but >7.5 s gap) and red (<7.5 s gap) warning icons and also to provide information about prohibited actions when an unsafe gap is detected in either the near or far lanes. Overall, this sign resulted in the largest mean accepted gaps and the largest safety margins across all groups. This sign detects unsafe gaps and presents warning levels based on gap information. It also advises about prohibited actions based on the detection of unsafe gaps. Drivers must choose whether they will cross or not based on the information provided.

The Icon sign had a significantly larger mean accepted gap than baseline and all the other smart signs. It also produced a significantly larger safety margin than the other signs. Although this sign produced the best gap acceptance performance of all driver groups, some of the subjective data suggests that the complexity of the sign may have contributed to the results. Overall, the Icon sign was rated as less trustworthy and not as easy to understand as the other smart signs despite all drivers showing a high comprehension of the sign’s states at the end of the study.

However, results for the young drivers and the older drivers in the night condition indicate that Icon sign was preferred by these groups and that the information it provided partially contributed to more drivers accepting gaps over the safe threshold. In particular, the sign was rated as significantly more useful for helping with the crossing decision by the night drivers compared with the day drivers.

8.3.1. Older Drivers

8.3.1.1. Day

In the day condition, the Icon sign resulted in the largest mean accepted gap and safety margin for the older drivers compared to all signs. This gap was significantly larger than for the baseline, Split-hybrid and VMS conditions. It was also larger than the Hazard condition, but not significantly different. The safety margin for this group was highly positively correlated with the accepted gap. Overall, 25% of drivers in this group accepted gaps larger than the safe gap threshold for the near lanes. There were also no collisions or conflicts for this group.

Many drivers (67%) found this sign confusing to use. This confusion appeared to be related to how well these drivers comprehended the Icon sign's states at the end of the study. Although the full function of the sign had been explained at this point, the drivers who rated the sign as confusing to use had a comprehension rate for the sign states of 62.5%. This is in contrast to the 100% comprehension rate of the sign states for the 33% of drivers who did not rate the sign as confusing to use. The reported confusion with the Icon sign may have resulted from the high information content represented by the various sign elements in this display.

Because eight of the twelve older drivers in the day condition (66.7%) reported being confused while using this sign, the larger mean accepted gap could be due to a longer wait time at the STOP sign as they tried to interpret the sign. However, the mean accepted gap for the eight drivers who found the sign confusing to use was 6.14 s compared with a mean accepted gap of 7.63 s for the four drivers who did not find the sign confusing to use. The mean accepted gap value of the older drivers in the day condition who were not confused can be examined in conjunction with the mean accepted gap value of 7.93 s for the seven older drivers in the night condition who did not find the sign confusing to use. This shows that when drivers did not find the sign confusing to use, they were more likely to comply with the information on the sign and accept gaps above the safe gap threshold. In contrast, confused drivers accepted shorter gaps. This suggests that the larger mean accepted gap for the Icon sign is due to drivers complying with the information on the sign and not because they spent more time interpreting it or because they were confused. Only a portion of the larger mean accepted gap may be due to drivers taking time to interpret the sign, although this is expected on a sign that has more informational elements as the Icon sign does.

Finally, the older drivers in the day condition ranked the Icon sign as their least preferred, and very few drivers (25%) said they used the sign to help them with their crossing decision. The Icon sign was also rated as the least useful and satisfying of all the smart signs by this group. Overall, the older drivers in the day condition were less receptive to the decision support provided by this sign than were the older drivers in the night condition.

8.3.1.2. Night

Older drivers in the night condition had the largest mean accepted gap compared with the other sign conditions at night, and it was significantly larger than baseline and the Hazard sign. The older drivers at night also had a larger mean accepted gap than the older drivers in the day condition and 50% of drivers accepted a gap larger than the safe gap threshold. However, there were six instances of collisions with this group with the Icon signs, which is more than for any other sign condition for this group. Four of the collisions occurred for drivers who experienced the Icon sign as the first condition of the study (and one collision was by a driver who had three other collisions in another sign condition). It is possible that these collisions occurred because drivers were still adjusting to the simulator while also trying to interact with the most complex of the smart signs. In particular, the older drivers in the night condition rated the driving scenarios as significantly more demanding than all other drivers, which supports the possibility than increased workload early on in the simulation may have contributed to more collisions with this sign.

Fewer older drivers in the night (36%) condition found the sign to be confusing to use compared to the older drivers in the day condition. Like the older drivers in the day condition, the older drivers who rated the sign as confusing to use at night were more likely to accept gaps below the safe gap threshold (M=5.44s). In contrast, older drivers in the night condition who rated the sign as less confusing to were more likely to accepted gaps above the threshold. Because drivers who found it confusing accepted smaller gaps than those who did not find it confusing, this suggests that accepted gap size did not result solely from increased wait times due to confusion with the sign display because longer wait times would have presented larger gaps in the specified pattern of traffic. This suggests that the larger accepted gaps for those older drivers that did not rate the Icon sign as confusing may be the result of these drivers complying with the safe gap advisory information provided by sign display. The difference in sign state comprehension was not as large for confused (83.3%) versus unconfused (90.48%) older drivers in the night condition.

Indeed, twice as many of the older drivers at night (50%) said they used the sign information to support their gap decisions compared to the older drivers in the day (25%). This supports early observations that older drivers are more receptive to the IDS signs at night when the increased workload resulting from the low visibility conditions makes the need for gap acceptance support apparent to them. The older drivers at night reported a high preference ranking for the Icon sign (second) and rated it a one of two of the most useful and satisfying smart signs, in contrast to the its low rating as useful and satisfying by the older drivers in the day condition. It was placed similarly to the Split-hybrid sign in ranking and usability by the older drivers at night.

8.3.2. Young Drivers

8.3.2.1. Day

Young drivers' performance overall was similar to the older drivers in the day for the Icon sign. They showed a significantly larger mean accepted gap compared with all the smart signs for the Icon sign condition, and the same percentage (25%) of young drivers accepted a gap over the safe gap threshold as the older drivers in the day condition. In general, young drivers in the day who reported finding the sign confusing to use (41.7%) had slightly lower comprehension rates (80%) than did the young drivers in the day who did not find it confusing to use (94%). This result is similar to the older drivers in the night condition. As well, like the older drivers in the night condition, young drivers ranked the Icon sign as their second preferred sign behind the

Split-hybrid sign, and rated it slightly below the Split-hybrid sign in terms of being useful and satisfying, but more useful and satisfying that either the VMS or Hazard signs.

8.3.2.2. Night

In the night condition, young drivers' performance was similar to the young drivers' performance in the day. The mean accepted gap for this group for the Icon sign was significantly larger than all other signs. In contrast to the older drivers at night, this group only experienced once collision in the Icon sign condition. This group also had the fewest conflicts (4) compared to the other smart signs. As with the young drivers in the day condition and the older drivers overall, the 58.3% of young drivers at night who reported the sign as confusing to use had lower comprehension (85.7%) of the sign states at the end of the study than did the 41.7% who did not rate the sign as confusing to use (93.3%). The drivers in this group ranked this sign a their second preferred, and rated it as similarly useful in comparison to the young drivers in the day and older drivers at night. However, this group rated it as less satisfying than did the young drivers in the day and the older drivers at night.

8.3.3. Summary

Overall, the results of the Icon sign indicate that it partially succeeded in its intended function to convey both one and two-stage maneuver information to drivers. It also resulted in the similar gap acceptance and comprehension results across all groups of drivers, regardless of how the drivers may have felt personally about the sign's information. However, the larger gap acceptance values may be partially due to drivers requiring more time to overcome initial confusion and comprehend the information on the sign such that larger gaps were inevitably available to them when they made their crossing decision given the prescribed nature of the traffic. However, the data also indicates that confusion was not the only factor in the increased wait times and larger accepted gaps for all groups. For drivers who did not find the sign confusing to use, there was a significant shift toward safer gap acceptance compared to baseline. Notably, all four groups of drivers had the highest rates of comprehension for the Icon sign compared with the other smart signs. However, drivers who reported finding the sign confusing had slightly lower comprehension rates than those who did not. Most likely, drivers found the complexity and amount of information on the sign to be initially confusing, but were still able to interpret the sign's function, use the sign, and understand its states.

There are some potential deployment issues for the Icon sign in terms of placement of the display only on the driver's side (right) of the intersection next to the STOP sign and in the median. Several drivers indicated that they felt the placement of the Icon sign made it difficult to interpret the sign in their forward field of view and then corroborate the information presented with their view of the actual traffic in their left (near-side) field of view. This necessity for drivers to split their attention between a sign on the right and traffic coming from the left potentially introduces a delay that could decrease the safety margin available to drivers once they have confirmed the information and decide to comply with the sign. Although it is important for drivers to check the oncoming traffic in addition to using information on the sign, the added delay of watching the sign on the right and then turning to look to the left may not be ideal. For example, the VMS and Split-hybrid signs are located on the left side at the STOP sign so drivers can monitor the signs and the traffic stream simultaneously.

8.4. Split-Hybrid Sign

The Split-hybrid sign supports both one and two-stage maneuvers. but this support is split across the two sign positions. Signs are placed on the left side of the driver at the STOP sign and in the median to help drivers make decisions for each stage of crossing. A timer countdown indicates time-to-arrival information for the lead vehicle in the traffic stream. A red timer background and a “do not enter” icon indicate a vehicle is within the safe gap. A black timer background indicates a vehicle is not within the safe gap. From the STOP sign, drivers may see a “do not cross or turn left” icon or a “caution” icon. The “do not cross or turn left” icon means a vehicle is detected in the safe gap for the far lanes, but not for the near lanes. Thus, drivers could turn right or proceed to the median, but should not cross the far lanes. The “caution” icon indicates that no vehicles are detected within the safe gap of either the near lanes or the far lanes. Therefore, a driver can potentially cross over the entire intersection. A second sign is located in the median to help drivers with crossing the far lanes. Overall, the Split-hybrid sign both displays information about the size of available gaps and provides advisory information about prohibited actions. Drivers must decide on the safety condition and choose an action.

The Split-hybrid sign’s overall mean accepted gap for the southbound lanes was larger than baseline in both the day and night conditions. In fact, the night condition mean accepted gap was larger than the day condition for Split-hybrid, whereas baseline showed a decrease in mean accepted gap for the night condition compared to day. Overall, the Split-hybrid sign was rated as making drivers feel safer compared with the other smart signs, was trusted more by driver’s over the other smart sign, was considered the most reliable of the smart sign’s and was considered significantly easier to understand than the Icon and VMS signs. The main effects of the Split-hybrid sign were driven mostly by the young drivers and the older drivers in the night condition. Older drivers in the day were less receptive to the Split-hybrid sign and the smart signs in general.

8.4.1. Older Drivers

8.4.1.1. Day

Older drivers in the day condition had a larger mean accepted gap than the VMS and baseline conditions with the Split-hybrid sign, but a smaller accepted gap than the Icon and Hazard sign. Only one driver in this group accepted a gap larger than the safe gap threshold of 7.5 s. This is a similar result to the Hazard and VMS conditions, where one and zero drivers, respectively, took a gap larger than the threshold. Three drivers in the Icon sign condition took gaps larger than the threshold. The safety margin was similar to that of the VMS sign, but was smaller than that for the Hazard sign and the Icon signs. Because the safety margins are significantly positively correlated with the size of the accepted gap, the pattern of safety margins mirrors that of accepted gaps. There were no collisions in this group, and only a single conflict. The results were similar across the smart sign conditions for this group, with one conflict for the Hazard sign and no conflicts for the Icon or VMS signs. Overall, drivers performed similarly with the Split-hybrid sign and the VMS sign, while showing differences in gap acceptance with the Icon and Hazard signs.

Fewer drivers in this group found the Split-hybrid sign confusing to use compared to the number of drivers in this group that found the Icon sign confusing to use. Comprehension of the sign states for the 58.3% of drivers who rated the sign confusing to use was 61.9% whereas comprehension of sign states was only 53.3% for the drivers who did not find the sign confusing to use. This suggests that confusion was not the primary barrier to a higher comprehension rate for this group. Comprehension of the sign states was highest for this group in comparison to the VMS and Hazard signs, but was lower than for the Icon sign.

Overall, 91.7% of drivers correctly identified that the "do not enter icon" coupled with a red timer background meant stop and wait while 75% comprehended that the "do not turn left or cross" icon coupled with a black timer background meant proceed to median and wait. However, only 8.3% (one person) comprehended that the "caution" icon coupled with a black timer background meant they could proceed across the entire intersection. The remaining 91.7% thought it meant "proceed to median and wait". The comprehension rates of the sign states shown by this group paralleled the results of the other three groups of drivers. Although drivers could not correctly identify the "cross entire intersection" state of the sign, their overwhelming response that crossing to the median and waiting was an appropriate action for that sign state is a safe and efficient response. The safest crossing strategy is to double-check the far lane traffic while in the median to ensure it is still safe to cross, particularly for this intersection where visibility of the far lanes is obscured. What this response suggests is that drivers perhaps did not fully comprehend that the Split-hybrid sign supported a one-stage maneuver. However, the Split-hybrid's support for a two-stage maneuver was comprehended by this group.

Drivers' subjective interpretations of the sign were similar to those of the Icon sign condition for this group, but again, did not fully match their performance results. The older drivers in the day condition preferred the Split-hybrid sign slightly over the Icon sign, but it was not as preferred as the VMS or Hazard signs. The usability ratings by this group also placed the Split-hybrid sign slightly ahead of the Icon sign, but well below the VMS and Hazard signs in terms of usefulness and satisfaction. However, 50% of drivers in this group did say they used the sign to help them with their crossing decision. This suggests that drivers may have used the sign differently than expected. Because many drivers said they understood the time to arrival information, they may have used the timer countdown as an indication that traffic was present, while not necessarily complying with the safe gap threshold.

As with the Icon sign, this sign was rated as more confusing to use by the group as a whole compared to the VMS and Hazard signs, yet comprehension of this sign's states was better than for the VMS and Hazard signs. In general, the subjective results of the older drivers in the day condition appear to indicate a perceived lack of need for decision support, which may be driving their rating of the signs as less useful and satisfying even though performance measures such as a larger mean accepted gap and higher comprehension indicate

8.4.1.2. Night

Overall, the older drivers in the night condition had notably different performance and subjective opinions of the Split-hybrid sign than did the older drivers in the day condition. First, the older drivers in the night condition showed the second largest gap acceptance with the Split-hybrid sign. It was slightly smaller than the Icon sign, but had a mean accepted gap 1.55 s larger than the Hazard sign, for which the older drivers in the day condition had a larger gap than with the

Split-hybrid sign. As well, 33.3% of older drivers accepted gaps over the safe gap threshold for the night condition compared with 8.33% of older drivers for the day condition. As in the day condition, safety margin was significantly correlated with the mean accepted. Thus, the Split-hybrid had a larger safety margin than the Hazard sign, which also had a smaller accepted gap, and a smaller safety margin than the Icon sign, which had a larger accepted gap. This group experienced one collision and eight conflicts while using this sign, which is more than occurred in the day condition. However, collisions and conflicts were higher at night for all sign conditions, and this group actually had fewer conflicts with the Split-hybrid sign than with the Hazard or VMS signs. The number of conflicts was similar to the number experienced by this group with the Icon sign.

Most notably, older drivers in the night condition overwhelmingly preferred the Split-hybrid sign compared to the other smart signs and rated it the most useful and satisfying of the smart signs. This is opposite to the low preference and low usability ratings for the Split-hybrid sign indicated by the older drivers in the day condition. Moreover, 100% of drivers in this group said they used the sign's information to help them make their crossing decisions and only 33.3% (4 drivers) rated it as confusing to use. The Split-hybrid sign shifted gap acceptance towards the safe gap threshold for this group. However, not all drivers waited for a safe gap before crossing. Most likely, the timer countdown made drivers more alert to the presence of traffic and it potentially helped them choose an acceptable gap based on their own judgment of what constitutes a safe gap for the driving conditions.

Drivers in this group had the highest comprehension for the prohibitive icons. The "do not enter" state had 100% comprehension while the "do not turn left or cross" state had 81.8% comprehension. No drivers correctly identified the "caution" icon with the black timer background as meaning they could cross the entire intersection, but all drivers did indicate that it meant they could safely proceed to the median. These results are identical to those for the older drivers in the day condition and again indicate that the presence of a sign in the median potentially indicated to drivers that a two-stage maneuver was supported by the sign.

The differences in preference and perceived usability of both the Split-hybrid sign and the Icon sign for the older drivers in the day condition versus the night condition appears to indicate a difference in acceptability of the decision support technology. As mentioned, the older drivers in the night condition perceived workload to be significantly higher than did older drivers in the day condition. When older drivers are aware of potential deficits in performance, such as may have been the case for crossing in the dark for the older drivers, they are more likely to adapt their behavior to accommodate any limitations and improve their safety. Therefore, the preference by this group for signs that provide more information about the presence of unsafe gaps and related safety behaviors (i.e., do not cross) most likely indicates a perceived need for decision support in a high workload situation.

8.4.2. Young Drivers

8.4.2.1. Day

The young drivers in the day condition showed a similar pattern of gap acceptance in comparison to the older drivers in the day condition, with the Split-hybrid sign resulting in a mean accepted gap smaller than the Icon and Hazard signs, but larger than the VMS sign and baseline condition.

However, their gap acceptance with the Split-hybrid, and all smart signs, was lower than for the older drivers, and their safety margin for the Split-hybrid sign was significantly smaller than for older drivers in the day condition. However, safety margin was still significantly, positively correlated with the size of accepted gap. Similar to the older group of day drivers, only one young driver in the day condition accepted a gap above the safe gap threshold. As with the older drivers in the day condition, there were no collisions in the young driver group for the day and there were only two conflicts.

Comprehension of sign states for the young drivers in the day condition mirrored that of all the older drivers in both the night and day conditions. Comprehension was highest for the “do not enter” and “do not cross or turn left” state and lowest for the “caution” icon combined with a black timer background that indicated it was safe to proceed across the entire intersection. As with the older drivers, all the young drivers who answered the latter state incorrectly also answered instead that it was safe to proceed to the median. Very few young drivers in the day condition found the sign confusing (N=2) to use, which is different than the number of older drivers (N=7) in the day condition who found the sign confusing to use.

The young drivers in the day condition most preferred the Split-hybrid sign of all the smart signs, and they found it the most useful and satisfying. Their usability results most closely matched those of the older drivers in the night condition. The Split-hybrid sign did not shift gap acceptance as close to the safe gap threshold as it did for the older drivers at night. Although 66.7% of the drivers in this group said they used the sign to help them make their crossing decision, few waited for the safe gap threshold. As with the older drivers in the night condition, these drivers may have used the time-to-arrival information to help them select a gap they felt comfortable with, rather than waiting for the safe gap threshold. Young drivers in the day condition also did not find the driving scenarios to be significantly demanding and therefore, may have felt comfortable taking smaller gaps sooner in the traffic stream than did the older drivers in the night condition.

Overall, relative performance for this group paralleled that of the older drivers in the day condition when compared to other smart signs. That is, this group had smaller mean accepted gaps for all sign conditions, but the differences between sign conditions matched that of the older drivers in the daytime. However, their subjective preference for the Split-hybrid sign over the other smart signs indicates that the time-to-arrival information was preferred by this group over the alerting nature of the Hazard sign and the iconic gap information provided by the Icon and VMS signs.

8.4.2.2. Night

Like the young drivers in the day condition and the older drivers in the night condition, the young drivers in the night condition most preferred the Split-hybrid sign and also found it to be the most useful and satisfying on the usability scale. Although the mean accepted gap of the young drivers at night was larger than that of the young drivers in the day, this group showed the smallest gap acceptance and the smallest safety margin with the Split-hybrid sign when compared to the other smart signs. The mean accepted gap for the Split-hybrid sign was slightly smaller than the VMS and Hazard signs, and much smaller than the Icon sign, whereas in the day condition for young drivers it was only smaller than the Icon and VMS signs. However, the differences in gap acceptance for young drivers in both the day and night conditions was not significantly different between the Split-hybrid, Hazard and VMS signs. Moreover, in the night condition, the mean gap acceptance for the Split-hybrid sign was significantly larger than baseline. Therefore, even though the relative performance with signs at night puts the Split-hybrid with the smallest mean accepted gap, the differences between it and the Hazard and VMS signs are nominal, and it also resulted in better performance than baseline.

Like the older drivers at night, 100% of this group said they used information provided by the sign to help them make their crossing decisions. However, like the young drivers in the day, there was not a significant shift towards the safe gap threshold, even though drivers said they used the sign for the decision making. The young drivers, overall, may have liked the time-to-arrival information, but were did not comply with the gap advisory information as often as the older drivers in the night condition did. The young drivers may have used the countdown information as a cue to the presence of a minimal safe gap the drivers habitually accepted. In this sense, the sign information was used by the older drivers to support their gap acceptance and by the young drivers to tune their recognition of a minimally safe acceptable gap.

Comments from the young drivers support this possibility, such as the driver who said he used the sign's information but felt it was too conservative so he went anyway or the driver who said he went if he had 4 seconds. This suggests that young drivers are making assumptions about their ability to accept gaps based mostly on their own judgment. The timer perhaps allows them to better estimate which gap they will accept (e.g., 4 s instead of 3 s), but does not necessarily encourage them to wait for a safe gap indication from the IDS sign. That is, younger drivers used the numerical gap data in the signs to find a minimal gap they perceived to be safe rather than using the IDS advice on what gap is normatively safe.

8.4.3. Summary

Overall, drivers were able to comprehend the information presented by the Split-hybrid sign and all the young drivers and the older drivers in the night condition were positive about the information it provided. The older drivers in the day condition did not find the Split-hybrid sign to be as useful or satisfying as the other groups and they preferred it third out of the four smart signs. The results thus far appear to indicate a pattern that the older drivers in the day condition may not have perceived a need for the decision support systems. As such, they may not have made as much of an effort to understand and utilize the information provided by the Icon and Split-hybrid signs. This is partially supported by the finding that both of these signs had the highest sign state comprehension rates of the four smart signs after the functionality of each was explained to all drivers, including the older drivers in the day condition. This suggests that the older drivers in the day were able to understand the function of the Icon and Split-hybrid signs when they were explained, but were perhaps less willing to try to understand them while driving because they did not perceive a need for them. The significant difference in perceived workload between the older drivers in the day condition and the older drivers in the night condition supports this possibility. When workload was perceived to be high, as with the older drivers at night, more gap information was preferred compared to less information. It was also perceived as less confusing. Perhaps when the need for information is apparent, more effort is applied to understanding it, which might explain why the signs were also perceived as less confusing by the older drivers at night compared with the older drivers in the day.

Both groups of young drivers preferred the Split-hybrid sign the most and also found it be the most useful and satisfying. However, the young drivers did not show a significant shift toward the safe gap threshold. The young drivers said they liked and used the timer information, but they did not use the entire sign as intended. Instead it appears they used the timer information to identify gaps that matched their typical acceptable gap size. Time-to-arrival information can be presented other than with an explicit timer countdown showing time in seconds. For example, a graphical representation of time-to-arrival information might show a bar filling in with red as a car approaches the intersection. A linear increase in the fill would indicate the time, but not explicitly. Because the time-to-arrival information is preferred by drivers and appears to be useful, an investigation of alternative ways to present time-to-arrival information is warranted. However, it is unknown if a change in presentation will reduce this behavior. For example, some drivers in this study said they went when it said "4 s" (below the safe gap threshold), but they may also learn what phase of a graphical representation they feel comfortable going on that is below the safe gap threshold.

Overall, comprehension for the "do not enter" or "do not turn left or cross" sign states was high for all groups. The least comprehended state while sitting at the STOP sign was the presence of a safe gap value from the left (black timer background) and the "caution" icon that also indicated that no unsafe gaps were detected in the far lanes. This sign state indicates that it may be safe to proceed across the nearside lanes and the far-side lanes. However, very few drivers understood that they might be able to cross the entire intersection from the STOP sign when the "caution" icon was present. However, all of the participants who answered this sign state incorrectly actually chose "proceed to median and wait" rather than interpreting the caution icon as meaning "stop and wait". This suggests that the misinterpretation is still safe and efficient. Moreover, although it was not explicitly tested, drivers appeared to understand that the caution sign meant they could cross the far lanes when they were stopped in the median.

Because drivers correctly interpreted the prohibitive sign states and provided a safe, but partially incorrect response for the "caution" icon, it seems drivers understood the function of the Split-hybrid sign as providing prohibited maneuver information from both the STOP sign and in the median. However, they did not necessarily comprehend the sign's ability to provide information about a one-stage maneuver from the STOP sign. In comparison, the diagram of the roadway on the Icon sign clearly indicates which lanes have traffic approaching and which do not, and drivers were better able to comprehend when they were able to cross the entire intersection with this sign. This could be because the prohibitive icons are removed on the Icon sign when no unsafe gaps are detected, whereas the Split-hybrid sign continues to utilize the "caution" icon even when crossing is possible.

8.5. Variable Message Sign

The Variable Message Sign (VMS) is designed around the same logic as the Split-hybrid sign, but without the timer countdown. Therefore, it provides information about unsafe gaps through the prohibitive icons it displays. For example, at the STOP sign, when a vehicle is in the near lane safe gap, the "do not enter" icon is present. When a vehicle is in the far lane safe gap, but not the near lane safe gap, the "do not turn left or cross" icon is present. When no vehicles are detected within the safe gap threshold of either lane, a "caution" icon is displayed. Like the Split-hybrid sign, a second sign is located in the median that provides information about the far lanes. From the median, either the "do not enter" icon or the "caution" icon is displayed depending on whether a vehicle is detected or not in the safe gap. This sign is advisory in nature and the driver must choose to comply or not with the information it presents. The Split-hybrid sign also provides the advisory icons, but in conjunction with information about the size of specific gaps.

Overall, the VMS sign produced the third largest mean gap acceptance across all drivers and lighting conditions. This value was significantly larger than baseline, but was not significantly different from the Hazard or Split-hybrid signs, and was significantly smaller than the Icon condition.

8.5.1. Older Drivers

8.5.1.1. Day

For the older drivers in the day condition, the VMS mean accepted gap was the lowest accepted gap value of all the sign conditions, although is was not significantly different than the Baseline, Split-hybrid or Hazard sign conditions. It was significantly smaller than the mean accepted gap for the Icon sign. As with the other signs, the safety margin was positively correlated with the size of the accepted. No drivers in this group accepted a gap above the 7.5 s threshold and all entered the intersection while the "do not enter" icon was present. No collisions or conflicts occurred for these drivers with this sign.

Drivers' descriptions of how the sign functioned after interacting with the sign, but before having its function explained, indicate that drivers in this condition did not initially perceive the sign to be a smart sign. Because no drivers in this condition accepted a gap larger than the threshold, they did not see the status of this sign change. That is, because the maximum gap accepted by the older drivers in the daytime condition was below the safe gap threshold used to operate the VMS sign, no driver would have seen the sign change status. Accordingly, all drivers in this group would have experienced this condition as a static sign with a prohibitive message to "do not enter" the intersection (see Figure 8.1). Given the static nature of this display, these drivers would not have had an opportunity to infer the function and meaning of the VMS sign information. As a result, these older drivers may not have perceived the sign as supporting gap acceptance and made their own decision. In this case, it would be expected that the accepted gap size for the VMS sign would be most similar to the STOP sign in the baseline condition that is designed not be a gap acceptance support system.

Figure 8.1. VMS sign with "do not enter" icon.

Indeed, the static nature of the VMS sign and its placement on the nearside lane of oncoming traffic misled many older drivers as to the intended meaning of the sign. Most of the older drivers in the daytime condition commented after driving that they thought the VMS sign was placed to warn them not to turn left into the one-way oncoming traffic. But once the functionality of the VMS sign as a dynamic decision support device for gap acceptance was explained to the older drivers, they rated it as the most useful and satisfying of all of the (IDS) signs on the usability scale, but still ranked it behind the Hazard sign as their most preferred sign. Comprehension of the sign states after the functionality of the sign was explained was also low for this group. Only one person in the group rated the sign as confusing to use and they were unable to correctly identify any of the VMS sign states. Of the 11 participants who did not rate the sign as confusing to use, the comprehension rate of the sign states was only 33.3%. However, the rating of how confusing the sign is to use was made before the sign's functionality was explained to the drivers. The drivers in this group initially thought they were interacting with a familiar static "do not enter" sign, thus it was not rated as confusing to use.

The ranking and usability scores for this group suggest that, once the functionality of the sign was explained, these drivers preferred a decision support sign that was less confusing than the Split-hybrid and Icon signs. However, their comprehension of the sign states was low, even after the function was explained. Therefore, although they preferred this sign over the more complicated signs, they were still unable to understand the information it provided after the study. However, because these drivers did not see the sign dynamically in the simulation, it may have been difficult for them to understand the written descriptions of the functions, which could have impacted their comprehension of the sign states.

8.5.1.2. Night

The mean accepted gap for VMS for older drivers at night was larger than it was for older drivers in the day. Moreover, the accepted gap at night for the older drivers was significantly larger for the VMS sign than for the least complex baseline and Hazard signs; however, it was not significantly different from the Icon and Split-hybrid signs. In this group, 41.7% of drivers accepted a gap larger than the safe gap threshold for the near lanes. This indicates that more drivers in this group likely saw the sign change.

This group experienced six collisions with the VMS sign. Three of the six collisions were by the same person. This person also experienced a collision with the Icon sign, which was the first condition they drove with. The VMS sign was the second condition they drove for the study. These collisions early in the study indicate that this driver had difficulty adjusting to the simulated driving scenarios. Without these collisions, the number of collisions drops to three for this group, compared with two for the Split-hybrid, two for the Hazard sign, and one for the baseline condition. This group also experienced 10 conflicts, compared with one for the day condition. This number is more than the number of conflicts experienced by this group using the Split-hybrid and Icon signs, but less than the number experienced with the Hazard sign.

Five drivers in this group found the sign confusing to use and this group's comprehension of the sign states at the end of the study was 46.7%. This is compared with a comprehension rate of 22.2% for the drivers who did not find the sign confusing to use. This sign was rated as the most confusing to use of all the signs by this group of drivers. Although older drivers demonstrated better comprehension of the VMS sign at night than during the day conditions, they still showed a high rate of misinterpretation about the sign. This could possibly be due to the fact that some older drivers in the night condition did accept larger gaps such that they were exposed to dynamic changes in the VMS sign. As a result, the older drivers at night had some opportunity to observe the operation of the VMS sign and infer its function. In contrast, the drivers who did not see the sign in operation would be more likely to misinterpret its function.

Performance for the older drivers in the night condition and preference ranking was similar for the VMS and Split-hybrid sign. This may be expected given that the VMS sign content is a subset of the Split-hybrid sign functionality. Once drivers in this group were informed of the sign's complete functionality, however, the VMS sign was rated much lower in terms of satisfaction and usability than the Split-hybrid and Icon signs, and it was rated similarly to the Hazard sign. This suggests that the higher information content of the Split-hybrid and Icon signs was appreciated by the older drivers at night. It also indicates that older drivers recognize their need for support during limited visibility conditions and will accept greater complexity in the sign information if it is recognized to improve safety for their gap acceptance.

8.5.2. Young Drivers

8.5.2.1. Day

Like the older drivers in the day condition, the young drivers in the day condition showed similar gap acceptance to the Split-hybrid and Hazard signs, and their mean accepted gap was significantly lower than for the Icon sign when using the VMS sign. Similarly, no drivers in this group accepted a gap over the near side safe gap threshold. This group also initially described the sign's function as a "do not enter" sign rather than as a smart sign. This group experienced no collisions and only one conflict for this condition. Like the older drivers in the day condition, these drivers did not see the VMS sign change states because they accepted gaps smaller than the safe gap threshold that would signal a change in the sign.

The main difference between the young drivers in the day condition and the older drivers in the day condition is that the young drivers did not rate the VMS sign as useful or satisfying once its functionality was explained. In fact, it was rated the least useful and satisfying of all the smart signs by this group. This group showed an average comprehension rate of 44.4% for the sign states at the end of the study.

8.5.2.2. Night

The young drivers in the night condition showed similar gap acceptance results to the older drivers in the night condition. The mean accepted gap for this group was similar to the Split-hybrid and Hazard signs, but was smaller than the Icon sign. However, the overall mean accepted gap for the young drivers at night was lower than for the older night drivers. Only 25% of drivers in this group accepted a gap above the safe gap threshold for the near lanes. This group also experienced one collision and seven conflicts. The number of conflicts was similar the Hazard sign condition, less than the number in the Split-hybrid condition, and more than the number of conflicts in the Icon condition.

Comprehension for the sign states was 33.3% for the drivers who rated the sign as confusing to use and was 29.2% for the drivers who did not rate the sign as confusing to use. Like the young drivers in the day condition and the older drivers in the night condition, once this sign's functionality was explained, young drivers in the night condition rated it as the least satisfying and useful of the smart signs.

8.5.3. Summary

Overall, comprehension of the sign's functionality was not understood by all the drivers in the day condition because of limited exposure to the dynamic nature of the sign advisory information. Under low volume traffic conditions, the VMS sign would change more frequently, thus providing a better indication to drivers of its function. The implication is that signs such as the VMS sign may appear static during high traffic volume conditions with a conservative gap threshold as the basis for its operating logic. In such cases, such a device may be misinterpreted as a standard sign rather than an "intelligent" decision support device, or as some sort of dynamic sign that is not functioning. In the later case, such signs may require an additional indicator to convey to the drivers that this sign is indeed operational and operating correctly. In this regard, it should be noted that the same symbology of the VMS sign when presented in the Split-hybrid sign did not produce the same misunderstanding. This suggests that the presence of the dynamic gap countdown and black-red coding of unsafe gaps presented dynamic information to drivers that provided an interpretative context for drivers to comprehend the function of the overall Split-hybrid sign including the (static) advisory symbol element.

8.6. Design Limitations

8.6.1. The Safe Gap Threshold

Because the IDS signs are not regulatory in nature, it was expected that not all drivers would comply with the advisory information. Therefore, the mean accepted gaps for the near lanes are lower than the 7.5 s design threshold for all groups. In several conditions, the upper 95% confidence interval does not reach the safe gap threshold, in part because many drivers in this study found the safe gap threshold to be too conservative and accepted gaps smaller than the threshold. For example, young drivers accepted fewer gaps near the threshold than older drivers and frequently commented that they could take gaps even if the sign was indicating an unsafe condition. Despite accepting gaps below the threshold, many drivers were able to comprehend the function of certain signs (i.e., Split-hybrid and Icon) even though they did not see the full range of information they provided. However, drivers sometimes appeared to develop an incomplete understanding of how the signs functioned because they may have detected what they considered an acceptable gap and could not understand why the sign still indicated an unsafe condition (i.e., VMS and Hazard). Therefore, the content on the signs may have been confusing to these drivers and they may have had doubts about the signs' functions. Because of this, they may have felt compelled to take a gap they felt was acceptable without waiting for a sign to change. This suggests that a perception of the threshold as conservative may affect how drivers interact with an IDS system.

However, although the threshold was often perceived to be conservative, shifts away from baseline gap acceptance did occur in each group with certain IDS signs. In particular, older drivers at night showed the largest mean accepted gaps for the Icon (7.06 s), the Split-hybrid (6.72 s) and the VMS (6.62 s) signs, and also appeared receptive to the decision support systems. This is in contrast to this older group's performance with the STOP sign alone (5.28 s) and the

Hazard sign (5.17 s). The near-side safe gap thresholds for the IDS system condition approach the safe gap threshold and are similar to values obtained by Kyte et al. (1996) for a crossing maneuver. Their research suggests 6.5 s for crossing a two-lane road from a minor-road with a 0.5 s adjustment for an additional lane. The addition of the older driver adjustment (0.5 s) to make the threshold 7.5 s may have increased the perception of the threshold as conservative for many drivers, particularly the young drivers. Additionally, drivers in this study were presented with an increasing gap threshold and could not take a gap until they perceived one to be safe. In contrast, drivers in the real world sometimes have the opportunity to select a large gap without ever seeing a small gap. Therefore, the increasing threshold presented in the simulator could result in smaller accepted gaps when compared to gap data collected in the real world because it represents drivers selecting a minimum acceptable gap.

Compliance with the threshold was also related to perceived workload demand in the driving scenarios for these groups. In particular, the older drivers in the night condition perceived the scenarios to be significantly more demanding than other drivers and were more likely to accept gaps above or close to the threshold and comply with the signs that provided specific advisory information about unsafe gaps (Icon, Split-hybrid, VMS) compared with other drivers.

The perception of the threshold as conservative may also have been exaggerated by the fact that drivers had to wait a significant length of time for a gap larger than 3 s to appear. This may have pushed their gap acceptance threshold down as they perceived the possibility that a larger gap may not appear soon. Drivers in the real-world do accept smaller gap thresholds when they are impatient, such as from waiting for a long time at the intersection, or in a hurry (Caird & Hancock, 2002). Overall, if the traffic model did shift drivers' thresholds towards the smaller range of gaps, that means the larger accepted gap values observed with the IDS signs indicates that the signs aided in shifting gaps away from an even smaller threshold, such as observed in the baseline condition. This shift towards the safe gap threshold occurred even when time to evaluate the sign is taken into account. Although it is the case that a portion of the increase in gap size may have occurred from drivers spending time interpreting the signs, it is also clear from the responses of the older drivers in the night condition that many chose to comply or at least partially use the signs to help them with their gap decisions. When no support was perceived to be present, gap sizes and safety margins were smaller at night than in the day, indicating that the ability to make a gap selection was impacted by the night condition.

In fact, it is most likely that a single, global threshold is not sufficient. In this study, the near-side threshold was designed to accommodate older drivers crossing two lanes of traffic and the far-side threshold was designed for an older driver making a left-turn. Not all drivers are older, nor do all older drivers have uniform abilities when it comes to perception and decision making. In actuality, the range of abilities among older drivers is more variable than among young drivers, depending on a person's individual health and visual acuity. Some older drivers may be comfortable with a smaller threshold while others may require a larger threshold. As well, some drivers are more conservative and others less conservative, regardless of age. Ideally, a decision support system would communicate with a vehicle and adjust the threshold based on the characteristics of the driver. Such "cooperative" systems could dynamically adjust safe gap thresholds based on the driver and situational characteristics of the crossing.

8.6.2. Traffic Model

The traffic model in this study was chosen to induce impatience in drivers, to systematically assess minimum accepted gaps, test 1-stage and 2-stage maneuvers, and to avoid the problem of drivers accepting a large gap early on which would not provide them with time to examine the signs (or judge small gaps). In general, the model worked in terms of providing drivers with time to examine the signs and for one versus two-stage strategies. It also appeared to induce impatience in some of the drivers who accepted small gaps (i.e., 3 s) and who commented on the lack of larger gaps sooner in the traffic stream. Ultimately, in order to accurately compare performance between signs in this early stage of investigation, a controlled traffic model was required. Now that the informational requirements have been tested and new information about how drivers accept gaps while using a decision support system, it will be important to test the signs in a naturalistic traffic model.

8.6.3. Light Conditions

For the night condition, an assumption was made about how to illuminate the signs. In this study, the decision was made to ensure that the signs were visible regardless of where the driver's headlights fell. This is because the main focus of the study was to examine the information presented on each sign. In essence, the signs appeared reflective in the simulation, but did not rely on the simulator's headlight model to be illuminated (see Figure 8.2). The illumination of the signs in real-world deployment will have to be evaluated to ensure they are visible to drivers otherwise the decision support information will be unusable.

Figure 8.2. Illuminated Icon sign in night driving condition.

8.6.4. Crossing Maneuver

In this study, drivers were only asked to cross through the intersection, although the signs were designed with a left-turn threshold in mind. Because most drivers in this study adopted a two-stage maneuver strategy, it is unclear whether the accepted gap values for the near lanes would change appreciably if the maneuver tested were a left turn. It is possible that drivers might consider a left-turn maneuver differently than a crossing maneuver and may take more or less time to cross to the median. Future testing should investigate the utility of the threshold for left turns.

8.6.5. Baseline

For this study, the STOP sign alone made a valid baseline condition for initially testing performance with and without IDS support. However, for the subjective rankings, participants did not rate the STOP sign as a condition with decision support absent. Instead, they rated the sign based on its function as a STOP sign. Therefore, from a subjective standpoint, drivers better comprehended the STOP sign than the new IDS signs because they were familiar with the sign and its function. As the IDS project moves to the next stage, a baseline condition such as the proposed Hazard sign or the simple Intersection Collision Avoidance Warning System (Peabody et al., 2001; see Appendix IV) which used simple flashing lights and signs with loop detectors to notify of approaching traffic would provide a better comparison across the levels of IDS information content (alert, perceive, accept) than the STOP sign alone.

8.6.6. Education

Preston and Storm (2003a) emphasized the need for driver education when developing and deploying new countermeasure devices. Although drivers were given basic information about how the signs worked, the results of this study suggest that an educational or advertising campaign would be warranted with the deployment of a smart sign. Although two of the sign conditions were well understood by drivers, an educational campaign would not only help drivers understand the function of the signs but why they are necessary to improve safety. This could help avoid the case where they older drivers who are resistant to technology may not believe they need help even though this group is over-represented in this type of intersection crash.

9. Recommended Design Concepts

Three signs from this study are recommended for future research. The informational content of both the Icon sign and the Split-hybrid sign were best understood by drivers and more frequently used to make crossing decisions. There are certain limitations associated with each sign. The Hazard sign is recommended for use in future testing as a baseline condition. It provides a simple alerting function that produced cautiousness in some drivers, resulting in them taking larger gaps.

9.1. Split-Hybrid

Most drivers preferred the time-to-arrival information on the Split-hybrid sign. However, many commented that they would prefer to know in advance what time value constituted a safe gap. The color coding on the timer background was meant to convey the unsafe nature of certain gap times, but younger drivers found the threshold too conservative. Notably, it is possible that the younger drivers used the Split-hybrid sign's countdown information for gap size as a cue for the minimal gap they would accept and ignored the advisory information regarding the safe gap determined by the system. For example, one driver commented that he went when the sign said 4 s. Drivers who calibrate themselves to a gap time they feel comfortable do not necessarily present a problem as they may be accepting gap sizes that they can safely use. However, the sign could potentially encourage some drivers to race certain gap times, thus reducing their safety margins and possibly leading to a collision.

To prevent system misuse, other ways of presenting time-to-arrival information in conjunction with the warning and advisory information might reduce misuse. For example, time-to-arrival could be displayed graphically by a fill bar as a vehicle approaches the intersection. The bar would fill as the car approached but would not give an explicit time value. Color-coding the bar using the black and red backgrounds would continue to indicate how close the vehicle was. In this way, the warning information is more clearly presented and is not obscured by a specific time value that drivers can fixate on. A bar is only one example of how to graphically display time-to-arrival. For example, another option could be to show a clock graphic that fills in when cars are detected near the intersection. The use of a clock graphic could indicate the relationship of the fill to time without explicitly stating a time value. An additional option is to present the time-to-arrival of a safe gap, rather than the time-to-arrival of approaching vehicles, which could allow drivers to anticipate the arrival of a safe gap and be prepared to make a maneuver when it arrived.

9.2. Icon

The Icon sign provided warning information about oncoming vehicles in conjunction with advisory information about prohibited actions. Although some drivers found the display to be complicated, the information was readily comprehended and resulted in the most consistent behavior among drivers. The full display of the intersection provided a one-to-one mapping between the sign elements and the intersection that potentially contributed to the high level of comprehension because drivers were able to map the traffic they saw to what the display was telling them.

However, the complexity of the full intersection display may have contributed to some problems. There were three collisions in the southbound lanes and four collisions with this sign in the northbound lanes at night with the Icon sign. One potential cause of this was that five of the seven collisions occurred with drivers who experienced the Icon sign as the first condition in the study. Because the sign was considered complicated due to more informational elements being present, drivers who saw the sign first may still have been learning how to handle the simulated scenarios and were also trying to understand the most complex of the smart signs at the same time. This may have contributed to collisions due to increased workload. In particular, six of the seven collisions were for the older drivers at night, who rated workload to be significant for the driving scenarios. One suggestion for re-design is to reduce the complexity of the information presented on the sign, while retaining the informational concepts of warning of approaching traffic, indicating prohibited actions and representing the intersection to better facilitate comprehension of the sign's information.

9.3. Hazard Sign

The Hazard sign is recommended for use as a baseline condition in future research. Next to the Icon sign, this sign resulted in the largest mean accepted gaps for older drivers in the day condition. As well, it is recommended that the Hazard sign be split and used both at the STOP sign and in the median as the Split-hybrid and Icon signs are. It is also possible that the Hazard sign flasher could be adopted for use with a timer countdown to reduce the use of icons on the Split-hybrid sign while still providing a clear cautionary message.

9.4. Critical Design Issues

9.4.1. Dynamic Information

Drivers most preferred and best comprehended signs with dynamic elements, even when drivers did not wait for the safe gap threshold. The higher level of comprehension for the Icon and Split-hybrid signs most likely occurred because other aspects of the sign changed while they waited to select their own gap, allowing them to interpret the overall function. In contrast, the simpler signs that appeared static in the traffic conditions, such as the VMS sign or the continuously flashing Hazard sign, did not provide an opportunity for drivers to experience all sign states and infer the sign function by correlating these sign states with recognized traffic situations. Given that high volume intersections will also likely produce traffic conditions that can result in static sign states, it may not be feasible to rely on the natural exposure of drivers to these signs to interpret the correct function of IDS systems. Instead, it may be necessary to consider strategies and programs to introduce and educate drivers about these signs. Such efforts may be similar in practice to methods used for existing driver education programs with respect to driving rules and interpretation of standard MUTCD signage and road markings. Although drivers did not necessarily see all sign states for the Hazard sign, the flashing alert drew some drivers' attention and some drivers commented that they were more cautious with the Hazard sign present. Design modifications for future testing should ensure that the dynamic aspect of the IDS sign is clear to drivers.

9.4.2. Split Design

Drivers preferred the presence of the Split-hybrid sign on the left so they could observe the traffic and the sign simultaneously. Many drivers commented that they did not like the location of the Icon sign next to the STOP sign because they could not watch it and the traffic at the same time. The time required for a driver to observe a change in the sign, turn their head and confirm the information with the traffic flow could increase the time it takes for a driver to begin their movement. This might result in smaller safety margins. Therefore, the presence of the IDS sign in view of the traffic stream is appropriate.

In addition, the presence of a sign in the median continued to help drivers with all aspects of the crossing maneuver. A two-stage crossing strategy is preferred to a one-stage strategy, therefore, the presence of a median sign may encourage drivers to stop in the median and also alerts them to the presence of traffic that may not be visible from the STOP sign. This factor is critical at intersections where the traffic in the far lanes may be obscured because of sight distance restrictions or improper grading. For example, the far lanes of the simulated intersection are obscured because of how the road is graded and drivers are not able to see approaching vehicles in the far lanes from the STOP sign until they are almost at the intersection. The fact that almost all drivers indicated that "caution" icon present on the Split-hybrid sign meant they could proceed to the median, rather than all the way across the intersection, suggests that drivers were good at understanding how the Split-hybrid sign applied to each set of lanes, but not for the whole intersection.

9.4.3. Sign Components

The Icon sign and the Split-hybrid sign both must be altered to include MUTCD compliant sign content and, more importantly, sign components that will not be confused with regulatory signs already in use. For example, the VMS sign was misinterpreted by drivers as a regular "do not enter" sign because it did not change in heavy traffic, thus drivers were unaware it was a dynamic sign. The presence of the time-to-arrival information in the Split-hybrid sign helped drivers better interpret the "do not enter" icon as meaning "do not cross into intersection". Without the contextual information provided by the timer countdown in the VMS sign condition, drivers confused the sign with a standard "do not enter" sign that is used to indicate one-way traffic. Whereas this conflict is partly due to the placement of the sign and its apparent static condition in the simulated traffic context (see Figure 9.1), it is also necessary to adopt an alternative icon representation that does not conflict with MUTCD standards.

However, it must be noted here that the current design iterations included the use of existing regulatory components as a first step to evaluate the types of informational concepts (i.e., do not enter, caution, do not turn) drivers would best understand. For example, in this study, drivers used the Split-hybrid signs' countdown component to make their decisions more frequently than they did the icons, suggesting that a future version of the sign might be one that does not require the use of the prohibitive icon framework. However, if the icons are removed, the Split-hybrid sign must retain its color-coding at minimum in order to indicate to drivers safe and unsafe conditions. Additionally, if the signs retain the icon symbol set, standard highway sizes would need to be implemented, which may result in signs that are impractically large. Therefore, the preferred content for each sign requires modification to conform to highway regulations.

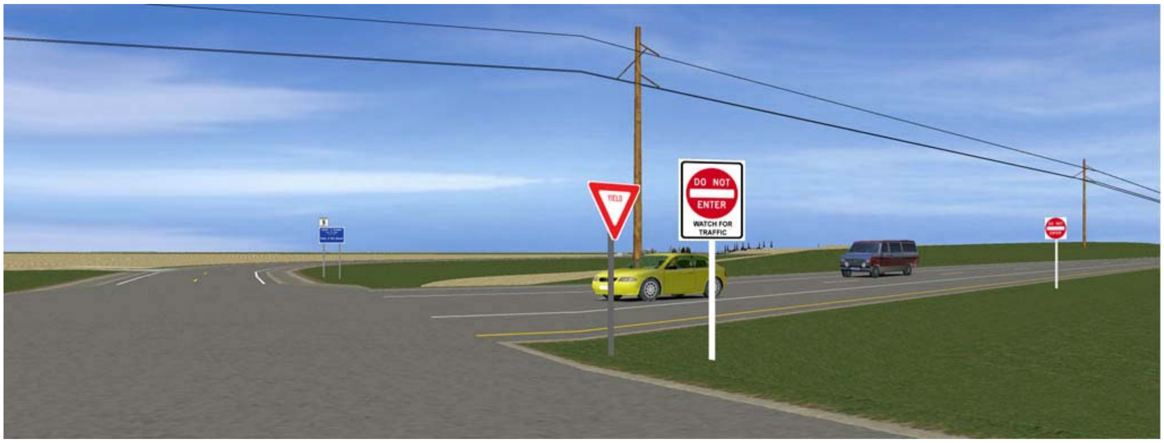


Figure 9.1. VMS sign in the median.
Notice the “do not enter” sign farther down the roadway. Placement of the VMS sign with “do not enter” is similar to the location of the actual “do not enter” sign used to prevent drivers from turning the wrong way in the lanes. Thus, its function could be confused.

The sign state questionnaire at the end of the study included two other icons that could potentially be used on the VMS and Split-hybrid signs in place of the “do not enter” icon (see Figure 9.2), although drivers did not see these icons appear on the signs during the simulated driving scenarios. The three-headed arrow had a high comprehension rate. Young drivers had a 100% comprehension rate while older drivers were slightly lower with 90.0% comprehension. However, if used on the Split-hybrid sign, which is recommended for further evaluation, drivers may not notice the change from the 3-headed icon for “do not enter” to the 2-headed icon (see Figure 9.3 above) that indicates a driver cannot cross over or turn left into the far lanes, but may be able to turn right or cross to the median. The “do not enter” hand icon had 100% comprehension for young drivers, while older drivers had 82.2% comprehension. A limitation to this icon is that it may be misinterpreted as a pedestrian signal by drivers not familiar with the sign’s function. Although these are both viable options to replace the “do not enter” icon they need to be tested further.

Figure 9.2. On the left is the 3-headed "do not enter" arrow with prohibitive circle and slash. On the right is the "do not enter" hand.

9.4.4. Use of Prohibitive Representations

A prohibitive message set was used for the advisory information to minimize liability issues for compliance that may result in a crash. The use of a prohibitory frame to provide advisory information has a number of disadvantages including interpretation load, meaning conflict, and omission inference.

9.4.4.1. Interpretation Load

A prohibitive sign states what behavior is advised against. This requires an additional cognitive step for the driver to infer what behavior is permissible. This inference imposes an additional cognitive load as the driver searches the possible set of behaviors to eliminate those that are prohibited and evaluate if those that remain as possible actions are consistent with the intended goal of the driver. For example, the prohibitive sign for crossing or turning left requires that the driver recognizes that the remaining option to turn right is an option (see Figure 9.3). As a result of this additional cognitive load, the decision time for the driver to engage the intended action may be delayed. In particular, older drivers may find it more difficult to integrate to analyze and compare the prohibited actions indicated with the implied permitted actions because of reduced working memory capacity (Craik & Jennings, 1992; Staplin, et al, 1998b). Although a prohibitive framework is necessary to reduce liability for crashes after deployment (Donath & Shankowitz, 2001), the extra time required to interpret the prohibitive messages should be considered in the design process.

Figure 9.3. Prohibitive “do not turn left or cross” icon.

9.4.4.2. Omission Inference

When using a prohibitory frame to provide advice, it is clear what actions are prohibited while this information is presented. However, it is not clear what inference drivers make when this prohibiting display is removed. The concern is that the absence of information prohibiting certain actions will automatically imply that all actions are then permitted. We do not see this in the current evaluation (see Sign Comprehension in Results). Such inferences will depend on what information state occupies the display in the absence of the prohibitory information.

The Split-hybrid sign defaults to a “Caution” icon in the absence of prohibiting information. Thus, the driver is instructed to actively engage in a decision process to ascertain what actions are safe. When asked to describe what the “caution” icon meant when it appeared on the sign, there were five types of answers that drivers gave. The first type of answer involved drivers who explicitly mentioned being able to cross the intersection but indicated that they should proceed with caution (25%). The second answer category was for drivers who stated more simply “proceed with caution” or “go with caution” without explicitly mentioning crossing the intersection (20.8%). The assumption for this group is that they meant it was safe to enter the intersection but that they should do so cautiously. The third answer type was related to drivers who simply said “caution”, “be careful” or “pay attention” without reference to crossing or proceeding (33.6%) into the intersection. The fourth type of answer was for drivers who said “watch for traffic” without any mention of proceeding or entering the intersection (8.3%). Finally, two drivers (4.2%) said the “caution” icon meant “do not go” while another two (4.2%) did not know the answer. These results indicate that almost half of the drivers understood that the “caution” icon meant that it was safe to go, but that they should still take care in doing so. Therefore, the caution sign itself did not encourage drivers to simply state that it was safe to go, without further action on their part, and they understood the implied available action was to go but to exercise caution.

With the Icon sign, the prohibitive “slash” is removed when no traffic is detected within the safe gap, but the sign continues to display the path icons. The path icons represent which paths the system is monitoring and does not imply these paths are necessarily safe. As such, these path icons are not permissive indicators of safe advice. However, when drivers were asked to describe what the path indicator for the near set of lanes meant without the prohibitive slash present, 75% indicated that it meant it was safe to cross. None of these drivers mentioned “with caution” as was seen with the Split-hybrid sign. Only three drivers (6.3%) indicated that it would be safe to enter the intersection but also responded that traffic might be approaching. An additional 8.3% indicated that the absence of the prohibitive slash on the path indicator meant no traffic was coming. This suggests that drivers interpreted the removal of the prohibitive slash as meaning it was safe to go. Because of the potential for crash liability issues, the prohibitive slash should perhaps be replaced with a caution indicator rather than simply being removed to reveal a path indicator.

In this regard, when the prohibitive slash was removed but the yellow icon was lit, fewer drivers (41.7% versus 75%) said it was safe to cross without indicating that they should still take caution. Overall, 16.7% said it would be safe to cross, but they should do so cautiously because a car was coming and another 18.8% correctly indicated that the yellow icon meant traffic was approaching. This suggests that the addition of a "caution" symbol, similar to what appears on the Split-hybrid sign, might increase the number driver responses indicating it is all right to cross but that they should do so with caution.

9.4.5. Safe Gap Determination

The implementation in this preliminary study of IDS concepts used a safe gap threshold based on AASHTO's Green Book (2001) and the FHWA Older Driver Handbook (2001) for older drivers making a left-turn (see Safe Gap Threshold section in this document). From these guidelines, an omnibus threshold was set based on the static assumption for the worst-case scenario of an older driver completing a far side left turn in a one-state maneuver. This default threshold was necessary because the infrastructure IDS system conceptualized in this study was non-cooperative. That is, the infrastructure displays tested here were linked to a vehicle system that could provide information about driver characteristics and infer the context of the intended crossing maneuver to better moderate the safe gap threshold. As a result, the gap threshold that was applied was deemed to be too conservative for many crossing cases with drivers reporting that the IDS advisory information did not appear to be personally relevant. This apparent incongruence between self-adjudicated safe gap thresholds and the safe gap criteria applied by the system reduced the perceived relevance and utility of the displayed information. Since drivers may not have been able to conceptually separate the information content of the signs from the functional logic that was driving the information display, the evaluation of the sign display content may have been contaminated by the perceived irrelevance of the operating safe gap threshold.

This suggests that for an IDS system to be used by drivers and accepted as a valued traffic safety support system, it is necessary to operate with safe gap thresholds that are perceived to be personally relevant. This will require the development of algorithms based on driver and context parameters that significantly predict safe gaps, acceptable gaps, and the discrepancy between safe and acceptable gaps (safety margin). Such algorithms would dynamically compute individualized gap thresholds to support IDS systems that present credible information to support those drivers most at risk during crossing maneuvers. These systems will be dependent on the formulation and parameterization of functional algorithms as well as the incorporation of cooperative systems to communicate message sets (congruent with the algorithm parameters) between the infrastructure and vehicles to provide dynamic information for the algorithm computations.

9.4.5.1. Compliance

The IDS concepts evaluated in this study were advisory rather than regulatory. As such, compliance was not necessary from a legal perspective. Therefore, it was not expected that compliance would be demonstrated as a step function with 100% of accepted gaps being above the safe gap threshold. However, unless the displayed information resulted in a shift in driver decision-making, the signs cannot be considered useful. In this sense, it was expected that the provided information would shift the decision criteria of drivers from their habitual decision point. As shown in Figure 9.4, compliance can be discussed in terms of the position of (A) the mean accepted gap relative to the gap threshold or (B) the percentage of drivers accepting gaps larger than the threshold. This figure demonstrates the frequency distribution of gap sizes for a group of drivers (or a single driver on different occasions). Distributions are shown for the case of no IDS system (solid line) and with an IDS system (dashed line) with an operating threshold (multi-line arrow). Each distribution has a decision point represented by the mean accepted gap assuming a near-normal distribution. In the example shown in Figure 9.4, it can be seen that because of variability in accepted gaps, not all drivers complied with the IDS gap threshold, although there was (A) a shift in the decision point toward a larger mean gap with the IDS system and (B) an increase in the number of drivers accepting a gap larger than the IDS threshold.

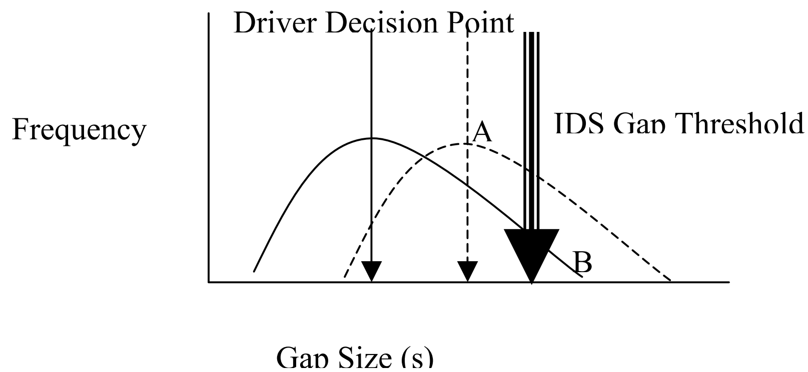


Figure 9.4. Depiction of shift in decision point for gap threshold compliance. A: Mean accepted gap of drivers. B: Safe Gap Threshold.

For example, for the Icon sign, older drivers in the night condition had (A) a mean accepted gap just below the safe gap threshold of 7.06 s and (B) 50% of drivers accepted gaps larger than the threshold. This is compared to baseline where (A) the mean accepted gap was (A) 5.28 and (B) 16.7% of drivers accepted gaps larger than the threshold. The 95th percentile results for the Icon sign are a lower confidence interval of 5.53 s and an upper confidence interval of 8.59 s. In comparison, the 95th percentile confidence interval for the baseline results for the older drivers at night are 3.99 s on the lower end and 6.57 s on the upper end. This interval does not include the safe gap threshold, whereas the interval for the Icon sign does. As well, both the Split-hybrid and VMS sign confidence intervals for the older drivers in the night include the safe gap threshold.

9.4.6. Comprehension, Education, and Training for Deployment

The cognitive task analysis (see Task Analysis – Chapter 2) for crossing behavior indicates that the range of information to support safe behaviors is complex. As a result, it may not be able to provide a simple and intuitive design to display this information to drivers. For example, a pilot study with a group of drivers that were given no information about the signs indicated that drivers were not able to understand the sign functions and ignored the displayed information. Indeed, in this study, not all drivers could comprehend the meaning of the sign information and function and comprehension was somewhat dependent on information content of the signs. For example, immediately after experiencing the Icon sign, 62.5% of older drivers and 83.3% of young drivers were able to adequately describe its function. In comparison, immediately after experiencing the VMS sign only 14.5% (1 older; 6 young) of all drivers were able to adequately describe the VMS sign's function. Even after explaining the full functionality of this sign to drivers, the overall comprehension rate for the VMS sign states was extremely low (39.26%), particularly in comparison to the high rate of comprehension for the Icon sign's states (88.15%).

Signs with more informational elements were also easier to comprehend (i.e., the Icon and Split-hazard sign) even though they were more often rated as confusing to use. It appears that ratings of confusion were tied more to the number of informational elements on each sign and the driver's initial perceptions upon seeing it rather than because the information itself was confusing. For example, drivers initially perceived the Icon sign to be confusing because it had many informational elements, but drivers were able to describe its function and showed much higher comprehension of its sign states compared with other signs that were rated less confusing.

This suggests that the initial perception of an IDS sign as confusing does not necessarily correlate to an inability to learn the sign's function and comprehend the information it provides. It more likely relates to the perceived clutter on the sign, particularly when viewed for the first time.

9.4.7. Older Drivers Perceived Need

Older drivers typically have the largest crash risk at intersections (Preusser, et al., 1998; Stamatiadis et al., 1991; Staplin & Lyles, 1991), and thru-STOP intersections pose significant problem for older drivers (Preston & Storm, 2003a; Preston & Rasmussen, 2002). This increased crash risk is evident in the day when older drivers do the majority of their driving (Hauer, 1988; Staplin & Lyles, 1991). However, older drivers often report difficulties with night driving, in part due to reductions in visual acuity and perceptual abilities (Rabbit & Holland, 1992). Deficits of visual perception potentially elevate the crash risk of older drivers at night (Scialfa et al., 2003; Staplin et al., 1998b). Like most drivers, the older drivers in this study rated their driving skill above average during daytime conditions (M=4.17, where 5 = very good driver) and did not report any problems with navigating intersection in the day. Consequently, the older drivers did not perceive a need for the IDS systems during the day and reported a low level of system use to support their crossing behaviors. Conversely, the restricted visibility conditions and increased driving effort was readily apparent to the older drivers at night. Before the study the older drivers in the night condition rated their driving skills high (M=4.42, where 5 = very good driver), but after completing the study, many of the drivers commented that they typically found night driving difficult or stressful. As a result, the older drivers recognized their own limitations and reported using the IDS interfaces as favorable support systems. This may suggest that (older) drivers may need to be educated about their limitations with respect to safe crossing behaviors in order that the function of the IDS systems can be appreciated as supporting their driving needs.

9.5. Future Research

- The current IDS concepts are limited to alerting and informing (advisory) functions. Future research should also consider the full spectrum of intervention philosophies such as Notification, Enforcement, and Automatic Control as shown in Figure 9.5. Some drivers may accept unsafe gaps because they are unaware that the accepted gaps are unsafe. In such cases, displaying information to the driver about the safety margin of the accepted gap after the crossing maneuver may increase driver awareness such that they "learn" by experience what a safe gap is. This is similar to publicly displaying speeds of speeding vehicles on roadside displays along with vehicle license plates. This approach has the additional benefit of "shaming" drivers into accepting more normative behaviors. For those drivers that deliberately take risks and accept unsafe gaps, some of the automatic enforcement (similar to red light running or speeding cameras) could be introduced. Finally, those drivers most at risk at intersection may benefit from automatic control systems. Such systems may retard the accelerator while the system detects an unsafe gap so that the driver is prevented from crossing (passive-control) or the vehicle may take full control to navigate the vehicle through the intersection once a safe gap is detected (active-control). Moreover, with the development of cooperative systems, it may also be possible to automatically adjust the approach speed of crossing traffic to generate greater opportunities for safe gaps (proactive-control).

Alert	Inform	Notice	Enforce	Control
System detects hazard.	*System detects hazard & presents information relevant to vehicle gap. Prohibited actions also indicated.*	*Driver receives feedback on safety of actual maneuver.*	*Driver automatically fined for unsafe maneuver.*	*System stops car if unsafe gap (passive-control); system guides car through intersection when safe (active-control); system controls mainline traffic to increase gap opportunity (proactive-control)*
Non-attentive driver.	Attentive, but needs support (e.g., cognitive impairment).	Attentive, but unaware of hazards associated (and own impairments) with unsafe gaps.	Attentive, but deliberate risk taking (accept short gap to make up lost time).	Removes human element, but assumes full system liability.

Figure 9.5. Full spectrum of intervention options.

- Develop MUTCD compliant variants of the IDS concepts for future deployment testing.
- Develop and test "do not enter" symbols for use with the Split-hybrid sign that do not conflict with other traffic signs in the same area with a different function.
- Investigate and test alternate ways for presenting time-to-arrival information to drivers.
- Continue to investigate how drivers interpret the disappearance of prohibitive information and the presence of cautionary information.
- Investigate how best to disseminate information about the function of the IDS signs to drivers and how best to educate users on the purpose of the sign to better encourage usage, particularly among older drivers who may not be aware of their increased crash risk at intersections.
- Parameterized models of safe gap and accepted gaps to provide dynamic threshold algorithms to adjust gap information.
- No data exists on the perception of gaps. Future research should have drivers estimate gap size directly (in terms of time and distance) and identify the factors that influence accuracy.
- Visual search data should evaluate how drivers cope with multiple gaps. If eye movements show that drivers fixate on vehicles that make up multiple gaps, this suggests multiple gaps are detected and perceived (and maybe even judged) simultaneously. However, if the analysis shows that drivers look at the vehicles closest to them, this implies that only the gap of immediate concern is processed by the driver. Visual search data could also show whether drivers perceive gaps or just fixate on the trailing vehicle. It

was not clear in this study if drivers were attempting to scan farther down the traffic stream for an acceptable gap rather than tracking one gap at a time.

- Future research should test drivers in more complex gap situations. Some of the factors that should be evaluated include multiple vehicles on different paths and when a driver is approaching an intersection as opposed to stopped.

- Information is needed on the decision making process for gap acceptance. It is unknown how drivers integrate multiple factors and whether all factors are considered when mental resources are limited. In other words, more studies should test gap acceptance when drivers are stressed, distracted, fatigued, rushed, etc. For example, night driving in the simulator was perceived to be significantly difficult by the older drivers and their gap acceptance behavior shifted towards the safe gap threshold when decision support was available.

- Some research showed that older drivers adopt a constant distance strategy that fails to take approach vehicle speed into consideration. This finding needs to be replicated in other studies.

- The relationship between arrival time and gap size needs to be tested. Most studies found that arrival time is underestimated but overestimation may occur with larger, more-variable times and greater speeds. There was some support for the idea that arrival time is not used in gap perception, rather gaps are perceived based on estimates of speed or distance.

- Some researchers have accounted for gender differences in gap acceptance by arguing that males accept smaller gaps because of greater risk taking. Measures of risk taking need to be correlated with gap acceptance behavior.

- More information is needed on the role intersection geometry and type has on gap acceptance. Gap acceptance may be qualitatively and quantitatively different for rural and urban intersections with different alignments and road configurations (i.e., left turn lanes).

- More research is needed to determine driver time requirements at intersections. Although basic research often finds age differences in PRT, some real world studies suggest no difference exists (Lerner et al., 1995). Data is also needed on age differences in maneuver time at real intersections and the role that other factors (i.e., slippery roads, longer vehicles, etc.) have on driver time requirements. Some field data collected at Minnesota intersections is recommended.

- Parameterized models to predict discrepancy between safe and accepted gaps (safety margins) to dynamically target IDS functions to at risk drivers and intersection situations.

- Real-time visual search data is needed to assess the visual demands of drivers as they approach and navigate intersections. By linking fixation points to objects in the environment in real-time, information can be obtained on what the driver looks at as they complete each task outlined in the task analysis.

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Appendix A
Psychological Functioning of Older Drivers

It is clear that older drivers (65+ years) are a population that requires special consideration for IDS system design. Drivers 65 and older have higher crash death rates per mile driven than all but teen drivers (Evans, 1991) and older adults are most susceptible to crashes at intersections and when turn decisions are required (Caird & Hancock, 2002; Preusser et al., 1998; Stamatiadis et al., 1991; Staplin & Lyles, 1991). In response to these observations, the literature on aging has identified a number of characteristics of older drivers relevant to intersection negotiation (Caird et al., 2002; Dewar, 2002; Hakamies-Blomqvist, 1996; Scialfa, Ho & Laberge, 2003; Stelmach & Nahom, 1992). The findings and conclusions of these literature reviews are summarized below. Some of this information is redundant with and supplements information in other sections of this report, including the sections on driver errors, visual search at intersections, gap detection, perception and acceptance, and driver time requirements. To help with interpretation, the results are discussed within the framework of the information processing model described earlier in this report and outlined below in Figure A-1.

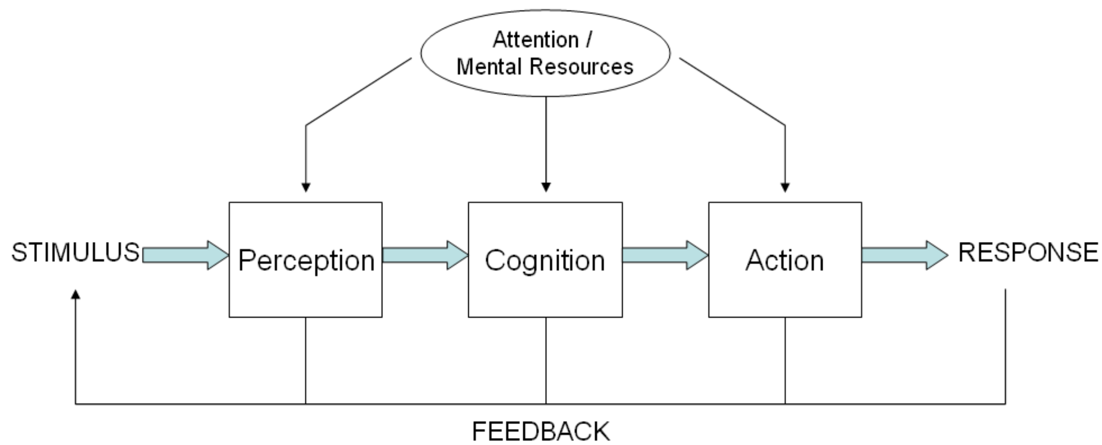

Figure A-1. A simplified three-stage information processing model (adapted from Wickens & Hollands, 2000).

Perception

One of the most salient visual changes due to age is a gradual reduction in the visual field. Scialfa et al. (2003) reviewed studies that found clinically measured visual fields are reduced from approximately 180 degrees to 140 degrees by age 70. Visual fields are important when negotiating thru-STOP intersections because vehicles on the IRC are detected in the periphery before a perception of gap size occurs. Therefore, older drivers approaching or stopped at an intersection may be slower to detect vehicles, pedestrians, and gaps in the periphery (Staplin et al., 1998b). This may account in part for the fact that many older drivers in accidents claim other vehicles "appeared out of nowhere" (Dewar, 2002). Some drivers compensate for their limited visual field by moving their head and eyes to scan the driving scene (Green, 2002; Staplin et al., 1998b). However, this ability may be limited in older adults who have a restricted range of motion in the neck (Isler, Parsonson & Hansson, 1997; Parsonson et al., 1996).

Another perceptual change that occurs with age is decreased spatial vision. Declines in static acuity are common in older adults (Klein, 1991) and are greatest for peripheral vision and under low-light conditions (Dewar, 2002; Scialfa et al., 2003). Dynamic acuity also suffers with age and refers to our ability to discriminate objects in motion relative to ourselves (Dewar, 2002). Contrast sensitivity also declines with age, especially at middle and high (> 15 cycles/degree) spatial frequencies (Staplin et al., 1998b). The consequences of reduced spatial vision are varied and in some cases severe. Reductions in acuity make it more difficult to detect traffic and may also contribute to difficulties older drivers have when reading traffic signs (Dewar, 2002; Staplin et al., 1998b). Age-related changes in dynamic acuity could account for older drivers' tendency to underestimate speed and overestimate the distance of other vehicles (Staplin et al., 1998b). Declining contrast sensitivity could delay the recognition of intersection features such as pavement/lane markings, island/median features and traffic signs and signals (Staplin et al., 1998b).

Older drivers also experience reduced light transmission, a finding that could account for why older drivers find signs and pedestrians difficult to detect at night (Dewar, 2002; Staplin et al., 1998b). There are two important ocular changes that contribute to this problem. Pupil size becomes smaller with age and the older lens becomes opaque and yellowed (Dewar, 2002; Scialfa et al., 2003). Diminished light transmission is particularly noticeable for short wavelength colors like blue.

Another perceptual problem that affects older drivers at intersections is reduced accommodation. Several studies have shown that the older adult lens loses its ability to change shape (i.e., accommodate) and bring objects into focus (Scialfa et al., 2003; Staplin et al., 1998b). As a result, image blur increases for near targets and requires many older drivers to wear multi-focal lenses. However, the optical corrections used by older adults reduce image blur only at distances of approximately 45 cm and optical infinity. Therefore, older drivers may have problems changing fixation from objects inside the car (i.e., speedometer, radio, etc.) to those located in the driving environment.

A perceptual change that has already been discussed in some detail is depth and motion perception. Difficulty with motion perception is related to problems with dynamic visual acuity, but also neurological changes due to age (Staplin et al., 1998b). The consequence of this problem is that older drivers have difficulty judging arrival time and TTC as well as approach vehicle speed and distance (Caird & Hancock, 2002; Scialfa, Kline, Lyman & Kosnik, 1987; Scialfa, Guzy, Leibowitz, Garvey & Tyrrell, 1991). These problems likely account for some of the difficulties older drivers experience with gap perception at intersections.

Negotiating intersections at night may also be challenging for older adults. Research has shown that older adults have problems with glare and this could exacerbate existing difficulties with spatial vision (Scialfa et al., 2003). Glare induced by light sources at intersections (other cars, lights, signals) could reduce older adults' ability to detect and perceive other vehicles and gaps (Staplin et al., 1998b).

Slower visual search is a perceptual change already discussed in an earlier section. To summarize, older drivers make more fixations and require more time to process information in a driving scene (e.g., Ho, Scialfa, Caird & Graw, 2001; McPhee, Ho, Dennis, Scialfa & Caird, in press). Older drivers also scan a limited area of the visual scene and may make more revisits to areas they deem important (Maltz & Shinar, 1999). This implies older drivers may take longer to detect vehicles, gaps, and the IDS display. This may also account for longer PRT for older drivers, and consequently the safe gap must increase.

The last perceptual change relevant to intersection negotiation is color vision. Color vision is important for detecting and perceiving traffic signs and signals. Staplin et al. (1998b) cite studies that found age-related reductions in scores on the Farnsworth-Munsell 100-hue test. This test measures color discrimination by requiring participants to arrange 85 closely adjacent color samples. Older adults experienced the greatest number of errors with colors in the blue-yellow spectrum. However, studies that evaluated the relationship between color vision and driving performance have found disappointing results. Consequently, color vision is a less important perceptual factor when negotiating intersections.

The perceptual problems older drivers experience can be accounted for by normal aging and disease. Research has found that older adults suffer from several optical disorders that affect driver perception. This includes glaucoma, cataracts, macular degeneration, and diabetic retinopathy. The consequences of these disorders include peripheral or central field loss, reduced acuity and contrast sensitivity, and problems with color vision (Klein, 1991; Staplin et al., 1998b). Unfortunately, there is no data on the number of older drivers suffering from each disease, although population estimates are available (Desai, Pratt, Lentzner & Robinson, 2001).

Cognition

In addition to perceptual difficulties, older drivers also experience cognitive changes that could affect their ability to negotiate an intersection. Converging evidence shows that memory suffers with age, including long-term memory, short-term memory, and working memory (Craik & Jennings, 1992). As a result, older drivers may have problems remembering route information, recalling expected behaviors in specific situations, recognizing and comprehending stimuli in the driving environment, and integrating information for subsequent action (Staplin et al., 1998b). An important consequence of reduced working memory is that older adults may have problems making decisions. Poor working memory may limit the amount of information and the speed that it is processed. As a result, older drivers require more time to make turn decisions and often fail to fully assimilate and consider all the available information. Staplin and Fisk (1991) showed that when given unlimited time, older adults required longer decision making times in turn situations. Caird et al. (2002) found that older drivers were less accurate when making right-of-way decisions at intersections. More specifically, older drivers fixated more on traffic-control devices and signs while excluding other sources of information such as vehicles and pedestrians. Therefore, although gap-acceptance studies showed that older adults accept larger gaps, it may take them longer to make a decision and when rushed, they may not consider all the relevant factors. These two hypotheses should be more thoroughly explored in future research.

Action

Processes involved in the action stage include those needed to select, plan, and execute motor responses. Stelmach and Nahom (1992) reviewed the literature on age-differences in motor time, movement time, movement coordination, sensory-motor integration, and joint flexibility. They showed that older adults were slower to initiate and execute movements and they executed movements with less precision. More specifically, they compared studies evaluating age differences in motor time and movement time. Motor time is the component of PRT that occurs when activity appears on an electromygraph (EMG) and ends with the beginning of the movement. Movement time is the time interval between when a movement is initiated until it is completed. Their review showed that motor time increased with age, but the difference between young and old may be only a matter of 10 ms.

Studies of movement time suggested movements were executed more slowly in the elderly. Table A-1 shows the results of some studies that measured motor and movement time in basic laboratory tasks. It can be seen that typical age-differences in motor time are around 15% whereas age differences in movement time are in the 20% to 30% range.

The review by Stelmach and Nahom (1992) also focused on three phases of limb movement: acceleration, steady speed, and deceleration. The studies they analyzed showed that older adults accelerated more slowly and had a longer deceleration phase. A more recent review by Scialfa et al. (2003) showed that the forces used to move the limbs are more jumpy, peak velocity is much lower, and more secondary corrective movements are made by the elderly. The available data also showed that older adults suffer from reduced joint flexibility and range of motion. These findings suggest older adults have problems coordinating multiple movements (Staplin et al., 1998b) and older drivers will be slower to complete maneuvers at intersections (Darzentas, McDowell & Cooper, 1980b; Parsonson et al., 1996). Then again, slower vehicle acceleration may also account for slower maneuver times (Hakamies-Blomqvist, 1996).

Table A-1. Age differences in motor and movement time (adapted from Stelmach & Nahom, 1992).

Study	**Measure**	**Young***	**Old**
Clarkson (1978)	Movement time	124-130 ms	164-170 ms
Larish & Stelmach (1982)	Movement time	185-193 ms	215-230 ms
Clarkson (1978)	Motor time	87-96 ms	98-112 ms
Weiss (1965)	Motor time	65 ms	75 ms

*Different experimental conditions contributed to the range of values reported. Interested readers are encouraged to refer to the original source for more information.

Attention

Older drivers also have problems dividing attention and attending to only one source of information in the presence of competing stimuli (Dewar, 2000; Hakamies-Blomqvist, 1996;

McDowd & Shaw, 2000). Attention is an important process because negotiating an intersection requires the division of attention between central and peripheral vision (Staplin et al., 1998b). Negotiating an intersection also requires selective attention so drivers can filter irrelevant information. The consequence of poor attention is that older drivers will be slower and less efficient at dividing attention between driving tasks and ignoring irrelevant information (Staplin et al., 1998b). Older drivers may also have problems sustaining attention in anticipation of hazards. Therefore, older drivers may fail to detect or will be slower to respond to important objects in the driving environment.

One measure often used to assess attention abilities in applied contexts is the useful field of view (UFOV). The UFOV is the area around an eye fixation from which information can be extracted (Wickens & Hollands, 2000). Measures of the UFOV are usually composed of three subtests: visual processing speed, divided attention, and selective attention. Several studies have shown that the UFOV is reduced in older adults (see Staplin et al., 1998b). However, research relating the UFOV to driver performance and accident risk is mixed (see Caird et al., 2002). Ball and Owsley (1991) found that the UFOV in combination with a measure of cognitive performance predicted 29% of the variance in older drivers' prior five-year accident rates at intersections. In contrast, Brown et al. (as cited in Caird et al., 2002) found that the correlation between UFOV scores and accident frequency was low ($r = 0.05$).

There are several problems with studies of the UFOV and accident frequency (Ball & Owsley, 1991). First, an accident is a rare occurrence and therefore it is difficult to find reliable predictors of such an unlikely event. Second, accidents have multiple causes, some of which are independent of the driver. Therefore, it is unlikely that a single predictor (or even a subset of predictors) will account for a large portion of the variance in accident frequency. Lastly, both self-report and driving record measures of accident frequency are fraught with problems. Self-report measures are problematic because they are subject to memory problems and biases and drivers may be reticent to report accidents. Driving records also have problems, including difficulty accessing records, relying on drivers to report accidents to authorities, and questionable accuracy of information. Therefore, although in theory the UFOV may have implications for safe driving, the relationship between it and accident likelihood is questionable.

Dementia

Dementia is a disorder characterized by memory impairment, impaired judgment and abstract thinking, problems interpreting visual, auditory, and tactile information, and personality changes like impulsivity (Parasuraman & Nestor, 1991; Staplin et al., 1998b). One of the most common forms of dementia is that associated with Alzheimer's Disease. Dementia of the Alzheimer's type (DAT) affects an estimated 12% of persons 65 years and older and as much as 48% of those over 85 years of age (Staplin et al., 1998b).

A review of dementia and driving showed that demented drivers were at an increased risk of crashes, especially as their condition worsened (Staplin et al., 1998b). Cooper et al. (as cited in Staplin et al., 1998b) compared the driving records of 165 older drivers with dementia to determine whether the disorder resulted in higher crash rates compared to an age and sex matched control group. Results showed the demented drivers were involved in 86 crashes or 2.5 times that of the control group. Demented drivers were less likely to have their crashes at intersections (53% vs. 87%), but intersection crashes were more likely to involve turning maneuvers (42% vs. 23%). Demented drivers were also more likely to be at fault compared to the control group (92% vs. 67%). The contributing factors for demented drivers included improper turning or passing, following too close, unsafe backing, and inattention. More than 80% of the demented drivers continued to drive after the crash and more than one-third had at least one more crash during a three-year period. Unfortunately, no data exists on the number of drivers suffering from dementia and the reason dementia affects accident risk is still unknown. Future research should focus on understanding how the symptoms of the disorder correlate with driving performance and accident risk.

Implications

Table A-2 summarizes the important age-related changes identified in the literature and discusses possible implications for the IDS system. Those in italics have the greatest implications for the design and effectiveness of the IDS system.

Section Summary

Several age-related changes in perception, cognition, attention, and action affect older drivers at intersections. The age-related changes discussed include:

- Reduced visual fields
- Decreases in spatial vision
- Reduced light transmission
- Problems with accommodation
- Difficulties with motion in depth
- Glare sensitivity
- Slower visual search
- Problems with color vision
- Poorer memory
- Slower and less accurate decision making
- Slower motor and movement times
- Less coordinated movements
- Difficulties with divided attention
- Problems with selective attention

These changes are responsible to some extent for the errors older drivers make at intersections. For example, problems with motion perception can account for some of the difficulties older drivers have perceiving gaps. Reduced visual fields and difficulties with divided attention can explain why older drivers fail to detect vehicles and pedestrians outside central vision.

Mental disorders like dementia can also contribute to older driver problems, but much research needs to be done. Little is known about the proportion of drivers suffering from dementia and information is scarce regarding the exact relationship between symptoms and performance or crash risk. Lastly, although much research has focused on the UFOV as an important measure for screening drivers, mixed results were found between scores on tests of the UFOV and accident frequency.

Table A-2. Age-related changes relevant to rural intersection negotiation and possible implications for the IDS system (continued on next page).

Age-related Change	**Summary of Research Finding(s)**	**Possible Implication(s)**
Reduced visual fields	- Visual fields shrink from 180 deg to 140 deg by age 70 - Older drivers may not be able to compensate by moving their heads	- Older drivers may not detect vehicles and gaps - Older drivers may not detect the IDS display - Signage may be needed
Decrease in spatial vision	- Static and dynamic acuity decline with age are greater for peripheral vision - Contrast sensitivity is lowest at middle and especially high (> 15 cycles/deg) frequencies	- Older drivers will have problems seeing fine detail in the display
Reduced light transmission	- Due to smaller pupil sizes and a yellowing of the lens, less light reaches the older eye - This is particularly noticeable for short wavelength colors like blue	- The IDS display should avoid using any colors in the blue-green spectrum - Older drivers will have problems seeing at night
Problems with accommodation	- The older adult lens loses its ability to change shape (i.e., accommodate) and bring objects into focus	- The IDS display should be located at a distance that allows drivers to rely on the far correction of their multi-focal lenses
Difficulties with motion in depth	- Older adults have problems perceiving motion and movement in depth	- Older drivers may have problems estimating speed, distance, and arrival time leading to a faulty perception of gap size
Glare sensitivity	- Older adults are more sensitive to glare and this could reduce older adults' ability to detect and perceive other vehicles and hazards at night	- The IDS display should not be so bright as to induce glare at night
Slower visual	- Older drivers make more fixations	- Older drivers may take longer to

search	and require more time to process information in a driving scene - Older drivers scan a limited area of the visual scene and may make more revisits to areas they deem important	detect vehicles, gaps, and the display - This may account for larger safe gaps - The IDS display must be located in an area of the visual scene where older drivers scan

Table A-2. Age-related changes relevant to rural intersection negotiation and possible implications for the IDS system (continued from previous page).

Age-related Change	**Summary of Research Finding(s)**	**Possible Implication(s)**
Problems with color vision	- Color vision worsens, especially for blue-yellow spectrum	- Limit use of color for IDS display - Avoid blue-green-yellow range
Poorer memory and decision making	- Memory suffers with age, including long-term memory, short-term memory, and working memory	- Older drivers may take longer to interpret the display and make turn decisions - Older drivers may not consider all factors when accepting gaps due to limitations of working memory
Slower motor and movement times	- Motor time and movement time both increase with age	- Older drivers may take longer to initiate and complete complex maneuvers
Less coordinated movements	- Restricted range of motion, more secondary movements, forces are jumpy, and reduced joint flexibility	- Older driver maneuvers will be more erratic and less smooth - This may confuse other drivers
Difficulties with attention	- Older adults suffer a reduction in divided attention abilities - Older adults are less able to attend to a single source of information in the presence of competing stimuli - Older adults suffer from a smaller UFOV	- Older drivers may be less able to divide attention between the IDS display an the rest of the driving environment - Older drivers will be slower to detect other vehicles and gaps and a larger safe gap is needed to compensate

Numerous traditional and ITS concepts have been suggested and tested as IDS systems to aid driver decision making at intersections. Many of these systems were successful at improving road safety and should be considered when proposing new IDS solutions. In fact, any new IDS development should capitalize on the hard work, careful planning, successes, lessons learned, and study designs of earlier research efforts. This will ensure the Minnesota IDS project is based on previous research and industry experience, which will hopefully lead to a better research design and a more feasible and effective solution.

The studies reviewed below have been organized into five categories of infrastructure-based solutions: implemented IDS, simulator-tested, potential IDS, run-the-signal, and other crash-avoidance solutions. An additional section on in-vehicle countermeasures is included to explore some relevant examples of these related systems.

Implemented IDS Solutions

The IDS systems below were implemented at potentially dangerous intersections. Various methods of performance evaluation were used to ascertain their effectiveness.

Collision Countermeasure System

The main goal of the Collision Countermeasure System (CCS) project was to reduce side-impact crashes at limited sight-distance intersections by enhancing major- and minor-road driver awareness of other vehicles that were either approaching or entering the intersection (Hanscom, 2001). The CCS study looked to accomplish this goal on a low-volume, high-crash-risk intersection where installing a conventional traffic signal was deemed inappropriate. The specific focus of the CCS project was to provide major-road drivers with an appropriate amount of advanced warning regarding the presence of minor-road vehicles. The system was also intended to give forewarning to vehicles on the minor approach where sight distances were limited by buildings.

An intersection on a rural roadway of Prince William County, VA, was the testing ground for the CCS. The intersection met through traffic on the two-lane Arden Road (major road) with STOP-controlled traffic on the two-lane Fleetwood Drive (minor road). This intersection was chosen due to limited sight distances and a history of crashes.

System Description

The CCS used vehicle-detection loops and a traffic signal controller to activate illuminated graphic signs on both the major and minor roads. Figure B-1 shows the intersection and diagrams how the system elements were configured on the roadways.

In-pavement inductance loops detected the presence of vehicles traveling toward the intersection in all four directions and the speed of vehicles on the major approach. Vehicles on the major approach crossed three detectors: an “advance” detector farther out from the intersection (at 950 ft.), another at an “intermediate” distance (410 ft. westbound, 350 ft. eastbound), and a third at the intersection. Vehicles on the minor approach encountered two detectors: one at 215 feet from the intersection and another at the intersection itself.

Appendix B
Review of Infrastructure-Based Solutions

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The controller used the information from the detectors to determine speed, distance to the intersection, and projected time-to-collision (PTC). These measures were also used to build a valid vehicle array model from recorded flow criteria in order to accurately predict the timing of cars driving through and crossing the intersection. This allowed the system to warn the drivers only when threats were present to either major- or minor-road vehicles. Signals indicating a vehicle traveling in the wrong direction or those that were unconfirmed (not activating the succeeding detector) were not analyzed by the controller.

Drivers on the major road were given two active warning signs. These consisted of the standard intersection ahead sign (a "+" on a yellow diamond-shaped sign) modified to flash an illuminated image of a car on the intersection approach corresponding to traffic waiting to cross the intersection (see Active Sign Type 1 in Figure B-1). Below this, a TRAFFIC AHEAD illuminated-text warning would light when the sign was active.

Drivers on the minor approach were shown a sign in front of them on the opposite side of the major road from where they were stopped. A constant text warning of Crossing Traffic (see Active Sign Type 2 in Figure B-1) was shown and two black lanes below showed animated illuminated vehicles corresponding to approaching traffic on the major road.

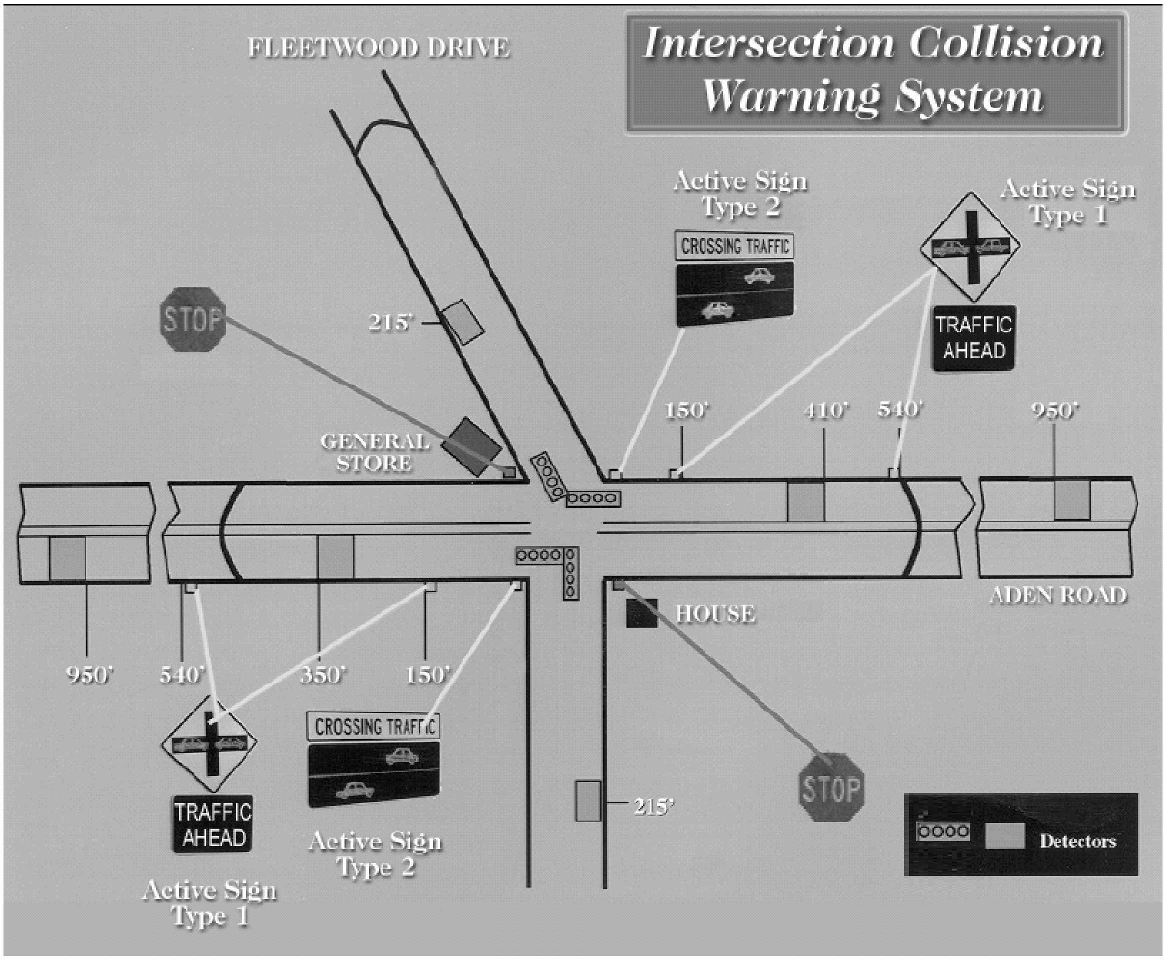


Figure B-1. Diagram of the intersection and location of CCS elements used in testing the system.

Methods

The field study consisted of four phases: before (immediately before installation), acclimation (immediately after installation), 4-months-after installation, and 1-year-after installation. The analysis focused on times when two vehicles were in sufficiently close time proximity to each other on conflicting roads (i.e. at least one on the major and another on the minor). Therefore, all findings below relate to when the system was active.

In addition, the analysis was limited to throughput traffic (e.g. cases in which cars turned were eliminated) during dry pavement conditions. All four conditions comprised a 48-day data sample of approximately 109,000 vehicles, though the specific breakdown of the number of vehicles per condition was not given.

The CCS evaluation consisted of accident-potential measures derived from the in-pavement inductance loops. These measures of effectiveness (MOEs) were selected based on the driver behaviors the CCS intended to affect. The MOE set included:

- *Sign response speed*: major-road vehicle's speed after passing the first sign and in clear view of the second sign (at intermediate detector).
- *Intersection arrival speed*: major-road vehicle's speed as it reached the intersection (at intersection detector).
- *First speed reduction*: major-road vehicle's speed difference between advance and intermediate detectors.
- *Second speed reduction*: major-road vehicle's speed difference between intermediate and intersection detectors.
- *Overall speed reduction*: major-road vehicle's speed difference between advance and intersection detectors.
- *Projected time-to-collision (PTC)*: theoretically elapsed time to which an approaching major-road vehicle would collide with a minor-road vehicle in the absence of a timely avoidance response. The major-road vehicle's speed and distance from the intersection were measured when a minor-road vehicle was simultaneously detected at the intersection. Each direction was separately analyzed due to differing sight distances between the east and west approaches.

The PTC measure was previously validated during the course of an FHWA study (Hanscom, 1981). This research showed that a minimum advance warning of 3 s would be necessary to perform an avoidance-maneuver or 4.6 s would be necessary to perform a full stop at this particular intersection. Therefore, these limits were used as guidelines for determining when the PTC values were within safe limits.

Familiarization was examined by comparing speeds of drivers before activation of the system and 1-year-after installation. Cost-effectiveness associated with observed accident reduction from before to after installation was also examined. The intersection was also videotaped prior to CCS installation in order to discern driver behavior before being assisted by the system.

Results

Overall, intersection approach speeds were lower in the acclimation and 4-months-after phases. The other MOE effects and some Target Vehicle Speed effects were mislabeled and unclear in the description. The author was also unresponsive to questions and consequently the results should be interpreted with caution.

PTC effects were analyzed specifically for the subsample of drivers with the shortest PTCs (shortest 10%) since they represented the greatest crash risk of all sampled drivers. These drivers significantly raised their average PTC from 2.5 to 3.5 s. They also reduced their average speed from 80 to 76 km/h (49 to 46 mph) when their performance was compared in the before condition to the 1-year-after installation.

Though there was a sizeable novelty effect during the acclimation period, the risk of side-impact accidents, as evidenced by smaller PTCs, stabilized over time (from before, to acclimation, to 4-

months-after, to 1-year-after periods). There were also smaller numbers and proportions of high-speed vehicles. In an analysis of drivers exceeding the 72 km/h (45 mph) speed limit one year after installation, there was a significant drop in the proportion of vehicles driving over the limit. There was also a significant reduction in the proportion of vehicles with PTCs less than 4.6 and 3.0 s. Overall, the PTC results showed that the CCS encouraged drivers to exhibit safer driving performance at the intersection where the system was installed.

Familiarization from the before to 1-year-after periods did not prove to significantly affect drivers' average, variation, 85th, or 95th percentile speeds for either major- road traffic direction. Additionally, though the intersection where the CCS functioned was prone to crashes, there were no incidents during the 2.25-year period of its operation. For this reason, the average benefit far exceeded the cost of installing and maintaining the system. However, there was one minor side-impact (incurring only property damage) during a time period when the CCS was not functioning. This may raise some concerns regarding a possible dependency on the system and may warrant a "failure mode" of operation.

It is worth pointing out that the researchers who designed and evaluated this system did not mind if the major-road traffic slowed down. In fact, the primary goal of the CCS system was to affect the speed and time-to-collision of major-road drivers. Thus, although the measures used focused on different goals than what the Minnesota IDS system intends to analyze, they may offer some suggestions about what to measure when evaluating the Minnesota IDS system in the HumanFIRST Virtual Environment for Surface Transportation Research (VESTR) and in the field.

Critique

The original intent of the CCS was to aid major-road drivers in noticing crossing minor-road traffic. This is counter to the Minnesota goal of aiding minor-road drivers in making better gap-acceptance decisions. However, the CCS design incorporated a means to convey warnings to minor-road drivers that not only told them the direction of approaching major-road traffic, but also the speed of those vehicles. This information has the potential to help minor-road drivers detect and perceive major-road vehicles, but may not directly support gap-acceptance decisions (see Laberge et al., 2003).

There was also poor experimental control in the sense that the intersection was only compared to itself at different times. Furthermore, the 1-year-after experimental time period was done after the road was repaved, making the comparison between this time and the other recorded periods somewhat tenuous. Comparing results to data from neighboring and/or similar intersections would have been more telling of the safety benefits from this system (Datta, 2004).

Intersection Collision Avoidance Warning System

Many STOP-controlled intersections in Maine contain severe sight distance limitations that make it impossible to meet AASHTO standards or MUTCD requirements for signalization. This project (Peabody et al., 2001) was a pilot study to develop and evaluate a dynamic, traffic-actuated warning system that warns minor-road drivers of approaching major-road vehicles. The objective of the project was to build a system that could be deployed at STOP-controlled locations exhibiting severe sight distance limitations where signal installation and realignment were not reasonable solutions.

The researchers piloted the intersection collision avoidance warning system (ICAWS) on a rural intersection along Route 201A in Norridgewock, ME, in February of 2001 (see Figure B-2). One of the reasons this site was selected was due to the fact that a multi-arch concrete bridge with large structural concrete columns and railings limited sight distance in one direction of the STOP-controlled intersection (see second image in Figure B-3).

Figure B-2. Aerial photograph of the Rt. 201A intersection in Norridgewock, ME, and locations of new warning signs.

System Description

The system was designed to be deployed at any site where sight distances were limited. The ICAWS prototype detected vehicles and warned all approaches to an intersection, but some components or features (e.g., warnings to the major road, warning one of the minor roads) could be eliminated if the situation was warranted.

The project focused on the STOP-controlled traffic on the minor road and was intended to inform these drivers of approaching major-road vehicles. The project was designed to be intuitive and easy to understand without previous knowledge. The researchers also emphasized the cost-effective nature of the system since it was shown to be a lower cost alternative to a typical traffic signal installation. A secondary focus was to notify stopped drivers that the system was operational.

An existing warning sign on the major road was retained during the evaluation. It read Traffic Entering When Flashing and flashed two yellow lights on both sides when a car was waiting at the STOP sign on the minor road or was traversing the intersection (Figure B-3). In essence, this is similar to the warnings of the CCS, but was non-directional in nature and was only visible to northbound traffic.

Figure B-3. The existing major road warning sign that warns vehicles approaching the intersection.

The ICAWS warnings for the minor-road traffic consisted of two signs: a yellow diamond sign that read Vehicles Approaching and a rectangular yellow sign depicting two cars that could be illuminated (Figure B-4). Underneath each car read From Left or From Right.

Figure B-4. ICAWS warning signs.

Loop detectors activated the warning signs after a vehicle stopped at the STOP sign and both vehicle icons were illuminated for 2 s to indicate the system was operational. If a loop detector, amplifier, or overhead detector failure occurred, the vehicle icons flashed continuously in an alternating fashion. If there was a power outage, the vehicle icon areas remained unlit.

When a vehicle crossed a major-road loop detector from either direction, the appropriate icon(s) started flashing for approximately 9 s; subsequent vehicles restarted this countdown timer. The detectors were placed at locations based on the 85th percentile vehicle speeds (i.e., 45 mph) and their associated stopping sight distances. The 9 s warning period was based on the arrival time required for a vehicle traveling at the speed limit (i.e., 25 mph).

Methods

The Traffic Conflict Technique (TCT) was used to estimate changes in crash rates using the FHWA recommend methodology. The Swedish Technique was also used, which is similar to TCT, only it adds a time-to-collision parameter. Both are observational techniques whereby observations of traffic moving through the intersection are made and a recording of the number of times in which a traffic conflict arises is counted. Traffic conflicts consisted of situations where evasive action was taken to avoid a collision between two or more vehicles. The number of traffic conflicts and the number of collisions were both used to predict crash potential. Observation sessions were on weekdays and lasted 9 hr.

For this evaluation, the main measures used were stop behavior on the minor road, vehicle speeds on the major approach, and crash history. In addition, a vehicle intercept survey (given at the minor approach) was conducted to assess driver perceptions and attitudes toward the IDS system. Pre- and post-installation spot-traffic counts and traffic movement studies were also completed.

Results

The findings suggested that most drivers arriving at the STOP sign from both minor approaches made a full stop before and after installation. About half of the drivers waited for the ICAWS display to turn off before entering the intersection. The other half proceeded after traffic had passed, though the display remained illuminated for the remainder of the 9 s warning period. This finding highlights an important issue that is characteristic of many IDS systems (including some of our own). The issue is that if there is a line of vehicles and the minor-road driver enters the intersection only after the first car has passed, a crash could result with later vehicles down the line. This problem is more clearly explained in the Gap Specific Design Issues (Chapter 4) of this report.

The ICAWS display also seemed to activate too early, especially if the major-road vehicle was traveling closer to the speed limit (25 mph) as opposed to the faster speeds the system was designed for (85th percentile speed of 45 mph). In addition, since the system did not take into account actual arrival time, there were many instances where minor-road drivers waited for the sign to turn off rather than proceed immediately after the major-road vehicle passed. This caused an unnecessary and inefficient queue to build up on the minor roads, though it was not a safety hazard.

Both before and after installation, vehicles on the major road did not significantly reduce their speeds upon seeing the existing warning sign (Figure B-3). Also, only 3% of all vehicles drove within the 25 mph speed limit. Most traveled an average of 42.4 mph (34 mph for heavy trucks), due partially to the fact that the intersection was located at the bottom of a hill. In general, there was no indication that activating the ICAWS display on the minor road affected speed on the major road.

The system also seemed to produce a significant reduction in conflict potential. A 35% reduction in conflict was found using the TCT and a 40% reduction was observed for the Swedish Method. The Critical Gap (here defined as the gap accepted and rejected by equal numbers of drivers) also increased from 5.7 s before to 8.5 s after installation. Specific crash data was not available at the time of the report, but the authors indicated that the data would be used to study long-term effects on crash risk.

Though the full results of the subjective data had not been completed at the time of the report, 59% rated the system good or very good and 64% recommended the ICAWS display for other intersections. However, 25% of respondents expressed concerns with increased traffic delays, system timing, and the potential for drivers to rely too heavily on the display.

Critique

The focus of this project was to warn minor-road drivers, though like the CCS, the system focused on the presence of major-road vehicles as opposed to the size and location of safe gaps. The ICAWS system did incorporate a feature that indicated to drivers when it was active. However, the design of the feature was flawed in that it blinked for 2 s then went off; a state that was similar to when the system was inactive, when there was a power failure, and when the system was active but free of main-road traffic. This may have confused some drivers and a more reliable and definite notification of the system state is recommended for future IDS systems.

Though the ICAWS warning was based on the 85th percentile speed, the warnings were based on a constant arrival time (i.e., the icons flashed for approximately 9 s) rather than actual arrival time. This was clearly a disadvantage as a large queue often developed and as many as 50% of minor-road drivers waited for the ICAWS warning to deactivate even though the major-road vehicle had passed and a safe gap was present. A more dynamic and accurate way to measure and display arrival time information is recommended for the Minnesota IDS system.

This study used the TCT and Swedish observational techniques to estimate changes in conflict potential. This has an advantage in that it does not have to wait years for crash data to validate the effect of the ICAWS system on safety. The technique is also helpful because it allows for an evaluation of changes in the size of the critical gap. However, since both methods are inherently subjective (i.e., what constitutes a conflict), the results should be supplemented with long-term crash data as well as short-term objective measures like changes in speed.

Limited Sight Distance Warning Signs

A number of safety concerns were raised on many of the formerly low-volume roads in Gwinnett County, GA. This was due primarily to limited sight distances resulting from the predominantly winding and rolling nature of the roadway as well as increases in traffic volumes. Bretherton and Miao (1999) developed and tested a system that could reduce crash risk when other infrastructure solutions were not feasible. The system was intended to work only for passenger vehicles on level, one- or two-way, STOP-controlled intersections on two-lane roads. However, the authors noted that the system could be modified to take other scenarios into account.

At the time this study was conducted, there were no formal guidelines for installing warning signs at Georgia intersections with limited sight distances. Since this study was conducted and based largely on the results from this evaluation, several guidelines were developed for the placement of warning devices at intersections with limited sight distances.

System Description

A VEHICLE ENTERING HIGHWAY (VEH) warning sign and beacon were used to warn approaching drivers on the major road (Figure B-5a.). Both the sign and beacon were placed on the major road at the AASHTO (1994) minimum required sight distance for the intersection. The sign was activated when a minor-road vehicle stopped at the intersection. Upon activation, two yellow lights above and below the sign flashed. Once the minor-road vehicle left the intersection, the lights went off.

The VEHICLE APPROACHING (VA) warning sign and beacons were used to warn drivers on the minor road (Figure B-5b). It was placed directly in front of the minor-road approach to the intersection and was actuated (via a loop detector) by a major-road vehicle approaching the intersection. An upper red beacon was always on to signify that the display was operational. A lower red beacon flashed until an approaching major-road vehicle triggered the loop detector, then the beacon stopped flashing and remained on. A warning sign was placed between the beacons indicating the direction from which the major-road vehicles were coming. For liability interests, an additional sign was placed below the lower beacon and read IF NO LIGHTS SIGNAL NOT WORKING.

a. 

b. 

Figure B-5. Limited sight distance warnings including the (a) Vehicle Entering Highway and (b) Vehicle Approaching signs with beacons.

Methods

Based on the AASHTO (1994) minimum sight distance requirements for each intersection, the system was installed at 18 Gwinnett County locations. Intersections were also considered if they met two conditions: (1) at least 75 vehicles passed through per day and three or more potentially preventable crashes occurred within the period of 1 year or (2) one or more such crashes occurred in a year for three consecutive years.

Two intersections met the sight distance criteria and had a significant number of preventable accidents. As a result, both the VEH and VA signs were placed at one intersection and a VA sign was placed at the other. A VEH sign was also placed at the 16 remaining Gwinnett County intersections that received complaints about sight distance problems, though they did not meet the crash or traffic volume criteria.

The main measure used in the project was a reduction in the number of crashes. The number of crashes three years prior to installation was compared to the number three years post installation.

Results

Some of the 16 intersections where the VEH was installed were selected for subjective reasons and did not experience any crashes before or after the system was implemented. Therefore, the effectiveness of the VEH warning sign on reducing crashes could not be decided just from crash numbers. However, Lyles (1980) found in an earlier study that lighted VEHICLES ENTERING WHEN FLASHING message signs reduced speed and increased sign recall when activated.

The one intersection that met the crash and volume criteria and only used the VA sign showed a significant safety benefit, going from seven preventable crashes to one preventable crash. The intersection that used both the VEH and VA signs reported no crashes before or after installation. Therefore, it was difficult to assess the effectiveness of both the VEH and VA systems in combination.

In summary, the crash data from this evaluation showed that the VA sign may be an effective solution. An earlier study also found the VEH sign may be a suitable option for reducing major-road speeds (Lyles, 1980). The author speculated that the VA sign may be a more promising countermeasure since minor-road drivers must stop before proceeding and could spend more time processing the information presented in the display. In contrast, the VEH system was thought to potentially be less effective since major-road drivers generally pass the sign very quickly and may not notice it or have time to process the information completely. This idea supports the Minnesota plan to target the gap acceptance of minor-road drivers rather than deliberately alter major-road speed or awareness of crossing minor-road traffic.

It should be noted that the author considered the VA and VEH systems interim solutions until realignment or other solutions could be implemented. When this occurs, the VA and VEH signs may or may not be removed.

Critique

This system illustrated that when simple solutions (like signs and flashing lights) are implemented to address complex driving situations like intersection negotiation, significant explanation is often needed to communicate how the system works. For instance, although the VA and VEH systems only notified drivers if a vehicle was either stopped (VEH) or approaching (VA), each display required two signs apiece. Therefore, the system may not be considered intuitive and further emphasizes the need to design systems based on a systematic analysis of the problem and consideration of driver information processing limitations. This observation is also in line with an issue raised by Preston and Storm (2003a) in their analysis of Minnesota crash reports at thru-STOP intersections. They made it clear that any new countermeasure would likely require some explanation or formal education/training.

The VA and VEH systems did inform both major- and minor-road drivers about the presence of other vehicles, but neither warning conveyed information about speed, distance, time-to-arrival, or number of approaching vehicles. To fully support intersection negotiation tasks like gap acceptance, an IDS solution needs to inform drivers about more than just the presence of other vehicles (see Laberge et al., 2003).

There was another problem with this system, namely the steady light notification. The top light was always steady and the bottom light became steady (from a flashing state) when a major-road vehicle approached. The sign stated that a VEHICLE IS APPROACHING ON STEADY RED, even when a vehicle was not approaching. It was also not apparent which red light was being referred to in the sign, since the top light was always in a steady red state.

The methodology for this study was compelling in that it took crash data from each intersection three years before the installation date and compared it to data from three years after the installation date. However, there were some limitations to the design in that data for the entire before period was not available for certain intersections. Also, some intersections were selected for more subjective reasons (i.e. people complained about the safety there) and did not have any crashes before or after installation. Therefore, the full impact of both the VA and VEH systems alone and in combination was difficult to assess. A more complete set of measures, including increases in critical gap sizes, changes in speed, and perceived usefulness or usability of the system would have made for a more compelling evaluation.

Simulator-Tested Solutions

The IDS systems below were implemented and driver-tested in driving simulators with the intent of finding potential benefits or pitfalls before real-world installation. It should be noted that since these concepts were tested in a simulator, it is uncertain exactly how well the findings generalize to real-world intersection situations. For instance, the specific geometry of an intersection, functionality, and display characteristics of the countermeasures may be drastically different in real-world settings; and therefore, drivers' reactions may also differ greatly. Based on this, it is important that our simulator experiment replicate the candidate intersection in as much detail as possible and ensure the IDS systems are simulated with the same functionality and display characteristics as are anticipated in the field tests.

Junction Accident Warning Systems

The purpose of this study was to develop an environment in which to study driver behavior and system performance of two Junction Accident Warning Systems (JAWS). The first system was an infrastructure based IDS solution and the second was an in-vehicle telematics system (Carsten & Tate, 1999). Both JAWS were meant to inform drivers intending to traverse from a minor ("give way") approach at an urban "T" or "+" crossroads intersection.

This study used the Leeds Advanced Driving Simulator (LADS) at the University of Leeds in the UK (left sided traffic). The simulator was a fixed-base simulator with a 120^{o} front field of view and the car was equipped with a manual gearbox.

System Description

The two JAWS systems were meant to represent two ends of the technology spectrum. The infrastructure system was essentially a "dumb" application of existing traffic signal technology. The infrastructure system detected major-road traffic and calculated the time period (arrival time) during which a major-road vehicle would cross the intersection. Flashing orange warning lights positioned across the intersection from the stopped vehicle were used as warnings to notify minor-road drivers that it was unsafe to enter the intersection.

The in-vehicle system was more intelligent in that it took the same calculations transmitted by the infrastructure system and warned drivers if they attempted to enter the intersection (indicated by raising the clutch). Audio warnings were presented to the drivers to indicate that it was unsafe to enter the intersection.

Methods

There were 64 participants split into two age groups: 25 to 50 years and 55 and older. A between subjects design was used in which each driver only experienced one of the two JAWS systems (in-vehicle or infrastructure). This was done to maximize each driver's exposure to one implementation and remove any carryover effects from one system to the other.

The experiment consisted of a practice drive followed by four experimental drives where participants stopped at eight intersections. Half of the intersections were "+" intersections and the driver was instructed to drive straight through. The others were "T" intersections (referred to as "Y" intersections in the report) where the driver was instructed to turn right (equivalent to a left turn in the U.S.). In the first two experimental drives, the system was available at all eight intersections. In the second two drives, the system was available at four of the eight intersections.

Major-road traffic conditions at the intersections were varied in terms of mean and variability (Standard Deviation) in speed. The first three vehicles on the major road were closely spaced (2.5 s gap) and following cars were spaced at successive semi-random gaps (starting at 3.5 s). The colors and direction of all vehicles were varied to increase the ecological validity of the scenarios and reduce learning effects.

The two systems were assessed in terms of the impact on safety, driver acceptance, and the potential to increase driver workload. Safety was quantified by driver gap-acceptance behavior and the post encroachment time (PET). PET was defined as the time between the participant's vehicle clearing the intersection conflict zone and the nearest vehicle entering the zone during a crossing maneuver. In some cases, PET was difficult to measure since drivers were careful and this resulted in few instances of dangerous times (dangerous being defined as a PET ≤1.5 s). In addition, the small number of dangerous maneuvers precluded a detailed analysis of system effects on PET in terms of intersection traffic characteristics and participant traits like gender and age.

Mental workload was measured by the NASA-RTLX after each experimental drive. The Van der Lann et al. (1997) acceptance scale was used to measure driver perceptions of usefulness and satisfaction. The acceptance scale was administered before the experiment and again after completion of the experimental drives.

Results

PET measures showed that using both JAWS reduced the number of dangerous maneuvers not only at treated intersections, but also at other non-treated ones. This implies there may have been some carryover effects when drivers negotiated intersections after having used JAWS. This positive transfer suggests the JAWS may provide safety benefits in terms of altering gap-acceptance behavior for all intersections, whether treated or untreated. PET results also showed that the systems reduced the number of dangerous maneuvers by 40% (in-vehicle) and 27% (roadside), respectively.

There was an increase in the likelihood of accepting a shorter gap as more intersections were traversed. Both JAWS also reduced the likelihood of short gaps being accepted, with the roadside system being almost twice as effective. The maneuver type (crossing vs. right turn) was not found to have a significant impact on gap acceptance.

Older drivers felt that the systems were more useful and satisfying than younger drivers. Neither system was found to increase driver mental workload, as there were no significant differences in overall mental workload or any of the subscales of the NASA-RTLX. Neither system completely fulfilled drivers' initial expectations, although the roadside system was found to be more acceptable than the in-vehicle system.

It is worth noting that in this experiment, there was a high frequency of simulator sickness (50% for older age group, 51.2% overall). This may have been caused by roundabouts, which were dropped from the analyses *post hoc*. No significant differences were found between participants who completed the experiment and those who suffered from simulator sickness.

Critique

The intention of this study was to gauge the extent to which IDS systems reduce crash risk as well as to compare the effectiveness of an in-vehicle system to that of an infrastructure IDS system. Though we will not be considering in-vehicle systems at this time, it was good to note that the infrastructure system, though somewhat less effective at reducing the number of dangerous maneuvers at the intersection, still assisted drivers while not increasing mental workload. It is important to note that the infrastructure system was more acceptable and older drivers perceived the IDS systems as being useful.

One advantage of using a driving simulator is that it is possible to control for the effects of the IDS systems by creating two versions of the same intersection: one that is treated with the system (the experimental condition) and one that is not (the control condition). This type of control is not possible in the real world where the best alternative is to compare similar intersections both equipped and not equipped with an IDS system over a given period of time. Another advantage of simulator studies is that it is possible to carefully assess the effect of important participant demographics, such as gender and age. This study also exposed each driver to only one interface for an extended amount of time. This allowed the researchers to make stronger conclusions about learning effects.

It is promising to note that the JAWS infrastructure solution resembled a number of the implemented IDS solutions already described, and favorable safety benefits were observed when the system was evaluated in a simulated environment. This adds credibility to our own methodology in that the evaluation of a simulated solution can be effectively applied and generalized to a real-world setting.

Compound Non-ITS Interventions

Research conducted by Harder, Bloomfield, and Chihak (2003) explored possible solutions to reduce crashes at rural thru-STOP intersections by manipulating various infrastructure features. Their focus was on non-ITS solutions in that they wanted to see how non-technological solutions could be used to curb the number of crashes at rural intersections.

The objective of the project was to assess the behavioral effects on both major- and minor-road drivers from making a rural thru-STOP intersection more salient. A focus group identified creative and innovative ways to improve safety at controlled rural intersections. The focus group also helped to identify a safety need at the intersection of Trunk Highway 58 (TH-58, major road with center left-turn lane at the intersection) and County Road 9 (CR-9, minor road) in Goodhue County, MN. The intersection was reviewed and analyzed from a human factors perspective and was modeled in the HumanFIRST VESTR.

System Description

A number of interventions (see Figure B-6) were investigated, all with the intention of increasing the saliency of the intersection. The following interventions were intended to increase the saliency for drivers on the minor approach:

- Adding traffic islands on the minor road.
- Using two STOP signs instead of one on each minor-road approach.
- Using reflective posts for the STOP signs.
- Improving the sight lines by removing foliage on one corner of the intersection.

Figure B-6. Traffic islands, two STOP signs with reflective posts as countermeasures on the minor-road approach to the simulated intersection.

The following interventions (Figure B-7) were intended to increase the saliency for drivers on the major approach:

- Adding two large guide signs across the major road to make the intersection of the minor road. The signs were added to existing light posts.
- Providing earlier warning signage of the intersection to drivers on the major road (not shown in Figure B-7).

Figure B-7. Guide signs across the major road as countermeasure on the major road approach to the simulated intersection

It is worth noting that since the costs of applying this combination of solutions to the real world would be relatively low, the researchers thought it best to include all potential saliency-enhancing cues together for this study. They also noted that though ITS solutions were not considered, they were recommended to aid drivers at this intersection.

Methods

Twenty-five male and 24 female drivers between the ages of 18 and 65 participated in the study. They were split into two groups, one experiencing the intersection before the interventions and another driving the intersection after the implementations were put in place. Both groups drove four times, approaching the intersection once from each direction.

The simulator used was the VESTR at the University of Minnesota's HumanFIRST Program. It has a 210^{o} forward field of view and complete rear views through the rearview and side mirrors.

The point at which drivers began to slow down was measured and was based on the moment the driver took his or her foot off the accelerator. Drivers' speed was also measured during the last 2,000 m (6,560 ft) before the intersection and was broken into 11 road segments based on distance from the intersection. The number of drivers who ran the STOP sign was also counted.

Results

Since running the STOP sign is a relatively rare event, especially in a driving simulator, it was no surprise that no drivers ran the sign in either condition. When on the minor approach, the interventions affected the distance before the intersection at which the participants began to reduce speed. When approaching from the West, distance increased from 236.6 m (776.2 ft.) in the before condition to 301.4 m (988.8 ft.) after implementation. The approach distance from the east also increased, but not significantly.

When approaching on the major road from the north, 20% of the drivers in the after condition reduced their speed dramatically (44% reduction) over the last 100 m (328 ft.) before the intersection. This would produce a 60% reduction in stopping distance, making it less likely for a right-angle crash to occur at the intersection. From the south, all participants in the after condition reduced their speed by an average of 11.8%. Even though this only leads to an 18.4% reduction in stopping distance and 80% of the southbound drivers in the after condition did not reduce their speed dramatically, the trends suggest that if a crash occurred, its severity would be reduced.

Taken together, the findings indicated the interventions allowed drivers to notice the intersection more clearly and respond earlier. Thus, the changes make minor-road drivers less likely to run the STOP sign while also giving major-road drivers more time to notice and react to crossing/turning traffic. It also allowed minor-road drivers better sight lines to vehicles on the major road and this may have helped them make better decisions when crossing or turning.

Based on their results and in order to help identify the correct intervention strategy for other intersections, the researchers recommended that rural locations be categorized with regard to:

- The horizontal cross-angles
- Vertical curves
- Relative position of vegetation and buildings
- Relative position of commercial and highway signage
- Presence of lighting

They suggested that after these categorizations are made, mitigating strategies can be developed that address each intersection's particular characteristics.

Critique

One drawback of this methodology was that so many infrastructure elements were used, which made it difficult to tell if any one element was more effective than the others. Furthermore, it was impossible to know if one specific concept could have been installed separately to produce similar safety benefits.

A related problem was that the interventions were selected based on the desire to make the intersection more salient to drivers. Since the goal of the Minnesota IDS project is to make safe gaps more salient to drivers, it is questionable how useful any one or any combination of these solutions will be in this regard.

Potential IDS Solutions

Numerous people have speculated and hypothesized on what would make an effective IDS system. Some of these concepts were inspired from crash-data analyses at problem intersections while others were more imaginative and technology-based. Many of the concepts below have not been formally tested at intersections and are mentioned for the purpose of idea generation.

The IDS concepts described in this section have been theorized, but not tested. One example was proposed in order to determine what equipment was needed to complete the system, though it was never implemented. White and Eccles (2002) outlined an infrastructure-based intersection collision-avoidance system that would provide guidance for left-turning (LT) vehicles that have secondary right of way and are attempting to turn across the path of opposite-direction (OD) traffic. This situation is challenging for drivers because when a car is making a left turn from a major road onto a minor road, the oncoming major-road traffic is difficult to perceive and judge. This is because the visual image of the vehicle produces no change in retinal position and only a slight change in retinal image size just before collision. This situation makes it difficult for drivers to judge when the vehicle will arrive (Caird & Hancock, 2002).

The proposed intersection collision avoidance system (ICAS), called the Left Turn Assistance Device (LTAD), would provide guidance through a dynamic sign placed in the line of sight of OD traffic. The sign would give turning drivers a "second opinion" regarding their left-turn decisions. The controller of the system would compare the predicted time of the vehicle to turn (it would discriminate between heavy and light vehicles) and the time before oncoming traffic would traverse the intersection (arrival time).

- The controller would be divided into four subsystems with the following functions:
- Determine the time to turn left for each motorist before the left turn is executed
- Determine the time for the nearest OD vehicle to reach the intersection
- Compare the two times, and
- Indicate to the LT driver the results of the comparison

The authors pointed out that specific information about the LT vehicle (driver perception-reaction time [PRT], age, behavioral habits, and comfortable buffer distance) would not be possible without the collaboration of an in-vehicle system. In the interim, they suggested the 85th percentile for each value be assumed. The system would also use a simple vehicle classification (i.e. passenger vehicle vs. heavy vehicle) based on the approach speed and position of the vehicle in the turn lane, with the default being a passenger vehicle. Much like the notion of the safe gap (Laberge et al., 2003), the proposed system would break down the time to turn left for each vehicle based on driver PRT and the time required for the vehicle to physically turn left. A buffer time would also be considered to ensure safety.

Other than the time estimation functionality, the LTAD system would also require vehicles to be detected. This functionality is currently available through radar, ultrasound, laser, or inductive loops. OD traffic need only be detected by any one of these means at three separate locations (across all lanes) that make up the "detection zone." The detector at the threshold of the detection zone would start a timer equal to the 85th percentile time for an OD vehicle to reach the intersection. A second detector would start a timer equal to the 85th percentile of time to execute a LT. A third detector would start a timer equal to the 85th percentile time for an OD to reach the intersection. Each of these detectors would send a separate signal to the controller that activates the LTAD until all timers count down to 0.

White and Eccles (2002) proposed that the appropriate LTAD must be made in the context of the intersection characteristics and the traffic-control device present. They recommended that the LTAD display be a concise and easily recognizable graphic display or text message. They also recommended avoiding permissive messages, such as A LEFT TURN IS UNEQUIVOCALLY SAFE, in case the sign should become disabled. The system could be applied to either signalized or unsignalized intersections, with the limitation that on the former, the LTAD be inactive or display a red arrow when the major-road traffic has a red light.

The authors noted additional requirements for the LTAD display. It should not be a simple VEHICLE APPROACHING message as this may be interpreted by other thru-traffic that vehicles are approaching on the minor road as opposed to oncoming. A solution to this problem may be to attach an optical lens to the display so that only vehicles in the left turn lane (i.e., directly in front) may view the display. Another problem is that if drivers encounter verbiage such as DO NOT TURN LEFT or the depiction of a left turn arrow crossed out, on subsequent visits to the intersection they might recall that left turns are not allowed and assume this is always the case. These two issues must be carefully considered when any IDS system similar to the LTAD is tested in the field.

Another example of a proposed IDS system that could help with driver gap acceptance was described by Ferlis (2001). This system would aid minor-road drivers stopped at the STOP sign and would notify them if they were about to traverse the intersection when there was an unsafe gap. To meet these requirements, the equipment used would need to determine the speed, acceleration, and/or deceleration rate of each major-road vehicle approaching the intersection. Ferlis proposed that these sensing requirements may be accomplished with either vision-based or radar sensors operating over a sufficiently broad field. In addition, sensors should also be needed to indicate when the minor-road vehicle is preparing to leave the stop line and enter the intersection.

A processor would be used to determine when major-road vehicles would arrive at the intersection and determine if there is a potential for conflict with a minor-road vehicle that is about to leave from the stop line. Ferlis (2001) imagined that the countermeasure could be implemented with a variable message sign or graphical display sign. Alternatively, a simple signal can convey permissive movements to stopped drivers. He recommended that the potential for cooperation with in-vehicle systems be considered in the design of infrastructure based countermeasures. The ideas represented in this solution are captured in the "Variable Message Sign" concept described later in this report.

A modified and simpler version of this interface has been installed at two thru-STOP intersections in Missouri (American Signal Company, 2004). Here, Variable Message Signs were installed on the major road and these signs used radar transducers to present drivers with their speed. When a vehicle approached the STOP sign on a minor road, loop detectors signaled to the signs to override their normal display and instead tell major-road traffic there was CROSSING TRAFFIC AHEAD. At this time, flashing beacons at the respective STOP signs alerted cross traffic to the presence of the intersection. Currently, no data is available on the effectiveness of the system, either in terms of safety or driver acceptance.

Some concepts are less specific to intersection situations, but warrant discussion nonetheless. In Europe, the need has been recognized to reduce traffic waves and jamming by increasing vehicle following distances (Lierkamp, 2003). Although larger following distances may reduce roadway capacity, it also reduces traffic waves and resultant crashes that can ultimately cause traffic jams.

Currently in Holland and Portugal, a video control system is being used to oversee sections of roadway. The system quickly assesses the following distance of every vehicle passing through the control section (over 1,300 ft). Vehicles with less than 0.5 s following distance (56 ft at the speed limit of 75mph) are issued an infringement notice.

Similar systems have been proposed to measure the speed and following distance of vehicles passing over road markers. This gives police the opportunity to replay recorded video and issue violations as needed. A more automated version of this system could use variable message signs to warn drivers if they are traveling too close or if traffic is jammed ahead. Such a system could also be used for enforcement purposes in order to send infringement notices to vehicles tailgating in non-dense traffic. Sensors on an overpass could measure the speed and distance between vehicles while a third camera or sensor could watch downstream to see if traffic is backed up. If traffic is jammed, smaller headways are acceptable. However, if traffic is not backed up and a vehicle is in fact tailgating, then infringement notices can be issued.

Run-The-Signal Solutions

There are numerous examples of ITS concepts that were meant to target other causes of intersection crashes. For instance, the argument has been made that at signalized intersections, deliberately running the signal (including failing to obey and trying to beat the signal) is the single largest cause of SCP crashes (Neale 2003, Ferlis 2002). Some researchers believe ICAS should be developed to address the run-the-signal problem. However, this suggestion contrasts with the data at unsignalized intersections (Chovan, Tijerina, Pierowicz & Hendricks, 1994, Preston & Storm, 2003b), where elements of driver judgment are most often to blame (including driver inattention, looking but not seeing, and looking but misjudging gap). Therefore, some concepts focus on reducing the number of SCP crashes at intersections by alerting drivers that they are about to violate the signal/sign. Though not precisely the problem we are trying to counter, it is helpful to examine these concepts for two reasons: (1) the concepts may be used to warn major-road drivers approaching a thru-STOP intersection of crossing or joining minor-road traffic and (2) elements of the proposed devices may be used for different IDS warning purposes other than what they were originally intended.

Neale (2003) reviewed SCP crashes and outlined some infrastructure solutions that could be used to determine if drivers would run the signal or sign. Though many of the details are not discussed in this report, some options for reducing the run-the-signal problem and SCP crashes include:

- Unsignalized
    - Passive stop ahead signs: provides advanced warning of controlled intersection
    - Major- and minor-road intersection warnings: provides advanced warning of the intersection
- Signalized
    - Passive symbolic signal ahead signs: provides advanced warning of the intersection

- Active warning signs: provides advanced warning of a signal phase change (i.e. STOP AHEAD WHEN LIGHTS FLASHING)
- Strobes on red light: increases detection speed for a distracted driver
- Red light photo enforcement: reduces violations by altering cost/benefit ratio
- Red light hold between phase changes: prevents cross traffic from entering the intersection and may help identify likely signal violators

- Either
  - Adding additional length to the intersection approach (before the stop line)

Though these solutions may be useful for reducing the number of drivers who run the signal (or sign), they are not expected to help drivers with intersection navigation decisions. However, the warnings could be integrated with other IDS systems in order to reduce intersection crashes in general.

Neale (2003) also provided examples of potential IDS solutions, starting with a system at an unsignalized intersection using an infrastructure-based concept. Here, the STOP sign would be equipped with the technology to detect and warn drivers when they are about to run the sign. There would be two lights atop the right and left angled portions of the STOP sign that provide warnings when the system predicted the approaching minor-road driver was about to violate the sign. Radar or another type of sensor would be mounted on the pole below the sign to detect the minor-road vehicle and gather the necessary data for predicting violations. Neale recommended using a solar panel to power the system.

Neale (2003) also suggested a number of other variants as possible IDS solutions. A system for signalized intersections could mount the sensors next to the road or on existing signs on the road and send a warning to an IDS system or an intelligent rumble strip (described below in more detail). Furthermore, an in-vehicle system might be beneficial to collect vehicle-centric data (driver PRT, velocity, GPS map position, lane position, etc.) and provide an in-vehicle warning, and later cooperate with an infrastructure system to provide even more information to drivers.

Both Ferlis (2002) and Neale (2003) recommended that an infrastructure system could initially assist a driver on its own, but could later be adapted to cooperate with in-vehicle IDS/ITS systems. The infrastructure components of Ferlis' system would involve sensing the speed and deceleration rate of each vehicle approaching the intersection. This could be done by means of loop detectors, optical sensors, radar sensors, or self-powered vehicle detectors inside each vehicle. Speed would be used to help identify potential violators on the minor road and the crash potential from major-road drivers. Deceleration data could significantly reduce the number of false detections. A traffic controller could calculate when a vehicle was to cross the intersection and then warn drivers using:

- Warning signs and lights to tell vehicles to STOP AHEAD
- Warning light incorporated in the traffic signal: strobe or another amber light

- Variable Message Signs
- Intelligent rumble strip that changes the viscosity of fluid with an electric charge to notify drivers they must slow down or stop

Both the infrastructure and a cooperative infrastructure system have the benefit of reducing the number of SCP crashes. Ferlis (2002) calculated that if only the infrastructure components of said system were to be installed, the benefit to cost ratio would be 12:1. The ratio for using an in-vehicle system that cooperates with the infrastructure system would only be 3:1 due to the extensive number of in-vehicle components that would need to be installed. For this reason, it would be important to establish infrastructure systems as a near-term aid to reducing SCP crashes. However, these infrastructure solutions should also have the ability to communicate with future in-vehicle systems.

Other Crash-Avoidance Solutions

Other crash-avoidance concepts are presented below as examples of potential warnings that can be adapted to meet the needs of the Minnesota IDS system. BMW AC has developed and tested a system to reduce the number of accidents and their related consequences through incident management on interurban roads (David, Klassen, Keller, Tarry & Tognoni, 1999; Kates, Keller & Lerner, 1999; Groves, 2000). Trials in Germany, Scotland, and Italy were used to test the COMPANION system, which alerted drivers via flashing light posts to incidents of traffic flow, congestion, and other unexpected events such as severe weather. All of the chosen sites had high-traffic volumes and were problem areas for congestion and frequent poor weather conditions (e.g. fog).

The electronic markers were variable flashing lights on poles placed at short distances from each other (see Figure B-8). The poles were interconnected and controlled by a central control unit that was activated manually at the time of the experiments. In other words, the system was activated by local authorities/experimenters after an incident was reported, but automated systems were expected to handle this function in the future.

The lights were activated differently according to the nature of the incident. At the time of the last report (Groves, 2000) there were 11 "states" in place, each activating the lights over different lengths, at different patterns/frequencies, and possibly with different colors depending upon the event or time of day. The system was expected to increase alertness and far-sighted driving as well as result in a collectively induced increase in the "viscosity" (or "diffusion") of the traffic flow, which in turn would reduce dangerous speed gradients and secondary accidents.

Figure B-8. COMPANION system roadside warning lights, which cover a 4 km section of highway in Scotland.

To determine the impacts that the system had on traffic, the researchers measured the change of velocity, following behavior, braking operations, and lane-changing behavior of traffic at the test sites. Since the system was not to be activated without an actual incident occurring, the researchers simulated a truck breaking down on the side of the road. Measures were taken through sensors (of unreported type) and video cameras at the location of the incident and 2 km before the truck's location.

They also measured the "harmonization" of speeds (difference) between the two lanes of traffic. Good harmonization entailed both lanes of traffic matching speed and thus increasing viscosity.

During each trial, the researchers measured the undisturbed traffic flow, disturbed traffic flow (truck incident) without COMPANION activation, disturbed traffic flow (truck incident) with activation, and undisturbed traffic flow after deactivation of COMPANION. The Scottish and Italian tests were conducted in daylight, while the German testing consisted of both daytime and nighttime exposures. Two lanes of traffic were affected by the system in Germany and Scotland, while three lanes of traffic were exposed in Italy.

The Italy trial had the additional aim of determining the effects of varying the warning distance, light pattern, and situation. This trial also included a scenario where one lane was closed for construction and at times COMPANION was used in conjunction with a VMS that gave additional information. This was done since they had an extra lane of traffic and so the same scenario (truck breaking down) did not prove to be as high of a concern for the drivers in Italy.

The researchers also measured user acceptance through a core questionnaire given at all sites with additional questions relating to site-specific issues. These were distributed with self-addressed stamped envelopes in Germany and as interviews in Italy.

Overall, the system showed a reduction in speed while activated for two lanes of traffic (Germany and Scotland). Higher speed levels were observed prior to activation and a significant speed reduction was noted when the COMPANION system was activated. In Germany, speed variation (Standard Deviation), the number of critical net time gaps, TTC values, and the number of unjustified lanechanging actions were all reduced during system activation.

There was a significant harmonizing effect in Germany and a smaller non-significant trend in Scotland. Crash data was compared between the COMPANION site and five other Scottish road segments. Data from the three years prior to introduction compared to the 16 months post introduction showed the COMPANION site to have the greatest decrease in minor crashes and injury crashes, while also having no severe crashes. This indicated that the system was indeed having some positive effect in terms of reducing both accident numbers and their severity.

As for warning presentation, a minimum distance of 750 m was felt to be adequate on the 65 mph (113 km/h) road while 1,000 m would be needed on the 75 mph (130 km/h) and deregulated roads. It was recommended that the distance that the warning lights are placed be extended as far as possible. This was because drivers slowed down more if they did not immediately see the cause of the warning. In this way, by warning the drivers sooner they are expected to slow down more and over a longer distance. The authors also concluded that the longer the warnings last, the more drivers tend to reduce their speeds.

There were no significant differences between the reactions to the activated system when a constant flashing “funnel effect” was used. The “funnel effect” was achieved by increasing the flashing frequency from 2 Hz to 4 Hz during the approach to the incident. The Italian trial was the only one conducted on a three-lane road and the researchers found that the funnel effect had more influence on drivers in the slow lane. They thought this was due to the fact that drivers in the slow lane were farthest from the warning posts and could experience the stroboscopic warning produced by the “funnel effect” the best.

Most drivers in Germany felt they were more attentive and that they were aware that COMPANION was a warning system. This latter point indicated that the warnings were interpreted as an active alert for impending danger and that action needed to be taken as opposed to a constant general warning.

When the system was combined with the VMS in Italy, the subjective findings were inconclusive as to the usefulness of the messages. Twenty-one percent were able to recall the message correctly, 14% recalled incorrectly, 48% noticed some messages but were unable to remember the content, while 17% didn’t notice any VMS at all.

A number of design and implementation issues were raised during the evaluation of the COMPANION system. First, the number of possible warning states that drivers were expected to learn should be limited. Second, though a combined VMS and COMPANION system was tested at the Italy site, the results suggested the messages were not very helpful for drivers. A future design might only communicate which lane drivers should be cautious of rather than the type of problem. A simple VMS message could be used to indicate the problem lane(s) to avoid or a standard lane-use control signal could be installed that displays a red “X” or green downward arrow to notify drivers of open/closed lanes.

Although the COMPANION system was designed to warn drivers on high-volume interurban roads of imminent danger or problem conditions, the system could be used as an additional warning to major-road traffic at thru-STOP intersections. In particular, the system could be adapted as a means of getting drivers to slow down. The system would be more focused, since the location of the hazardous event (i.e., the intersection) would be constant. This contrasts with the original COMPANION system that warned drivers at numerous trouble areas over the entire road's length and where multiple states were used to communicate different warning messages (i.e., congestion, accident, bad weather, poor road conditions, etc.). The notion of adopting a COMPANION like system for thru-STOP intersections is incorporated in the "Phi-Poles" concept described later in this report.

An example of a less technologically advanced yet seemingly effective crash avoidance solution was tested by Uchida, Katayama, de Waard and Brookhuis (2001). This project aimed to reduce crashes at two-lane rural intersections in Japan with good visibility. Japanese crash data showed that many fatal crashes in rice field areas occurred when drivers failed to notice other vehicles approaching from crossroads. The authors suggested this situation was challenging for drivers because when other vehicles approach the intersection at the same speed and from the same distance, these vehicles appear to be static objects in the driver's field of view. Only the apparent growth of the approaching vehicle retinal image appears just before a crash. This situation makes the detection and estimation of arrival time for vehicles on a collision course difficult (see also Caird & Hancock, 2002).

In their first experiment, Uchida et al. (2001) replicated a study of the detection performance of drivers when a vehicle approached on collision and non-collision courses. Participants viewed video clips from the viewpoint of a vehicle driving through an intersection (one every 300 m) with cruise control set at 60 kph. In addition to a forward view, participants also saw six other eccentricities (+/- 30, 45, or 60 degrees). At some of the intersections, a vehicle approached from a crossroad either on a collision or non-collision course. Results showed that if the approaching vehicles had similar velocities and were on a collision course, participants took longer to detect the vehicle. This trend was consistent no matter what eccentricity the other car appeared to be to the participant. When the approaching vehicle was not traveling on a collision course, participants were able to detect the vehicles more quickly. Also, participants were able to detect the vehicles at a farther distance when they appeared closer to the intersection (i.e. +/- 30 degrees).

In a second experiment, the authors used the same cruise control driving task and a similar peripheral detection task, but the approaching vehicle only appeared at an eccentricity of +/- 45 degrees. The driving scene also included fences that obscured the view of the approaching vehicle until the participant was 2 or 3 s from crossing the intersection. Results found that there was a significant difference in the standard deviation of mean detection distance between the no-fence and both the 2 s and 3 s conditions. This accounted for an average detection distance that was 10 m greater compared to the no-fence condition. In addition, in the fence condition the distribution of distances at which the vehicle was detected peaked just after the vehicle appeared from behind the fence.

The researchers concluded that, "…road side fences, which provide abrupt appearance by hiding the other vehicle until appropriate timing, can enhance the conspicuity and help the detection of vehicles on collision course" (p. 9). They did recommend further testing to investigate the efficiency of the measure for older drivers, since their initial experiments only included participants that were 20 to 41 years of age.

In-Vehicle Solutions

There have been numerous in-vehicle countermeasures to reduce crashes, including ones that heighten safety at intersections. Some of these enhance the visibility and salience of ambient traffic and furniture, while others involve cooperation with infrastructure equipment at intersections. Since these systems are related to IDS safety measures and may prove to have useful elements relevant to infrastructure countermeasures, some of these solutions are chronologically summarized in Table B-1.

Table B-1.Concepts relating to in-vehicle solutions that have not been implemented or tested at intersections or in simulator, in chronological order. Table continues on next page.

Reference	Objective	Interface	Methodology	Results
Huey, R.W., Harpster, J.L. & Lerner, N.D. (1997). Summary report on in-vehicle crash avoidance warning systems: Human factors considerations. Office of Crash Avoidance Research, National Highway Traffic Safety Administration, USDOT, Washington, DC. DOT HS 808 531.	Present set of human factors recommendations for the design of in-vehicle backup warning systems based on a review of all the studies completed in this project.	(testing general principles of attention and acceptability, so no interface was the subject of these studies.)	Driver log study; Multiple attribute evaluation (MAE) of sounds- subjective judgments of sounds on various warning characteristics; Acoustical localization of warning sounds- accuracy of direction sound emanated from in vehicle; Alarm rates and annoyance- FOT with randomly occurring warnings, drivers needed to press a response button if a light was blinking (representing a valid warning)	Log- Intersections not thought of as hazardous or where assistance would be useful, though high frequency of incidents there; MAE- acoustic sounds performed better than voice stimuli; Localization- directional cues have potential to speed response to hazards; Alarm- nuisance alarms occurring at 1-4/hr frequency were still acceptable, and voice messages may lead to greater problems with acceptance.
Kiefer et al. (1999). *Development and validation of functional definitions and evaluation procedures for collision warning/avoidance systems* (Rep No. DOT HS 808 964). Washington, DC: NHTSA.	Reduce number of rear-end collisions in car-following situations through in-vehicle countermeasures.	Uses forward sensors to determine critical measures (i.e. TTC) and alerts driver through audio, dash, and head-up warnings. Continuously operates, only senses objects visible by line-of-sight from front of vehicle and autonomous of infrastructure. Could fail if overhead objects, road surface and debris, or roadside clutter are present.	Crash alert timing and modality requirements were developed by series of closed-course studies using "surrogate target" methodology.	Drivers preferred non-speech tone (required) and visual icon (recommended) on high head-down display; brake pulse haptic alert not suggested.
Pierowicz, J., Jacoy, E., Lloyd, M., Bittner, A. & Pirson, B. (2000). Intersection Collision Avoidance Using ITS Countermeasures – Final Report: Performance Guidelines. Veridian Engineering, Inc., NHTSA. US Dept. of Transportation.	Intersection Collision Avoidance using ITS Countermeasures program, NHTSA: study collisions that occur within intersections (signalized and unsignalized LTAP, SCP), investigate technologies that could be applied, develop effectiveness of system.	HUD, audio, and haptic brake uses radar and GIS/GPS to warn drivers of upcoming intersections if they don't respond by certain threshold distance. For collision targeting, works for STOP-controlled intersections.	System performance measures only.	ICAS has capability to prevent 63.9% of intersection collisions, this high estimate based on 100% compliance and installation in all vehicles.
Sugimoto, M., Aoyama, K., Shimizu, D. & Maekawa, Y. (2000). Realization of head-on collision warning system at intersections- DSSS: Driving Safety Support Systems. *Proceedings of the IEEE Intelligent Vehicles Symposium 2000*. Dearborn, MI, USA, October 3–5. 731-735.	Support safe driving and alleviate congestion through the use of in-vehicle and intersection installed technology.	A number of DSS using infrared beacon or VMS: dangerous zone ("dilemma zone") warning; head-on collision warning; opposite approaching vehicle warning; approaching RT; motorcycle & pedestrian visibility/warning.	Verification tests were planned in 2000.	

Section Summary

The solutions reviewed in this section were important for understanding the problems other researchers have attempted to address. It was critical to note that no existing or potential systems conveyed gap information directly to the driver and most seemed to focus on informing the driver that other vehicles were present.

The review also showed that a number of techniques have been used to analyze the effectiveness of each system. At times IDS solutions were proven effective or ineffective from the analysis of crash data before and after system installation. This method of evaluation was useful when the overall goal of the intervention was to reduce the number of crashes at the intersection. However, this type of analysis does not account for specific driver reactions like changes in gap acceptance or speed, driver acceptance, or perceived usefulness of the system. Additionally, in cases where the system warns both major- and minor-road drivers, the crash analysis methodology cannot determine which drivers are benefiting or reacting to the system. The method also fails to account for the possibility that the number of crashes at an intersection may decrease because drivers do not like or want to deal with the IDS system and thus fewer drivers frequent the intersection after system installation. Another possibility is that drivers may adapt to the system, and as a result, the number of crashes at an IDS equipped intersection may decrease initially, but then increase over time. In these cases, a more long-term analysis of crash data is required. One approach that can address many of these issues is to analyze and compare crash data at a control intersection. This will help account for potential changes in traffic levels or changing behavior of traffic as a whole (Datta, 2004). In addition to crash data, changes in speed, time-to-contact, critical-gap size, and driver expectations should also be analyzed.

Appendix C
Untested Interface Concepts

Prescreening Methodology

The expert panel consisted of representatives from the FHWA, NC DOT, IA DOT, NC DOT, NH DOT, and MN DOT. Reviewers were given a cover letter with evaluation instructions, a rating sheet, and a brief report that described the problem scope, content domain, general limitations and design premise, and the individual concepts. Reviewers were asked to rate the nine proposed interface concepts using the rating sheet that was provided, from (1) most to (9) least preferred using five separate evaluation criteria:

- Overall opinion – what is your general impression of the merit of the interface considering any combination of evaluation criteria?
- Improve safety – how do you rank the interfaces ONLY based on their likelihood of reducing rural thru-STOP crashes for crossing or turning minor-road traffic? A favorable system would improve safety.
- Maintainability – how do you rank the interfaces ONLY based on the anticipated cost to maintain the system once installed at a rural thru-STOP intersection in your jurisdiction? A favorable system would have a low maintenance effort and cost.
- Implementation cost - how do you rank the interfaces ONLY based on the anticipated cost to install and implement the system at a rural thru-STOP intersection in your jurisdiction? A favorable system would have a low implementation effort and cost.
- Conforms to existing standards - how do you rank the interfaces ONLY based on the anticipated obstacles of having the proposed interface accepted by AASHTO as conforming to existing MUTCD guidelines? A favorable system would already conform to existing guidelines, or would readily be approved.

Results

A total of seven rating sheets were returned, yielding an overall response rate of 37%. Table C-1 shows the correlation between the rankings overall and the individual criteria. The positive correlation between safety and overall criteria demonstrates that reviewers based their overall rankings primarily on considerations of safety. Standards rankings were also positively correlated with overall rankings. This implies reviewers judged the overall merit of each concept based partially on whether the concept conformed to existing guidelines or would readily be approved. Some reviewers also reflected on issues of maintainability and implementation costs, but to a lesser extent.

Safety rankings were also positively correlated with standards rankings. This suggests reviewers perceived the concepts that conformed to standards as being safer. Maintainability and implementation were related. This was not surprising since a system that is costly to implement and install would also be costly and difficult to maintain. Reviewers also ranked concepts that conformed to existing standards as being easier to maintain. Lastly, implementation and standards rankings were related such that higher implementation costs were associated with those concepts that conformed less to standards and/or would be more difficult to obtain approval.

Table C-1. Correlation between rankings for all reviewers and all concepts.

	Overall	Safety	Maintainability	Implementation	Standards
Overall	-				
Safety	.808(**)	-			
Maintainability	.352(**)	.078	-		
Implementation	.336(**)	.139	.776(**)	-	
Standards	.583(**)	.417(**)	.740(**)	.790(**)	-

** Correlation is significant at the 0.01 level (2-tailed).

However, there was little consensus among the reviewers in terms of overall and safety rankings and no concept emerged as a clear victor. This suggests there is variability in the engineering and safety community about how best to solve the problem of gap acceptance at thru-STOP intersections. This emphasizes the need to rely on a scientific approach to design an analysis of the crash problem. In an earlier report, the crash problem was delineated and the scientific basis for the proposed concepts was described (Laberge et al., 2003). The information in this earlier report and the results of the Abstraction Hierarchy (AH) and the skills-rules-knowledge (SRK) analyses served as the foundation for the proposed design concepts.

1. Title

Dumb Pole

2. Content Domain

Primary Content

A. Judge whether a gap is safe

E. Localize a safe gap and/or inform when a safe gap is about to arrive

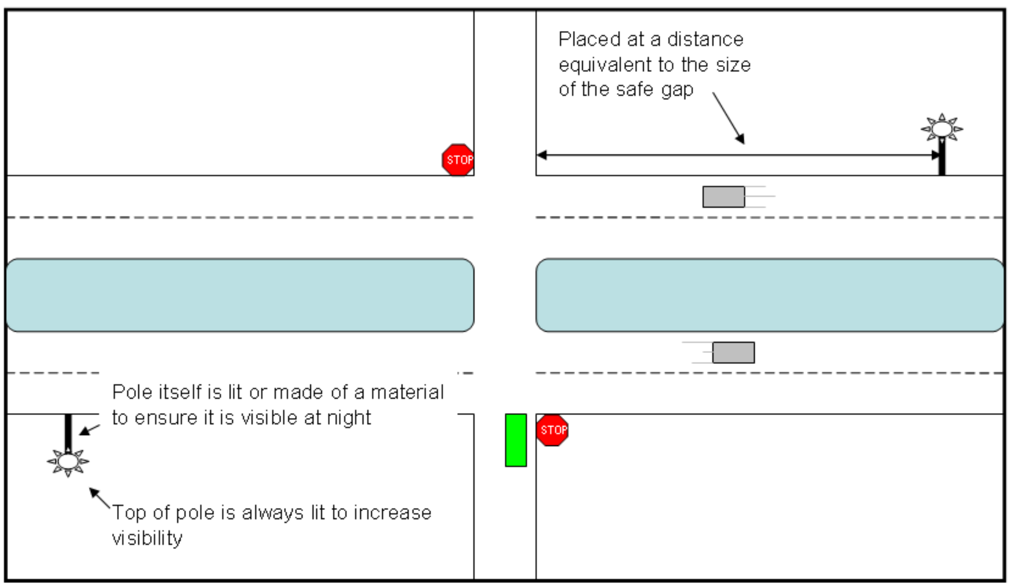
Secondary Content

F. Alert major-road drivers to the presence of intersection

3. Description

Large poles are set at a distance equivalent to the size of the safe gap. When a major-road vehicle is far from the intersection and has not passed the pole, minor-road drivers have sufficient time to execute their maneuver. When a major-road vehicle moves past the pole and is within the defined distance, it is unsafe. In other words, drivers stopped on the minor road use the poles as a visual cue to indicate when it is safe to proceed. The pole itself is lit or is made of a material that can be easily seen at night and at far distances. The top of the pole is also lit to increase conspicuity. A secondary benefit may be to alert major-road vehicles to the presence of an intersection. Signage would be needed for the minor road to explain how the system works.

4. Diagram



5. Options/Variants

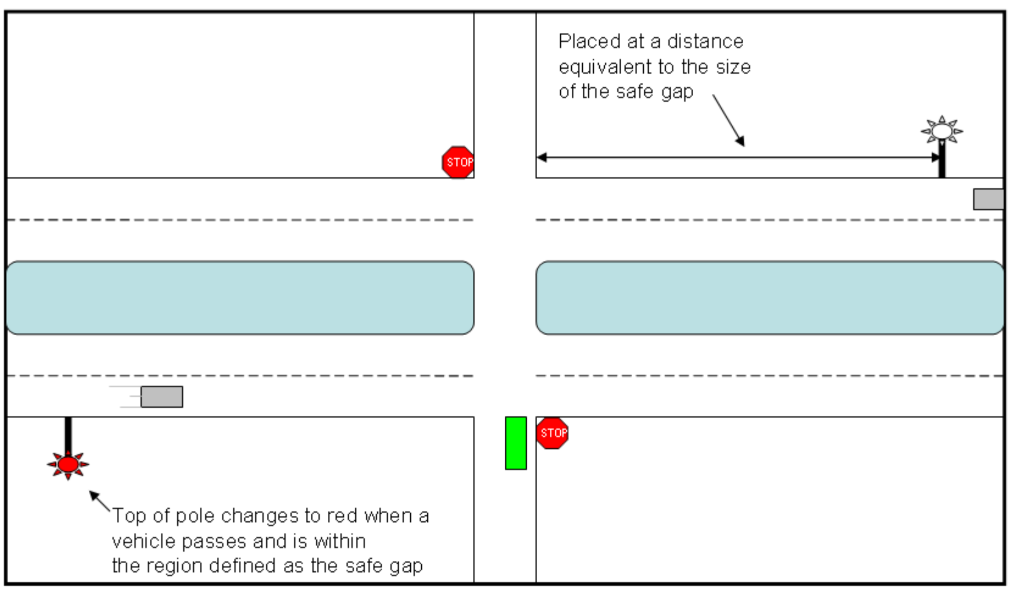
Alternatives to using a pole include a line painted on the road, a suspended sign (fixed or variable message), or a street light.

A different color can be used for the light on top of the pole.

The pole can be placed on the median either by itself or in conjunction with the other side of the road. Installing at both locations increases conspicuity but may interfere with sight lines (and increase cost).

The light on top of the pole could flash to signal to major-road vehicles that a car has just arrived at the minor road and is waiting to cross. Additional signage would be needed for the major road. Multiple poles can be installed to accommodate different minor-road vehicle sizes. Different poles could be lit depending on what type of minor-road vehicle is detected. However, this would be confusing for the minor-road driver and difficult to convey using signage. See also "Smart Pole" and "Pole Row."
6. Limitations/Caveats Sight lines to pole may not be sufficient at all locations. Using one pole for the near and far side assumes a fixed safe gap distance that is independent of minor-road vehicle size, surface conditions, or actual speed. To ensure safety, the safe gap would need to be defined for a combination truck and slippery roads (i.e., worst-case scenario). This could result in a long queue on the minor road and consequently increase driver frustration and impatience for drivers in passenger vehicles. Minor-road drivers will likely have difficulty judging vehicles on the near side. This is because people have more problems judging motion in depth (near-side vehicles coming straight toward minor-road drivers), compared to motion across the visual field (Hills, 1980; Laberge et al., 2003). Installing poles or other markers at both the median and on the other side of the road could partially mitigate this problem. Conspicuity and correct interpretation of information may be problematic since the poles will be viewed at a far distance. The poles will need to be large and bright enough to be detected in the driver's peripheral vision.

1. Title Smart Pole
2. Content Domain Primary Content A. Presence of vehicles that make up gaps D. Judge whether a gap is safe E. Localize a safe gap and/or inform when a safe gap is about to arrive Secondary Content F. Alert major-road drivers to the presence of intersection
3. Description Similar to "Dumb Pole." Large poles are set at a distance equivalent to the size of the safe gap. The pole itself as well as the top of the pole is always lit to enhance conspicuity. When a vehicle passes the pole, the light on top changes to red to indicate to the minor-road driver that it is unsafe to enter the intersection. This feature also helps drivers identify vehicles that make up gaps. In other words, drivers stopped on the minor road use both the pole and light as a visual marker to indicate major-road vehicles are approaching and when it is safe to proceed. Similar to the "Dumb Pole" solution, a secondary benefit may be to alert major-road vehicles to the presence of an intersection. Signage would be needed for the minor road to explain how the system works.
4. Diagram

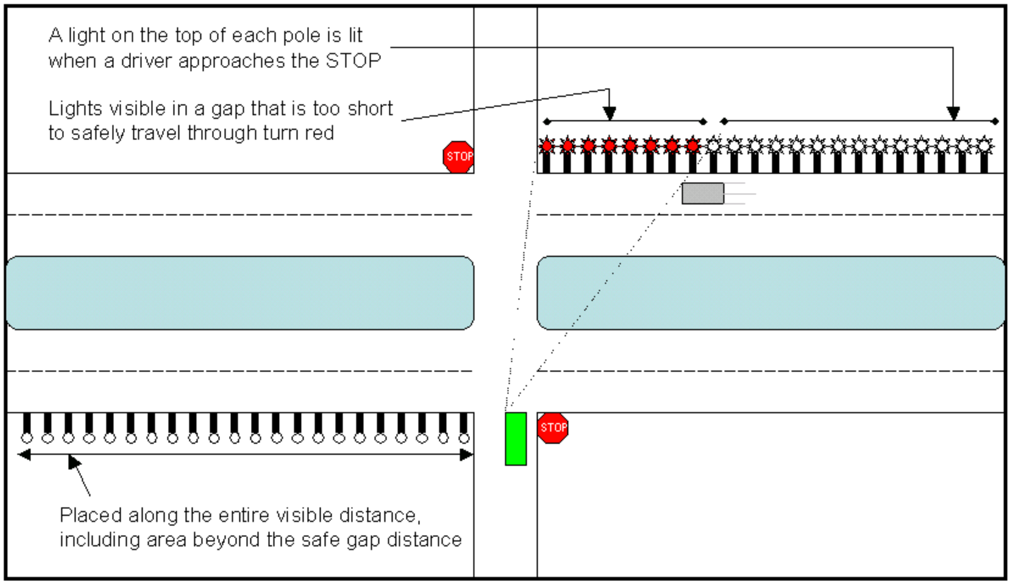


5. Options/Variants Same as "Dumb Pole." The light on top of the pole could flash as well as change color when a vehicle passes. See also "Pole Row."
6. Limitations/Caveats

	Same as “Dumb Pole.” Potential exists for minor-road drivers to misinterpret the meaning or purpose of the red light change.

1. Title
Phi-Poles
2. Content Domain Primary Content A. Presence of vehicles that make up gaps B. Convey speed, distance, and arrival time C. Size of available gaps D. Judge whether a gap is safe E. Localize a safe gap and/or inform when a safe gap is about to arrive Secondary Content F. Alert minor- and major-road drivers to the presence of the intersection G. Alert major-road drivers to crossing minor-road vehicle I. System state
3. Description A row of short poles, each with a red and white light on top, are placed along the side of the road. The poles are consistently spaced from the intersection to some distance beyond the safe gap (see "Dumb Pole" for a discussion of safe gap distance). The white lights on the poles are always lit and when a minor-road vehicle arrives at the STOP sign, the white lights flash to indicate the system is working. When a major-road vehicle approaches the intersection and is within the distance or arrival time that defines the safe gap, the lights on the poles between the major-road vehicle and the intersection turn red. This indicates to the minor-road driver that it is unsafe to enter the gap in front of that vehicle. This type of notification is intuitive since it gives an immediate cue (red lights) corresponding to the region that defines the safe gap (i.e., "lag") and indicates whether the intersection is unsafe to enter. Similar to the "Dumb Pole" and "Smart Pole" solutions, a secondary benefit may be to alert major- and minor-road vehicles to the presence of an intersection. Signage would be needed for the minor road to explain how the system works.

4. Diagram



5. Options/Variants

A longer row of the poles extending well beyond the safe gap distance will give drivers a longer preview of the vehicle.

The size of the safe gap can be adjusted based on the type of vehicle detected on the minor road and pavement surface conditions.

The height of the poles can be either high (above car height) or low (at a car's grill). Higher poles may increase conspicuity when sight distances are limited (such as due to a hill) while lower poles could help minor-road drivers match the lights on the poles to specific major-road vehicles.

Poles may be placed at an increasingly smaller distance the closer they are to the intersection. Placing the poles closer together may create an illusion of higher speeds when major-road vehicles approach the intersection. This could enhance speed perception by minor-road drivers since people (and especially older adults) usually underestimate speed when vehicles are traveling at a high velocity (Laberge et al., 2003).

The white and red lights could be mounted on guardrails or existing barriers at the intersection.

6. Limitations/Caveats

Same as "Smart Pole."

Minor-road drivers will likely have difficulty judging vehicles and gaps on the near-side. This is because people have more problems judging motion in depth (near-side vehicles coming straight toward minor-road drivers) compared to motion across the visual field (Hills, 1980; Laberge et al., 2003). Additional lights placed in the median may help minor-road drivers perceive near-side vehicles and safe gaps.

Activation of the red lights on the poles may startle drivers on the major road.

Each pole will have to be high enough and robust enough to withstand snow conditions and plowing. Low-mounted lights may get covered by plowed snow.

When traffic volumes are high, the red lights may activate and deactivate rapidly as the system tracks more than one vehicle. This may be confusing for the driver.

1. Title

Pole Row

2. Content Domain

Primary Content

A. Presence of vehicles that make up gaps

B. Convey speed, distance, and arrival time

D. Judge whether a gap is safe

E. Localize a safe gap and/or inform when a safe gap is about to arrive

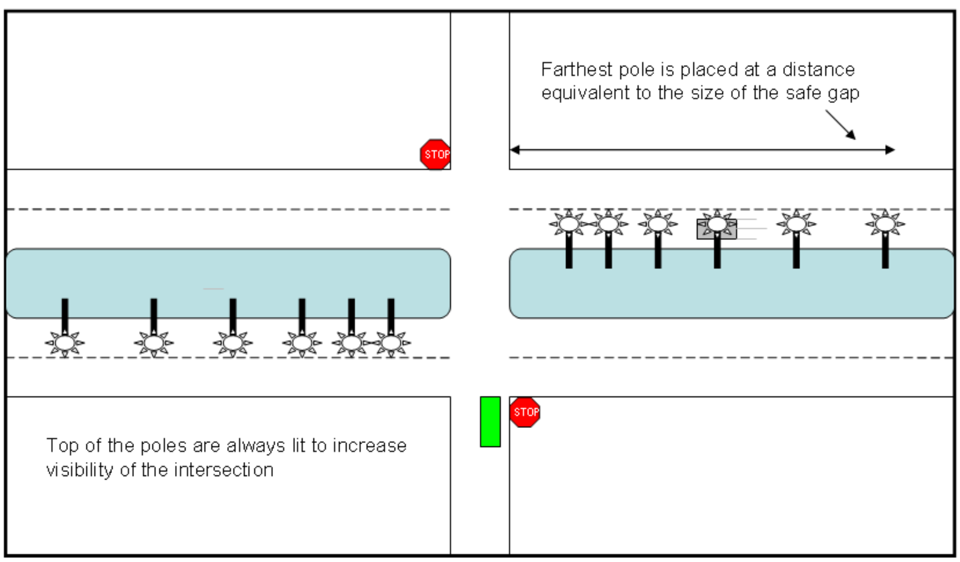
Secondary Content

F. Alert minor- and major-road drivers to the presence of the intersection

3. Description

A row of light poles is placed in the median so that they partially and infrequently obscure the minor-road driver's view of major-road vehicles. Partially obscuring the movement of traffic could enhance peripheral detection of major-road vehicles (Uchida et al., 2001). This is because the major-road vehicles appear suddenly from behind each pole and this increases their conspicuity. The poles are also placed at increasingly larger distances the further they are from the intersection. This may aid minor road drivers in determining the speed of approaching vehicles. Similar to "Dumb Pole," the pole farthest away is placed at a distance equivalent to the size of the safe gap. In this way, it can be used as a guide to indicate when it is unsafe to enter the intersection. The additional constant illumination from the lights will also make the intersection more visible to drivers approaching and crossing from all directions. Signage would be needed for the minor road to explain how the system works.

4. Diagram



5. Options/Variants

Same as "Dumb Pole."

Adding a sign to each pole that conveys absolute distance values (i.e., 100 ft, 200 ft, 300 ft) could help drivers judge distance. The signs would need to be large to be seen at far away distances.

The lights may change color as a vehicle approaches (see “Smart Pole” and “Phi-Poles”).

6. Limitations/Caveats

Same as “Dumb Pole.”

The poles may obstruct sight lines to major-road vehicles.

The poles will not obscure near-side vehicles in the same way as far-side vehicles. Therefore, the system may not be effective for decisions concerning near-side traffic. Adding poles at both the median and opposite side of the road could partially mitigate this issue.

1. Title Hybrid	

1. Title

Hybrid

2. Content Domain

Primary Content

A. Presence of vehicles that make up gaps

B. Convey speed, distance, and arrival time

D. Judge whether a gap is safe

Secondary Content

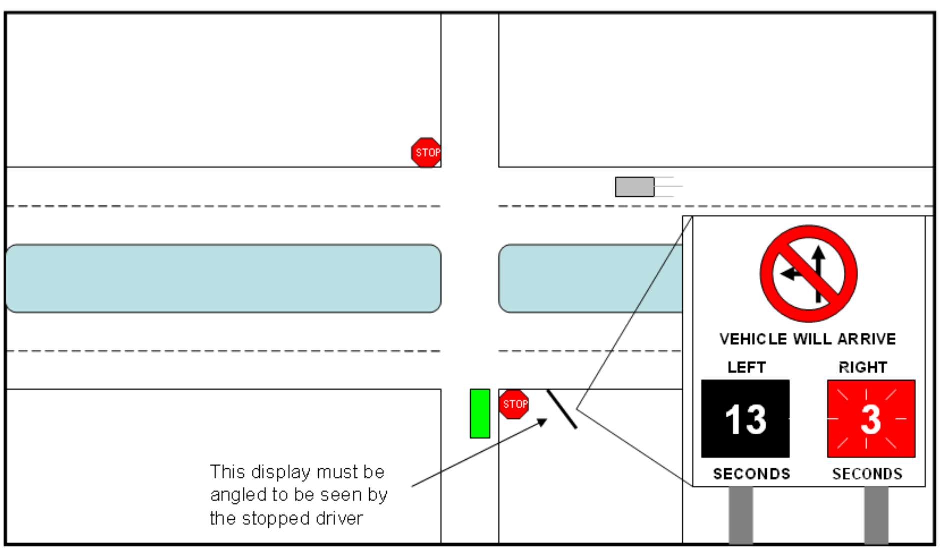
F. Alert minor-road drivers to the presence of the intersection

I. System state

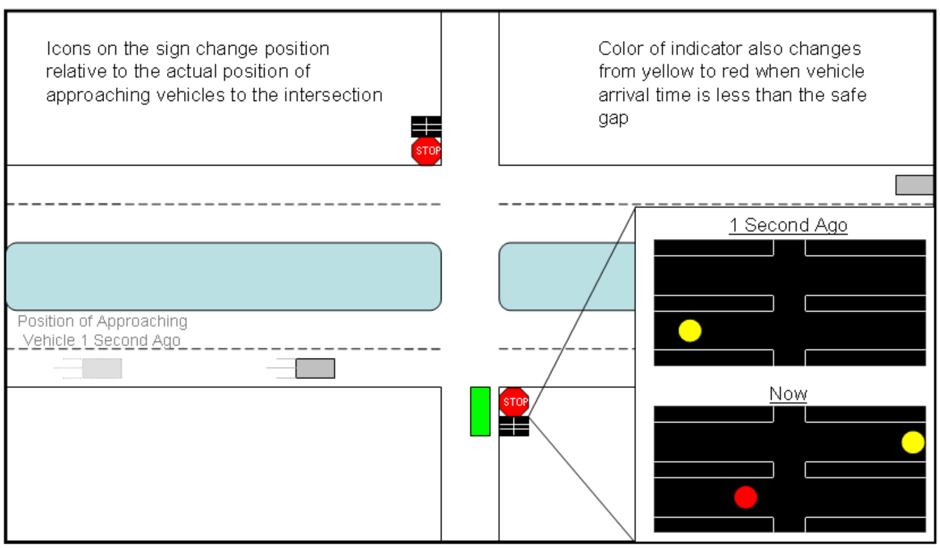
3. Description

This system is an integrated hybrid of the Variable Message Sign and Countdown concepts. While the Split-hybrid interface was being simulated, the design team felt is was important to get reactions to an integrated display called the Hybrid interface. A single display on the right side of the minor road draws attention to the arrival time of major-road vehicles, while also conveying when it is unsafe to enter the intersection. The association between arrival time and the prohibitive message should help minor-road drivers learn when it is unsafe to complete each maneuver. More specifically, the system tracks the lead vehicle in both the near and far lanes starting at a distance of 15 s from the intersection. The arrival time counts down in 1 s increments as the major-road vehicle(s) approach. Arrival time flashes and the background changes red when the lead vehicle is within the arrival time that defines the safe gap (e.g., current default is 8 s). The logic used to display the prohibitive message is the same as the near-side (left) Split-hybrid display.

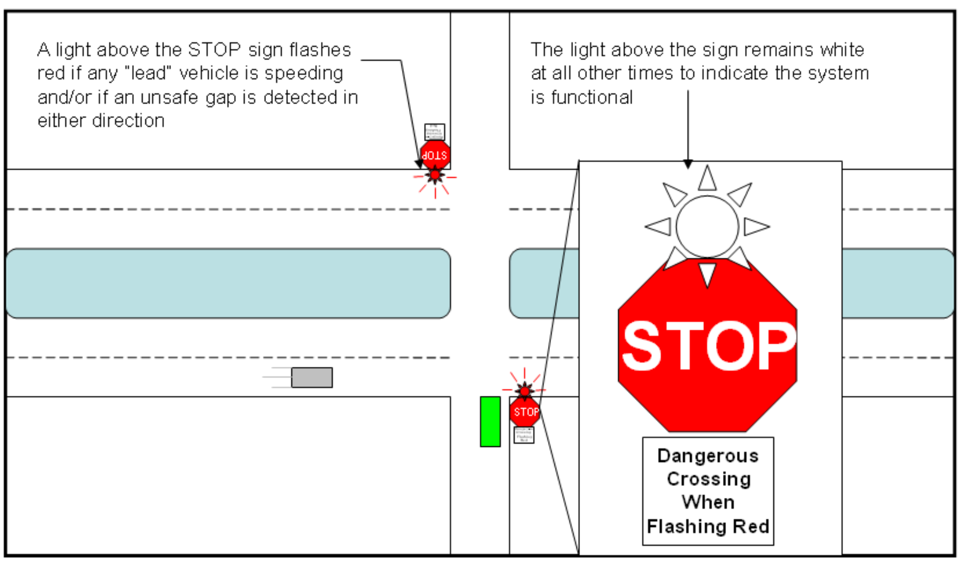
4. Diagram



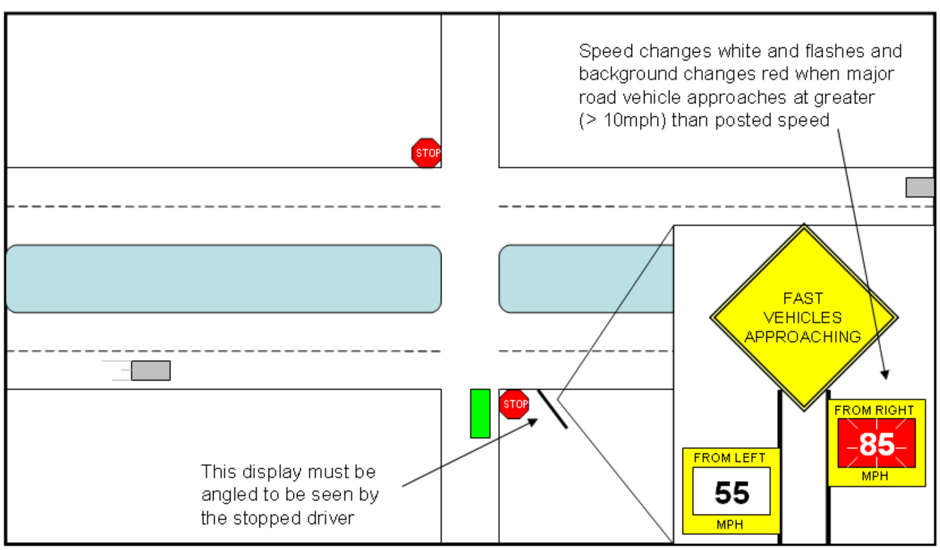
5. Options/Variants Same as "Split-hybrid."
6. Limitations/Caveats Same as "Split-hybrid." The amount of dynamic information on this display could overwhelm and distract drivers.

1. Title Pac-Man
2. Content Domain Primary Content A. Presence of vehicles that make up gaps B. Convey speed, distance, and arrival time D. Judge whether a gap is safe Secondary Content F. Alert minor-road drivers to the presence of the intersection
3. Description A display is used to indicate the location of the first, or lead, major-road vehicle in each direction as they move toward the intersection. The display also shows a continuous outline of the major and minor roads as they intersect. When a major-road vehicle enters the monitored area around the intersection (from either lane) it appears as a yellow indicator moving toward the center of the display. The position of the lead vehicle in the display moves toward the intersection as arrival time decreases. When the lead vehicle is within the distance or arrival time that defines the safe gap, the indicator turns red and continues through the intersection. When the lead vehicle moves past the intersection, it disappears. In this way, information about the location, speed, and distance of lead major-road vehicles is presented to minor-road drivers and judgments are made about when it is unsafe to enter. Signage would be needed for the minor road to explain how the system works.
4. Diagram 
5. Options/Variants The size of the safe gap can be adjusted based on the type of vehicle detected on the minor road and pavement surface conditions. Sign can be placed at different locations (below STOP sign, at median, before STOP

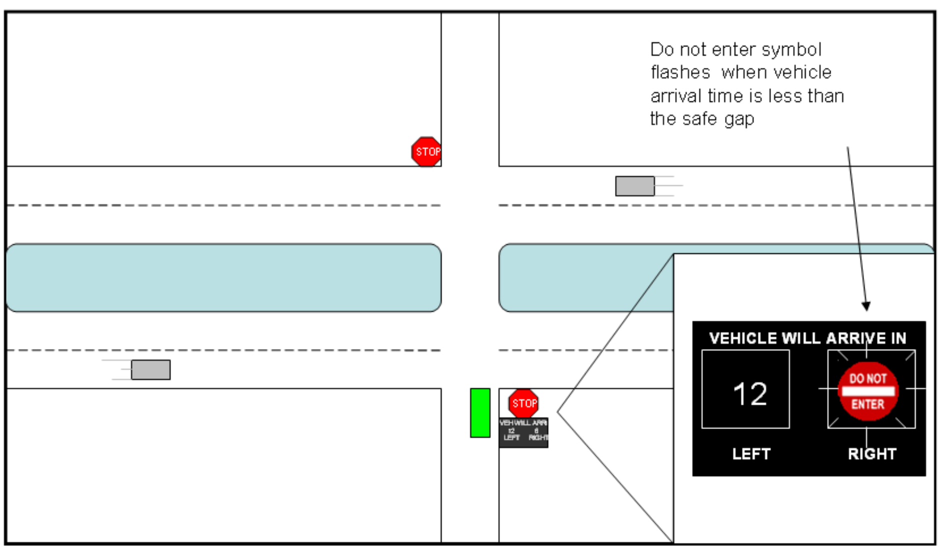
sign, etc.). The amount of the intersection that is monitored and depicted can be increased. This may be particularly useful for intersections that have known sight distance problems since portions of the intersection that fall outside of the sight lines for minor-road drivers could be shown in the display. A different icon can be used to represent the major-road vehicles. Other icons include a small car or a large block of color filling the lane. An additional color may be added to represent an intermediate distance or arrival time (i.e., similar to the yellow light on a stoplight). Multiple vehicles approaching in all four lanes may be displayed separately.
6. Limitations/Caveats The sign is visually complex and interpreting symbols can be cognitively demanding and error prone. There exists a potential for rapid fluctuation between yellow and red states (especially when traffic volumes are high and there are vehicles in multiple lanes). For example, if multiple cars are in one lane, more than one symbol could be shown and depending on approach speed and arrival time, yellow and red states could change rapidly. This may be overwhelming and confusing for the minor-road driver. Minor-road drivers may have problems mapping the icons to actual major-road vehicles. This will be more of an issue as traffic volumes and the number of lanes on the major road increase. Displaying multiple lanes and multiple vehicles in a platoon is difficult to display in a simple format. There is insufficient display resolution to include multiple vehicles in each direction that will not be cognitively overwhelming to the driver.

1. Title Hazard Beacon
2. Content Domain Primary Content A. Presence of vehicles that make up gaps D. Judge whether a gap is safe Secondary Content F. Alert minor-road drivers to the presence of the intersection I. System state
3. Description A beacon or light is placed above the STOP sign in order to raise the awareness of minor-road drivers to dangerous conditions of major-road traffic. The light is always white to alert minor-road drivers to the presence of the intersection. The light also flashes when the vehicle first arrives to indicate the system is working. When the lead major-road vehicle in either direction is within the distance or arrival time that defines the safe gap (i.e., < 8 s) OR is speeding (i.e., > 10 mph over posted limit), the beacon flashes red until the hazardous condition(s) has passed. A sign below the STOP sign will read DANGEROUS CROSSING WHEN FLASHING RED. This is intended to alert drivers to potentially dangerous conditions rather than provide information regarding specific vehicles or specific gaps.
4. Diagram 
5. Options/Variants The size of the safe gap can be adjusted based on the type of vehicle detected on the minor road, pavement surface conditions, or speed. Different speeding criteria can be used depending on the intersection. The default is > 10 mph.

	The criteria to activate the red light could be modified to a detected speeding vehicle AND an unsafe gap. The amount of the intersection that is monitored can be changed. This may be particularly useful for intersections that have known sight distance problems. The white light could flash as the minor-road vehicle approaches the STOP sign. This could indicate the system is working and further increase driver awareness of the intersection.
6. Limitations/Caveats	
	This is a general, non-specific hazard warning. Using multiple criteria from any direction makes the warning hard to interpret on the basis of the signal alone, thus the appropriate action to take is also ambiguous. There may be some issues related to text legibility and comprehension (especially for older drivers). This will need to be tested using a diverse driver population.

1. Title Speedometer
2. Content Domain Primary Content A. Presence of vehicles that make up gaps B. Convey speed, distance, and arrival time Secondary Content F. Alert minor-road drivers to the presence of the intersection I. System state
3. Description Drivers (and older drivers in particular) often have difficulty judging the speed of fast-moving vehicles. This system draws attention to the speed of the lead major-road vehicle in each direction. Speed is displayed on a white background with black text, much like a speed limit sign. When the lead major-road vehicle in either direction is traveling more than 10 mph greater than the posted limit, the speed text flashes and changes to white and the background changes to red. This should help minor-road drivers (and especially older drivers) be aware that larger safe gaps are needed because major-road vehicles are traveling faster than expected. Like the hybrid interface, when no vehicles are present, the speed box is left blank. This will help make drivers aware of the fact that major-road vehicles are present and also help draw attention to the presence of major-road vehicles when sight lines are restricted. Also like the Hybrid interface, when the system is not working, a black flashing question mark "?" is displayed in the left and right speed boxes (normal white background). The speed panels are also staggered to help the driver better map the speed information to the spatial location of the relevant vehicle(s). A double mounting pole is used to increase crashworthiness.
4. Diagram 

5. Options/Variants A flashing icon can be used to indicate a speeding car rather than display absolute speed. Speeding criteria is the same as "Hazard Beacon." The default is > 10 mph based on the posted speed. The amount of the intersection that is monitored can be changed. This may be particularly useful for intersections that have known sight distance problems. Separate signs for left and right can be placed on corresponding sides of the road.
6. Limitations/Caveats Minor-road drivers may have problems interpreting absolute speed (Hills, 1980). In other words, drivers may not perceive speed as a numerical value or may not be sensitive to small differences in speed. Minor-road drivers could have problems mapping speed values to specific major-road vehicles. This will be more of an issue as traffic volumes and the number of lanes on the major road increase. There may be some issues related to text legibility and comprehension (especially for older drivers). This will need to be tested using a diverse driver population.

1. Title Countdown
2. Content Domain Primary Content A. Presence of vehicles that make up gaps B. Convey speed, distance, and arrival time D. Judge whether a gap is safe Secondary Content F. Alert minor-road drivers to the presence of the intersection
3. Description This system draws attention to the arrival time of major-road vehicles by tracking the lead vehicle starting at a distance of 15 s from the intersection. Arrival time counts down in 1 s increments as the major-road vehicle approaches. A flashing or constant symbol (e.g., DO NOT ENTER) is used when vehicles are within the arrival time that defines the safe gap (e.g., 8 s for a passenger car turning left on four-lane highway). This should help minor-road drivers judge when it is safe to proceed. Drivers are also made aware of the fact that major-road vehicles are present since the sign will not activate unless a vehicle is approaching from the left or right. This feature will draw attention to the presence of major-road vehicles when sight lines are restricted.
4. Diagram 
5. Options/Variants Same as "Speedometer." The size of the safe gap can be adjusted based on the type of vehicle detected on the minor road and pavement surface conditions. The amount of the intersection that is monitored can be changed. This may be particularly useful for intersections that have known sight distance problems. The

	current default is 15 s from the intersection. Arrival time can count down in different increments (1 s, 0.5 s, 0.1 s, etc.). The current default is 1 s. Instead of flashing the DO NOT ENTER symbol, the actual arrival time could flash and change to red when major-road vehicles are within the time that defines the safe gap.
6. Limitations/Caveats	
	Drivers may not be able to interpret absolute values for arrival time. In other words, drivers may not perceive arrival time as a numerical value or may not be sensitive to small differences in arrival time. Drivers may not be aware that arrival time units are seconds. Supplementary signage may be needed. The actual timing of the countdown will not be at a constant rate of 1 s since arrival time varies with approach speed. This may confuse the minor-road driver.

Section Summary

- The general function and the basic display components of nine proposed concepts were described.
- Dumb Pole: A fixed pole placed on both the near and far sides of the road at a distance equivalent to the safe gap. When a vehicle passes the pole, it is unsafe.
- Smart Pole: Same as "Dumb Pole," but a light on top of the pole changes to red when a major-road vehicle passes it.
- Phi-Poles: A series of poles on both the near and far sides of the road that light up red to convey that a gap is unsafe.
- Pole Row: Median placed poles partially obscure major-road vehicles, which may help minor-road drivers detect and judge the speed of the vehicles.
- Hybrid: Arrival time information is shown in real-time for both near-side (left) and far-side (right) vehicles in an integrated display. A single prohibitive message is shown based on the same logic used for the Split-hybrid interface.
- Pac-Man: Displays major-road vehicles as moving elements and conveys speed, distance, and gap information.
- Hazard Beacon: A non-specific red warning light that activates when major-road vehicles in either direction are within the safe gap or are speeding (> 10 mph above posted limit).
- Speedometer: Displays the speed of approaching vehicles from the left and right. The background changes to red and the speed flashes when speeds are greater than expected (> 10 mph above posed limit).
- Countdown: Displays the arrival time of approaching vehicles from the left or right. Flashes when arrival times are within the safe time gap (< 8 s for a passenger car turning left on four-lane highway).

Appendix D
Simulator Study Materials

Recruitment Screener

RECRUITMENT SCREENING

Criteria	Response	COMMENTS	OK
Do you have a valid driver's license?	☐Yes ☐ No	Must be YES	
How old are you?	___ Years	Must be 20-40 OR 55-75	
Are you?	☐ Male ☐ Female		
What is your native language? If other:	☐ English ☐ Other	Prefer ENGLISH	
Have you participated in a previous experiment in our lab? If yes, describe:	☐ Yes ☐ No	Either YES or NO = OK to participate	
SIMULATOR SICKNESS QUESTIONS			
Do you have any health problems that affect your driving? If yes, what:	☐ Yes ☐ No	If yes, CANNOT participate	
Do you experience inner ear problems, dizziness, vertigo, or balance problems?	☐ Yes ☐ No	If yes, increases risk for simulator sickness	
Do you have a history of motion sickness?	☐ Yes ☐ No	If yes, CANNOT participate	
Do you have a history of claustrophobia?	☐ Yes ☐ No	If yes, CANNOT participate	
Are you suffering from any lingering effects of stroke, tumor, head trauma, or infection?	☐ Yes ☐ No	If yes, increases risk for simulator sickness	

Do you or have you ever suffered from epileptic seizures?	☐ Yes ☐ No	If yes, CANNOT participate	
Do you have a history of migraines?	☐ Yes ☐ No	If yes, increases risk for simulator sickness	
Is there any possibility that you are pregnant?	☐ Yes ☐ No	If yes, CANNOT participate	
MEDICAL QUESTIONS			
Do you have healthy normal vision (20/40 corrected or uncorrected)?	☐ Yes ☐ No	Must be YES	
Do you wear glasses to drive?	☐ Yes ☐ No	Prefer NO, glasses OK for older drivers	
Do you wear contact lenses to drive?	☐ Yes ☐ No	Contacts are OK	
Are you color blind?	☐ Yes ☐ No	Must be NO	
Are you currently being treated for a serious medical condition or mental illness? If yes: What: Since when:	☐ Yes ☐ No	Must be NO	
Are you currently taking any medications? If yes: What: Since when:	☐ Yes ☐ No	OK if reporting no side effects that affect driving (see below)	
Are you experiencing any side effects as a result of this medication?	☐ Yes ☐ No	OK if NOT drowsiness, vision, dizziness, memory, attention	

If yes, what side effects? If other:	☐ Drowsiness ☐ Vision ☐ Dizziness ☐ Mood ☐ Memory ☐ Attention ☐ Aches/Pain ☐ Movement ☐ Speech ☐ Other		

REMINDERS

It is important that you do not use any alcohol within 24 hours of participation.

It is important that you do not use recreational drugs within one week of participating.

It is important that you bring your driver's license and glasses if you use them to drive.

As a reminder, we will contact you 24 hours before your scheduled participation.

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 current employment status: ☐ Full Time ☐ Part Time

☐ Retired ☐ Student

☐ Unemployed ☐ Other:____

4. Where do you currently live: ☐ Rural area ☐ Urban area

☐ Suburban area ☐ Other:________________________

Part II. Driving Experience

5. How many years have you had your driver's license (excluding learner's permit)?

_____________ year(s)

6. On average, how many miles do you drive per year?_______________ miles / year

7. How often did you drive last month?

☐	☐	☐	☐	☐
Never	Rarely	Sometimes	Most Days	Every Day

8. Do you drive frequently on *Highways*? ☐ Yes ☐ No

9. Do you drive frequently on *Urban Roads*? ☐ Yes ☐ No

10. Do you drive frequently on *Rural Roads*? ☐ Yes ☐ No

11. In the last 5 years, have you ever been the driver in a motor-vehicle accident?

☐ 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 $1,000

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 $1,000, or both.

If yes, how many times were you cited as being at fault in the accident? _

12. What type of vehicle do you drive most often (check one)?

☐ Motorcycle ☐ Passenger Car

☐ Pick-Up Truck ☐ Sport utility vehicle

☐ Van or Minivan ☐ Other:_______________________________

13. How would you rate your driving skill compared to your peers?

☐	☐	☐	☐	☐
Very bad driver	Bad driver	Average driver	Good driver	Very good driver

14. How would you rate your overall health compared to your peers?

☐	☐	☐	☐	☐
Very Poor	Poor	Average	Good	Excellent

Mental Workload Ratings

Think about the maneuver you just completed to cross the intersection only (i.e., do not include the drive to reach the intersection). Please place a vertical line through 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 to look, searching, did you need to do?

LOW — HIGH

Physical Demand
How much physical activity was required?

LOW — HIGH

Time Pressure
Did you feel under pressure to complete the driving task in the time available?

LOW — HIGH

Performance
How satisfied were you with your level of performance?

POOR — GOOD

Effort
How hard did you have to work?

LOW — HIGH

Frustration Level
How insecure, discouraged, irritated, stressed and annoyed were you during the maneuver?

LOW — HIGH

Post-Condition Questionnaire

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

Example:
I feel happy today.

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

1. I felt confident using this sign.

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

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

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

3. Using this sign made me feel safer.

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

4. I trusted the information provided by the sign.

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

5. I like this sign.

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

6. The sign was reliable.

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

7. I felt this sign was easy to understand.

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

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

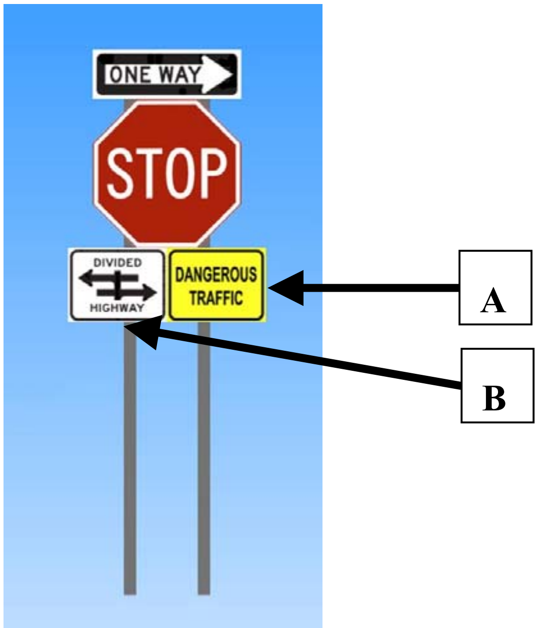
1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

9. This sign was useful.

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

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

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



11. Please describe in your own words how this sign worked. What information does it provide?

12. Describe your understanding of the indicated features.

A:

B: (more space provided on actual questionnaire)

13. Did you use information provided by the sign to help make your decisions during the crossing maneuver? (circle your answer)

Yes / No

Please explain your answer.

14. What did you like most about this sign? Please explain.

15. What did you like least about this sign? Please explain.

16. Use the space below to make additional comments about this sign.

Usability

Please rate your opinion of each sign using the items listed next to them.

For example, if you thought the sign was very easy to use but required a lot of effort to learn, you might respond as follows:

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

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

Note: This format was used for each sign type. Only one sign is shown here.

Sign Ranking

Please rank the signs from 1 to 5 (1 = best; 5 = least) based on your preference and how helpful you felt each sign was for making the crossing maneuver. Please explain your ranking in the spaces provided.

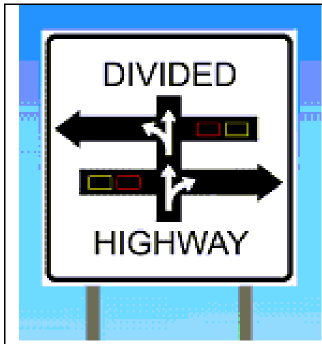
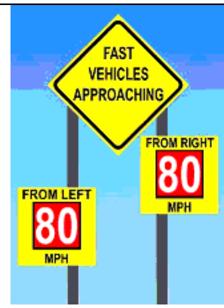
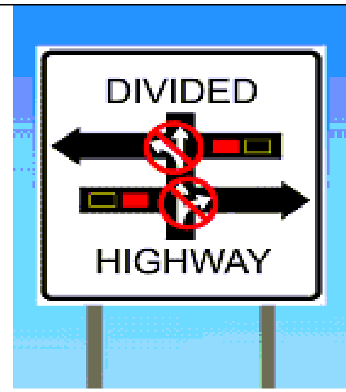
<table>
<tr>
<td>
</td>
<td>
</td>
<td>

One of these signs is located on the right side of the road next to the stop sign and another is located in the median (two signs total at intersection). The signs above show two possible messages that can appear on each sign.</td>
<td>

One of these signs is located on the left side of the road at the STOP sign and another is located in the median. The signs above show two of three possible icons that can appear on this sign. The third icon that can appear on this sign is: </td>
<td>

One of these signs is located on the left side of the road when stopped at STOP sign, and another is located in the median on the right side (two signs at intersection). The signs above show two of three possible icons that can appear on the sign. The other possible icon that can appear on the sign is: </td>
</tr>
<tr>
<td>Rank___</td>
<td>Rank___</td>
<td>Rank___</td>
<td>Rank___</td>
<td>Rank___</td>
</tr>
</table>

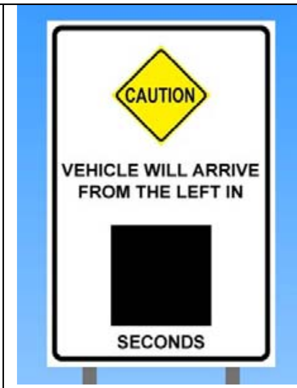
Sign State Questionnaire

 ___ Stop and wait ___ Proceed to median and wait ___ Cross entire intersection	 ___ Stop and wait ___ Proceed to median and wait ___ Cross entire intersection	 ___ Stop and wait ___ Proceed to median and wait ___ Cross entire intersection	 ___ Stop and wait ___ Proceed to median and wait ___ Cross entire intersection
 ___ Stop and wait ___ Proceed to median and wait ___ Cross entire intersection	 ___ Stop and wait ___ Proceed to median and wait ___ Cross entire intersection	 ___ Stop and wait ___ Proceed to median and wait ___ Cross entire intersection	 ___ Stop and wait ___ Proceed to median and wait ___ Cross entire intersection

___ Stop and wait
___ Proceed to median and wait
___ Cross entire intersection

___ Stop and wait
___ Proceed to median and wait
___ Cross entire intersection

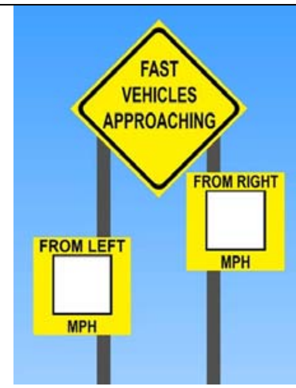
___ Stop and wait
___ Proceed to median and wait
___ Cross entire intersection



___Stop and wait
___ Proceed to median and wait
___ Cross entire intersection

___ Stop and wait
___ Proceed to median and wait
___ Cross entire intersection

___ Stop and wait
___ Proceed to median and wait
___ Cross entire intersection



___ Stop and wait
___ Proceed to median and wait
___ Cross entire intersection

___ Stop and wait
___ Proceed to median and wait
___ Cross entire intersection

Appendix E
Simulated Traffic Stream

The IDS traffic consisted of two separate streams of traffic. The southbound stream of traffic consisted of 60 vehicles. The northbound stream of traffic consisted of 56 vehicles. At the start of the scenario, both streams began moving. The vehicles were positioned such that they would cross the intersection in a predetermined pattern. The table below describes the vehicle pattern it terms of determined arrival time to the intersection. These arrival times constitute the gaps (or lags) within the traffic stream.

Gap: This is the time, in seconds, between that particular vehicle and the vehicle before it. For example, Vehicle #5 southbound arrived at the intersection 3 s after Vehicle #4 southbound.

Time at intersection: This is the absolute time when the vehicle arrived at the intersection. Time is in seconds. Time 0 is the start of the scenario. Time 60 is one minute into the scenario.

Time at intersection	Southbound gap	Northbound gap	Rationale
0	3	10	Hold driver at intersection & Permit one-stage strategy
3	3		
6	3		
9	3		
10		10	
12	3		
15	3		
18	3		
20		10	
21	3		
24	3		
27	3		
30	3	10	
33	3		
36	3		
39	3		
40		10	
42	3		
45	3		
48	3		
50		10	
51	3		
54	3		
57	3		
60	3	10	
63	3		
66	3		
69	3		
70		10	
72	3		
75	3		

78	3		
80		10	
81	3		
84	3		
87	3		
90	3	10	
93	3		
96	3		
99	3		
100		10	
102	3		
105	3		
108	3		
110		10	
111	3		
114	3		
117	3		
120	5	3	Permit 2-stage strategy
123		3	
125	3		
126		3	
128	3		
129		3	
131	3		
132		3	
134	6		
135		3	
138		3	
140	3		
141		3	
143	3		
144		3	
146	3		
147		3	
149	7		
150		3	
153		3	
156	3	3	
159	3	3	
162	3	3	
165	8	3	
168		3	
171		3	
173	3		
174		3	
176	3		
177		3	
179	3		

180		3	
182	9		
183		3	
186		3	
189		3	
191	3		
192		3	
194	3		
195		3	
197	3		
198			
200			
201		3	
204		3	
207		3	
210		9	
219		3	
222		10	
232		3	
235		11	
246		3	
249		12	
261		3	
264		13	
277		3	
280		14	
294		3	
297		15	
312		3	