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16. Abstract

Engineers with the Texas Department of Transportation (TxDOT) frequently make changes to traffic control devices (TCDs) to improve intersection safety. To use available funds judiciously, engineers make incremental changes in order to select the least costly yet effective improvements. The goal of this project was to obtain a better understanding of modern TCD capabilities. Researchers conducted the following tasks: literature review, crash data examination, TxDOT district survey, laboratory survey, field study, and development of principles for selecting TCDs. Adding flashing lights to signs, either through beacons or embedded light-emitting diodes (LEDs), serves two purposes: to attract attention and to convey a message. The findings of this research demonstrate that while the lights do improve detection distance, legibility distance of the message suffers at night due to the glare of the lights. Cautious engineering judgment should be used when adding lights to any word message sign beyond a Stop sign because the legibility distance for the words will be shorter than when lights are not present. For Stop signs, the unique color and shape of these traffic control devices prompts drivers' responses to them long before the word "stop" is actually read. The driving study found no difference in sign detection at night between those with an overhead flashing beacon and those where the ground-mounted sign has embedded LEDs. The detection distances observed for the signs with lights in this study were extremely long, over 2000 ft in most cases. The other general observation regarding the magnitude of the results is that for all of the Stop signs, both lit and unlit, the detection distance for sign recognition was always greater than stopping sight distance. So the existing static Stop signs are sufficiently visible for an alert driver under clear weather. The research project found that there appears to be a benefit to detection from dimming the LED brightness at night. The LED sign set on the high brightness setting was detected furthest during the day, while the lower setting was detected best at night. The research concluded with guidance principles to consider when selecting countermeasures for rural stop-controlled intersections.

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DISCLAIMER

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CHAPTER 1

INTRODUCTION

In Texas, about one-third of all crashes on rural highways occur at intersections. The combination of high vehicle speeds and multiple, complex guidance and navigational choices at rural intersections complicate the driving task and increase the potential for a severe crash. Various design and traffic control device (TCD) improvements can be implemented at intersections to decrease the likelihood of a crash. The most common objectives of these improvements are to increase the conspicuity of the intersection (to decrease Stop sign violations) and to provide more information about approaching traffic on the major road. In order to use available funds judiciously, traffic engineers make incremental changes in order to select the least costly yet effective improvement. The steps engineers use to determine the incremental improvements and to decide whether a given TCD will be used uniquely or in combination with other devices vary.

This research evaluated different TCD alternatives for a rural stop-controlled intersection and evaluated reasonable decision criteria and sequences for implementing progressively more expensive devices. It focused on Stop signs with supplemental characteristics such as beacons and light emitting diodes (LEDs).

RESEARCH OBJECTIVES

The objectives of Texas Department of Transportation (TxDOT) Project 0-6462 are as follows:

- Identify traffic control device alternatives for stop-controlled intersections.
- Determine characteristics of each alternative, such as costs, maintenance requirements, driver understanding, and driver reactions.
- Develop guidelines that can be used to select appropriate traffic control device alternatives for a rural stop-controlled intersection.

REPORT ORGANIZATION

This report has eight chapters.

- Chapter 1 **Introduction—**describes the objective of the project and the report organization.
- Chapter 2 **Literature Review—**includes a summary of previous research relevant to the subjects of traffic control device alternatives at rural stop-controlled intersections, strategies used to select alternatives, safety, and vendor products.
- Chapter 3 **Crash Characteristics for Texas Rural Stop-Controlled Intersections—** provides a review of the current knowledge regarding safety at rural stop-controlled intersection. It then documents the efforts to identify the characteristics of crashes for Texas rural stop-controlled intersections.
- Chapter 4 **Expand Knowledge of Selected Traffic Control Device Alternatives—** documents the efforts to collect additional information for traffic control devices selected

for evaluation. This additional information included costs, maintenance experience, and safety experiences and was obtained by conducting a survey of selected TxDOT districts. The survey also collected the order in which improvements are made to TCDs by TxDOT districts to improve safety at intersections.

- Chapter 5 **Lab Study to Identify Driver Reaction to Traffic Control Devices with LEDs or Beacons—**documents a lab study which examined driver reactions to selected modern traffic control devices with various features which purport to enhance driver visibility, comprehension, and compliance.
- Chapter 6 **Closed-Course Study to Identify Driver Detection of Traffic Control Devices—**describes the methodology and results from the Closed-Course Study that examined driver detection of traffic control devices.
- Chapter 7 **Guidance for Selecting Treatments for a Rural, Stop-Controlled Intersection—**provides a brief summary of the relevant literature and the TxDOT survey conducted within this research. The final section of this chapter presents principles to consider when selecting a treatment for a rural stop-controlled intersection.
- Chapter 8 **Summary and Conclusions—**provides the summary and key findings from each study along with the conclusions from the research.

CHAPTER 2

LITERATURE REVIEW

INTRODUCTION

The initial task in the project was to gather information from various sources to establish the state-of-the-knowledge on traffic control device alternatives for rural stop-controlled intersections. This chapter provides a summary of the literature with respect to traffic control device alternatives and with respect to safety at rural intersections. It also includes information gathered from a vendor on signs with embedded LEDs.

TRAFFIC CONTROL DEVICE ALTERNATIVES

Several TCD alternatives are available and are being used at rural stop-controlled intersections to improve safety. Following is a synopsis of the literature on relevant traffic control devices.

Changes to the Stop Sign

Previous studies have evaluated effectiveness of changes made to the Stop sign, like increased size, improved retroreflectivity, or dual-posting of Stop signs, in improving the conspicuity of the sign. A field observational test of increasing the size of Stop signs showed that drivers, especially older drivers, braked at greater distances for the largest size Stop sign (*1*). A recent FHWA study conducted a safety evaluation of increasing retroreflectivity of Stop signs using before-after data from South Carolina and Connecticut (*2*). The aggregate analysis indicated that higher retroreflectivity may affect the likelihood of crashes at unsignalized intersections, but the effect was not detectable with the study design and available sample size. The disaggregate analysis concluded that installations at all three-leg intersections were found to have statistically significant reduction in crashes. The disaggregate analysis also showed that the strategy is more effective at lower traffic volumes for motorists approaching the intersection on the minor road.

Various alternatives can improve conspicuity of the sign and increase compliance. The latest addition is LEDs embedded in the face of regular traffic signs. In 2004, researchers studied the effectiveness of flashing LED Stop signs at two locations by analyzing before and after speed data and Stop sign compliance (*3*). The overall rate of vehicles not fully stopping at these intersections was reduced by 29 percent after installation of the flashing LED Stop sign. The flashing signs resulted in no statistically significant effect on vehicular speeds or decelerations on the approaches. The study recommended the use of the flashing LED Stop signs as a special treatment on an as-needed basis.

Arnold and Lantz evaluated the use of flashing LED Stop signs and optical speed bars at three locations in Virginia (*4*). The study showed a statistically significant decrease in approach speeds at the study sites but questioned the practical significance of the decrease. The speed reductions were greater during dusk and nighttime. The study recommends the device as a potential countermeasure for “crash-prone” stop-controlled intersections. Installation of optical bars also caused statistically significant decreases in approach speeds. The study reports that speed decreases were higher when the bars extended across the travel lane. Figure 1 shows an example of optical bars approaching an unsignalized intersection.

Figure 1. Example of Optical Bars (4).

Supplemental Plaques for the Stop Sign

Picha et al. conducted laboratory and field studies to determine ways to improve two-way stop-controlled intersections. Based on the results of their study, they formulated several general guidelines. They suggested that the existence of any one of the following seven conditions may be indicative of a location where drivers may misinterpret a two-way for an all-way stop-controlled intersection (*5*):

- Intersection of two single-jurisdictional roadways in a rural or isolated area.
- Average daily traffic (ADT) that is similar on all approaches to the intersection but is not large enough to warrant the use of a traffic signal.
- A rate of four or more traffic conflicts for every 1000 vehicles.
- Right-angle crash frequency of three or more per year.
- A system of roadway intersections not consistent with respect to traffic control schemes.
- Similar high speeds (greater than 50 mph) on all approaches.
- Similar cross-sectional elements (e.g., number of lanes and widths) on all approaches.

If one of these conditions is met, Picha et al. recommended adding the supplemental Cross Traffic Does Not Stop sign with a two-way arrow. One review of safety studies by Gattis found mixed results in crash frequency as a result of cross traffic signing, but does point out that these supplemental plaques may help specifically at locations experiencing high numbers of crashes due to driver errors in understanding right-of-way (ROW) (*6*). Another study by the same author tested driver comprehension of different styles of the Cross Traffic Does Not Stop plaque and found that the 2000 *Manual on Uniform Traffic Devices* (MUTCD) version is not well understood by motorists (*7*).

Houten and Retting compared the effectiveness of using an LED sign that featured animated eyes scanning left and right to prompt drivers to look left and right for approaching traffic with a 'look both ways' supplemental plaque at three sites (*8*). The results of the study indicate that introduction of the animated eyes prompt increased the percentage of vehicles coming to a complete stop at all the study sites, whereas the look both ways sign was not associated with any change in behavior at the one site it was introduced. However, the authors recommend further research to understand sustainable benefits of the improvement. Figure 2 shows an example of using LED animated eyes look both ways supplemental plaque.

Figure 2. 'Look Both Ways' Prompt and the Animated Eye Prompt (8).

Advance Warning of Stop Using Beacons

Zwahlen found that drivers at night approached a stop-controlled intersection at lower speeds when a Stop Ahead text sign was present. The advance warning sign had no noticeable effect on eye glance behavior at night or during the day (*9*). Hawkins et al. conducted a survey of 1745 Texas drivers to assess their comprehension of selected traffic control devices. The survey for comprehension of the Stop Ahead symbol sign (W3-1a of the MUTCD) indicated that 87 percent of the drivers understood the sign (*10*). Figure 3 shows an example of the Stop Ahead symbol warning sign.

Researchers believe the addition of a yellow beacon on a Stop Ahead or Intersection Ahead Sign improves the conspicuity of the advance warning sign. Figure 4 shows an example of an advance warning sign with yellow flashing beacon.

Several studies have examined advance warning signs with beacons for high-speed signalized intersections (*11*, *12*, *13*, *14*). A late 1990s study used 106 intersections to identify the effects of advance warning flashers (AWFs) (*11*). The results from the study indicated that intersections equipped with AWFs have a lower frequency of crashes than similar locations without AWFs.

However, the results were not statistically significant. A mid-1990s study found that the impacts of the different signs vary among intersections with tangent and curved approaches (*12*). The study showed that the Prepare to Stop When Flashing (PTSWF) and Flashing Symbolic Signal Ahead (FSSA) signs generally have similar effects on driver behavior. The authors recommend using the Continuously Flashing Symbolic Signal Ahead (CFSSA) sign before using the PTSWF sign because the PTSWF and FSSA signs had undesirable effects on vehicle speeds. When flashers are off and the signal indication was green or yellow, drivers on an approach with a PTSWF or FSSA sign generally increase their speed in an apparent attempt "to beat the light." This behavior is more evident on intersections with a tangent approach than on intersections with a curved approach because the roadway curvature provides restrictions to the drivers on the selection of their speed. Figure 5 shows an example of an advance warning flashers for a signalized intersection ahead.

Source: http://tti.tamu.edu/documents/4048-2.pdf

Figure 3. Stop Ahead Symbol Warning Sign.

Source: http://tti.tamu.edu/documents/4048-2.pdf

Figure 4. Example of Yellow Beacon on Advance Warning Stop Sign.

http://www.tfhrc.gov/pubrds/07jan/images/mor6.jpg

Figure 5. Example of Advance Warning with Beacon for a Signalized Intersection.

Source:

Two research projects sponsored by TxDOT developed and made improvements to an Advance Warning of End of Green System (AWEGS) (*15*). AWEGS is unique from other systems with advance warning flashers in that it maintains the existing dilemma zone protection provided by intersection detectors and enhances it by providing an advance warning about the termination of green. Traditional AWF systems could not provide the existing dilemma zone protection provided by the intersection detectors. AWEGS have been installed at seven intersections in Texas, and more are being planned. AWEGS have reduced red light running at most intersections by about 40 percent.

Austin et al. evaluated the effects of prompting and feedback on drivers' stopping at Stop signs (*16*). They conducted the study at two opposing signs in a university campus. A volunteer stood next to the Stop sign holding a poster that read 'Please Stop – I care' with 'Thank you for stopping' on the reverse. The volunteer held the poster such that drivers approaching one of the Stop signs could read it. The volunteer showed the 'thank you' side whenever the approaching driver came to a complete stop. The study suggests that prompting and feedback increased complete stops. However, the study recommends further research to investigate whether the effect was that of the prompt or merely having a person holding a sign on the side of the road.

Pavement Markings/Rumble Strips

Agent noted that providing drivers adequate warning of the intersection is of primary importance. He recommends stop bar placement on the stop approaches for minor streets to encourage drivers to stop at a location that maximizes their sight distance of vehicles on the through roadway (*17*). He noted that the number of side-street vehicles that do not stop at the Stop sign illustrates the need for adequate warning on the stop approach. Figure 6 shows an example of use of stop bar at a rural intersection.

Figure 6. Use of Stop Bar at a Rural Intersection.

Pavement markings can also provide advance warning for intersections. Figure 7 shows an example of advance warning pavement markings. A 2008 Federal Highway Administration (FHWA) before and after study using data collected in Arkansas, Maryland, and Minnesota evaluated the effectiveness of STOP AHEAD pavement markings (*18*). Empirical Bayes methods were incorporated in the analysis. The results show a reduction in crashes with the installation of STOP AHEAD pavement markings. The aggregate analysis indicates a total crash reduction of at least 15 percent. The disaggregate analysis indicates that the reduction may not be consistent across intersection types; however, it provides evidence for those locations where this strategy may be most effective. The study concluded that installation of STOP AHEAD pavement markings has the potential to reduce crashes cost effectively, particularly at three-leg and all-way stop-controlled (AWSC) intersections with high crash frequencies.

Source: http://tti.tamu.edu/documents/4048-2.pdf

Figure 7. Example of Advance Warning Pavement Markings.

Another traffic control device used for advance warning is approach rumble strips. Approach rumble strips consist of intermittent narrow, transverse areas of rough-textured or slightly raised or depressed road surface that alert drivers to unusual motor vehicle traffic conditions. Through noise and vibration they attract the driver's attention to such features as unexpected changes in alignment and to conditions requiring a stop (*19*). Harwood reported that rumble strips placed on intersection approaches can provide a reduction of at least 50 percent in the types of crashes most susceptible to correction, including crashes involving running through a Stop sign (*20*). In an evaluation conducted by the Virginia Department of Highways and Transportation in the early 1980s in which rumble strips were installed at stop-controlled intersections, the treatment reduced total crash frequency by 37 percent, fatal crashes by 93 percent, injury crashes by 37 percent and property-damage-only (PDO) crashes by 25 percent (*21*). In the study, 39 of the 141 crashes in the before period were classified as susceptible to correction by rumble strip installation, particularly rear-end crashes and ran-Stop-sign crashes. The rumble strips reduced the crash rate for these crash types by 89 percent. Additionally, a study by Zaidel et al. indicated that transverse in-lane rumble strips maintained their speed-reducing effects when evaluated after one year (*22*). Figure 8 shows examples of approach rumble strips.

Source: http://tti.tamu.edu/documents/4048-2.pdf

Figure 8. Examples of Approach Rumble Strips.

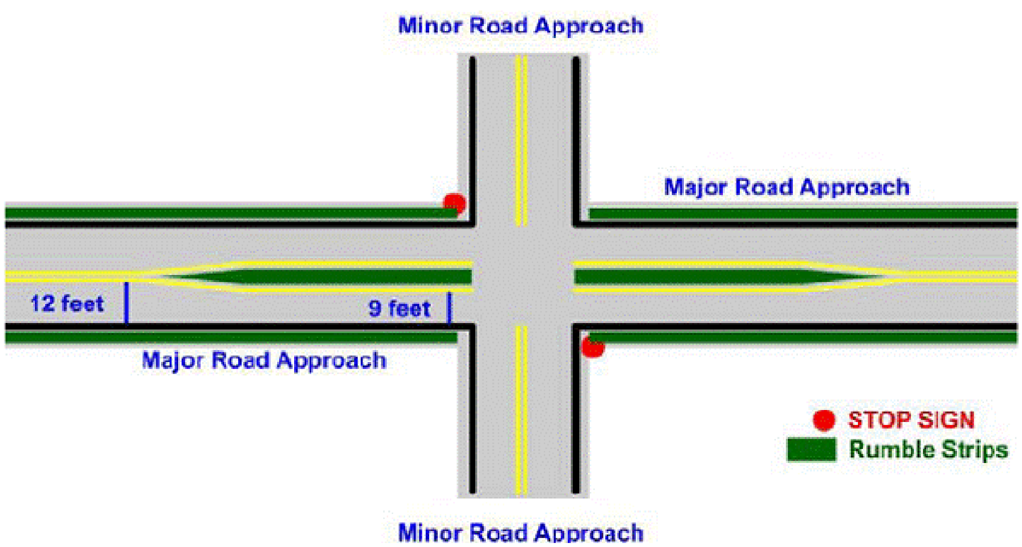
FHWA (*23*) explored two concepts to reduce speed and improve safety at rural two-lane, two-way roadways with two-way Stop-controlled (TWSC) intersections:

- Concept 1: Rumble strips on outside shoulders and in a painted yellow median island on the major road approaches (see Figure 9).
- Concept 2: Channelizing separator islands on side road approaches with supplemental Stop signs (see Figure 10).

The general conclusion from the research was that installation of Concepts 1 and 2 have positive operational and safety effects. The lane narrowing in Concept 1 resulted in significantly reduced speeds on the major road approaches. The results were consistent across the nine sites. The minor road splitter-island concept (Concept 2) improved driver compliance as well as reduced speeds on the minor approaches. While the results for the minor road splitter-island concept were based on just one site, the authors felt the initial indications were promising.

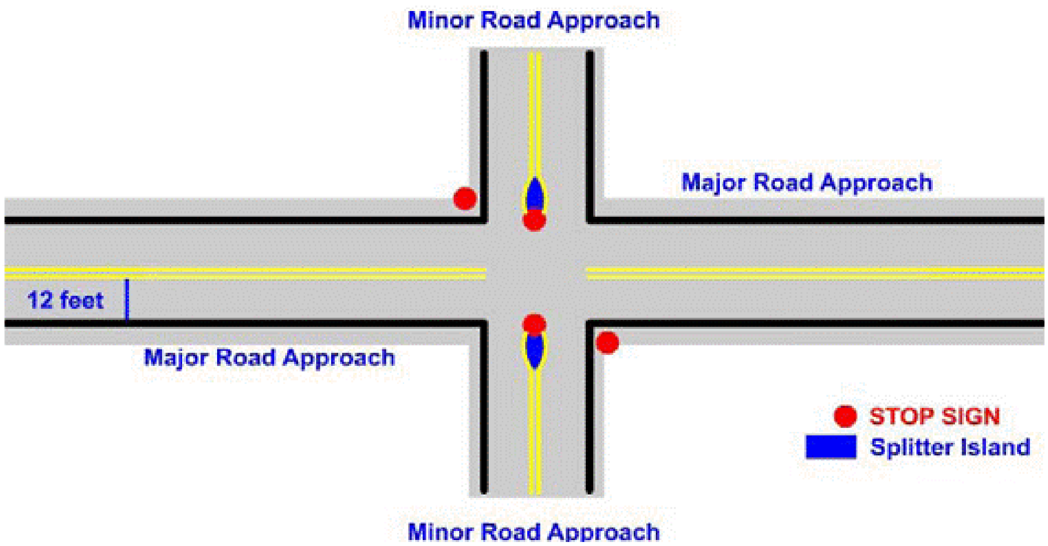
The authors found a general reduction in crashes associated with the implementation of Concepts 1 and 2 based on limited after data. For the lane narrowing concept, total, fatal/injury, and angle crashes decreased in the after period, but rear-end crashes increased at some sites. For the minor road splitter-island concept, the crash rate decreased for all categories in the after period.

Based on the relatively low cost and initial effectiveness of Concepts 1 and 2 with respect to operational and safety measures, it is expected that these strategies will prove to be cost-effective methods for improving intersection safety. The authors concluded that more comprehensive analysis is needed before they can recommend wide-scale implementation. They also recommend developing guidelines for where these strategies should be implemented.



Source: http://www.fhwa.dot.gov/publications/research/safety/08063/08063.pdf

Figure 9. Concept 1 from FHWA Study (*23*).



Source: http://www.fhwa.dot.gov/publications/research/safety/08063/08063.pdf

Figure 10. Concept 2 from FHWA Study (*23*).

Advance Warning on Major Street

The Advance Warning for Intersection Ahead sign is another TCD that warns major road users to expect cross-traffic. Figure 11 shows an example of an Intersection Ahead Warning sign for a major road.

Stokes et al. identified factors that contribute to crashes at two-way stop-controlled intersections and determined traffic control devices or other measures that could be effective in reducing the frequency of these crashes (*24*). They concluded that disregard for Stop signs and other traffic control devices is not the primary cause of crashes at rural two-way stop-controlled intersections. The majority of crashes appear to be due to drivers who enter the major roadway and do not (or cannot) accelerate quickly enough to avoid being struck by major roadway vehicles. This suggests that drivers on the minor roadway either did not see oncoming vehicles or failed to accurately estimate the speeds of oncoming vehicles on the major roadway. On the basis of these conclusions, they recommended that the Kansas Department of Transportation (DOT) consider implementing signing treatments directed at reducing the speeds of motorists on the major roadway. Figure 12 shows an example of a Reduced Speed Ahead warning sign.

Figure 11. Example of Intersection Ahead Warning Sign for Major Road.

Source: http://www.trafficsign.us/650/warn/w3-5.gif

Figure 12. Reduced Speed Ahead Warning Sign for Major Road.

Intersection Control Beacons

Intersection Control Beacons are used in conjunction with Stop signs at isolated intersections or intersections having sight distance obstructions. Research findings recommend that they not be used at Y-intersections, offset intersections, or intersections with more than four legs because the geometry of these intersections frequently does not provide an adequate line of sight from all intersection legs to a center-mounted beacon (*19*). Figure 13 shows examples of use of intersection control beacons.

Source: http://www.tfhrc.gov/safety/pubs/08048/index.htm

Source: http://tti.tamu.edu/documents/4048-2.pdf

Source: http://tti.tamu.edu/documents/4048-2.pdf

Figure 13. Examples of Intersection Control Beacon.

Several previous studies have examined intersection control beacons. A late 1990s study used two to three years of crash data to analyze right-angle crashes at seven beacon-controlled intersections (*25*). The data showed a decrease in fatal and serious injury crashes and an increase in minor visible injury and PDO crashes. However, none of these results were statistically significant; therefore, the researchers determined the results to be inconclusive.

A 1996 study by Stackhouse and Cassidy (*26*) used surveys to assess drivers' understanding of overhead and sign-mounted beacons. Drivers indicated that they were more likely to come to a full stop when red overhead flashing beacons were present than when pedestal-mounted red flashers on Stop signs were present. Approximately one-third of drivers stated that under some conditions they had been confused by the meaning of flashing lights. About 38 percent of young drivers and 46 percent of older drivers believed that if an overhead flashing red light was present for the minor approach, an overhead flashing light was also present for the major approach. They concluded that this may lead drivers to assume that the major road traffic stops in all cases when a flashing red overhead beacon is present. The researchers also conducted an analysis using crash experience for three years before and three years after the installation of overhead flashing beacons at eight intersections in Minnesota (*26*). Overall, crashes decreased by 39 percent after the installation of overhead flashers, varying from a 4 percent increase to a 63 percent decrease in crashes.

Because of concerns that the beacons were giving the false perception that all the flashers were red, the Minnesota Department of Transportation (Mn/DOT) is replacing the four-headed overhead flashing beacons with red flashing beacons mounted on the minor road Stop sign and a yellow flashing beacon mounted on the appropriate intersection warning sign for the major approach (*27*). The effectiveness of the practice will be evaluated as part of a pooled fund study per a 2006 Public Roads article (*27*). Figure 14 illustrates examples of the sign-mounted beacons replacing overhead flashing beacons.

Source: http://www.tfhrc.gov/pubrds/06jul/08.htm

Source: Hallmark et al. (*28*)

Figure 14. Examples of Replacement Beacons for Overhead Flashing Beacons.

A recent FHWA study evaluated the safety effectiveness of flashing beacons at stop-controlled intersections (*29*). Three types of flashing beacons—intersection control beacons, beacons mounted on Stop signs, and actuated beacons—were considered collectively at stop-controlled intersections. Although these could be considered three distinct safety strategies with different expected performance, due to sample size limitations these were analyzed collectively in the study. The study included 64 sites in North Carolina and 42 sites in South Carolina, and used the Empirical Bayes study method in the evaluation. For the combined results, the study found the following estimates of reduction in crashes per site-year to be statistically significant:

- 21 percent angle.
- 15 percent injury and fatal.

The disaggregate analysis found the following:

- Flashing beacons seem to be more effective at rural and suburban locations.
- Beacon types include standard beacons that flash all the time and actuated beacons. Some of the actuated flashers are supplemented with a sign that reads "Vehicle Entering When Flashing." Standard beacons can be located overhead or on a Stop sign. There seems to be a significant reduction in crashes at sites with standard beacons mounted on Stop signs. However, only five sites belonged to this category, and so it was not possible to draw definitive conclusions regarding beacon location.

The economic analysis based on the combined results for angle and nonangle crashes from both states indicates that standard flashing beacons and some types of the actuated ones (i.e., the less expensive beacons) are economically justified, but that a benefit cost ratio of 2:1 may not be achievable for the more expensive actuated beacon types.

Illumination

Lighting systems can improve safety at isolated rural at-grade intersections. A fixed lighting system supplements the headlights of automobiles and renders objects that are distant or complex, or that have low contrast, more visible to motorists. However, because of costs, continuous lighting systems are not generally employed in rural areas.

A 2005 study in Quebec evaluated the safety aspect of roadway lighting at rural and near-urban intersections (*30*). The study concluded that any type of lighting improves safety at rural intersections. Lighting significantly reduced the frequency of nighttime crashes, particularly PDO crashes. However, the study found no evidence of a positive effect on personal injury crashes. A report by the FHWA documenting the effectiveness of various types of intersection and traffic control improvements found that intersection lighting had the highest benefit-cost ratio (21:1) of the treatments studied (*31*). A 1999 Minnesota report found that street lighting had a benefit-cost ratio of 15:1 and concluded that its use in reducing nighttime crashes at rural intersections would likely be far more effective than either rumble strips or overhead flashing beacons (*32*).

A synthesis of safety research found that "night crashes can be substantially reduced in number and severity by the use of good road lighting" (*33*). A quantitative meta-analysis of 37 evaluation studies was conducted to determine the safety effects of public lighting and to examine the validity of the combined results (*34*). The results of the evaluation studies were the same for all three environments: urban, rural, and freeway. The analysis concluded that the best estimates of the safety effects of public lighting are, in rounded values, a 65 percent reduction in nighttime fatal crashes, a 30 percent reduction in nighttime injury crashes, and a 15 percent reduction in nighttime PDO crashes.

Hallmark et al. (*28*) evaluated strategies to address nighttime crashes at rural unsignalized intersections with a focus on illumination. They found that locations without lighting had twice as many crashes as locations with lighting. They concluded that the use of lighting at rural intersections is most likely to be effective when there are two or more nighttime crashes in a three-year period.

Intersection Decision Support

Rural Intersection Decision Support (IDS) is a new system being considered for improving the driver's ability to successfully negotiate rural intersections. The system identifies safe gaps in oncoming traffic and communicates this information to the driver using sensing and communication technology (*35*). Researchers used a simulator-based evaluation to test the information concepts of the designs. Figure 15 shows a matrix of interface concepts, highlighting information elements and the roles of the driver and the system.

According to the study, the informational content of Icon and Countdown sign were best understood by drivers, and most drivers reported that they used information from these signs while making crossing decisions. The authors also noted that the signs would require alteration to be included in the MUTCD and that safe gaps individualized to the driver may increase the usability of the signs' content, which needs to be evaluated.

A similar intersection collision avoidance warning system was evaluated by the Maine Department of Transportation at rural stop-controlled intersections with severe sight distance limitations (*36*). The signs warn drivers waiting at the Stop signs on the minor approaches when traffic is approaching from either direction. Another warning sign located on the major approach with limited sight distance warns drivers approaching the intersection when a vehicle is waiting at the Stop signs on the minor approaches. The preliminary study concludes that the signs seem to be fairly well understood. The minor approach drivers selected much longer gaps after the installation. Additionally, the number of traffic conflicts decreased by 35 to 40 percent; however, the highway capacity also decreased and delays increased.

	No Support	Hazard Detection	Gap Information		
	Baseline	Alert	Display	Warn	Advise
Design Concept	STOP Sign (no support)	Hazard Sign	Countdown Sign	Icon Sign	Variable Message Sign (VMS)
					
Driver Role	Driver recognizes hazard, gathers information, decides on safety condition and chooses action.	Driver gathers information, decides on safety condition, and chooses action.	Driver decides on safety condition and chooses action.	Driver must choose action.	Driver chooses to comply.
System Role		System detects hazard and provides alert.	System detects hazard and 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.	System displays prohibited actions (unsafe action advisory).

Figure 15. Matrix of Interface Concepts (*35*).

STRATEGIES

In a study on nighttime crashes (*28*), the authors reported on the progressive approach used by Pierce County, Washington. Pierce County recommends considering the least aggressive alternative first in addressing crash problems at rural intersections, according to the following ascending order of invasiveness:

1. Install Stop Ahead signs.
2. Increase the size of Stop and Stop Ahead signs.
3. Install transverse rumble strips.
4. Install overhead flashing beacon with illumination.

National Cooperative Highway Research Program (NCHRP) Report 500 Volume 5 provides a range of strategies for unsignalized intersection collisions (*37*). The document notes that intersections constitute only a small part of the overall highway system, yet intersection-related crashes constitute more than 50 percent of all crashes in urban areas and over 30 percent in rural areas (*38*). An analysis of California data found that, on average, 1.5 crashes per year occur at unsignalized intersections in rural areas, compared with 2.5 crashes per year in urban areas (*39*). By contrast, urban signalized intersections averaged 4.6 crashes per year. However, these values are averages—many intersections have substantially higher crash frequencies, and these higher frequencies are the appropriate targets for improvements. There are many more unsignalized intersections than signalized, so the number of crashes is undoubtedly much higher at unsignalized intersections nationwide than at signalized intersections. Table 1 lists a sample of the strategies discussed in NCHRP Report 500 Volume 5.

A 2009 paper by Hochstein et al. (*40*) on rural expressway intersections categorized intersection safety treatments into three groups:

- Conflict point management—treatments that remove/reduce, relocate, and/or control the 42 conflict points which occur at a traditional two-way, stop-controlled rural expressway intersection.
- Gap selection aids—countermeasures that aid a driver in selecting a safe gap into or through the expressway traffic stream.
- Intersection recognition devices—countermeasures that enhance intersection conspicuity for either minor road or expressway drivers.

Table 2 lists rural expressway intersection safety treatments identified by Hochstein et al. (*40*).

Forbes and Garvey (*41*) examined whether LED-embedded traffic signs (LETS) are appropriate for use on Canadian roadways, and, if so, developed sound guidelines for their use.

Phase 1 research provided the following framework concerning LETS use in Canada:

- LETS offer increased conspicuity over static signs, but due to their potential to be distracting and to decrease the effectiveness of similar static signs **LETS use should be limited.**
- There is no evidence to suggest that LETS are any more or less effective than a static sign enhanced with a flashing beacon.
- LETS have a distinct advantage over static signs (even those embellished with a flashing beacon) when the LEDs highlight the shape of the sign or the pictogram/legend of the sign.

They noted that embedding LEDs in the face of a traffic sign is one of many possible strategies to increase the conspicuity of a traffic sign. They recommended that practitioners should consider implementing measures in the order presented in Table 3. Table 3 also includes additional guidance regarding the treatments.

Table 1. Sample of Strategies by Implementation Timeframe and Relative Costs Presented in NCHRP Report 500 Volume 5: A Guide for Addressing Unsignalized Intersection Collisions (37).

Timeframe	Strategies	Relative Cost *			
		L	M	D	H
Short (less than 1 year)	• Implement driveway turn restrictions by signing, channelization, or closing median openings	•			
	• Provide bypass lanes on shoulders at T-intersections	•			
	• Clear sight triangles on stop- or yield-controlled approaches to intersections	•			
	• Clear sight triangles in the medians of divided highways near intersections	•			
	• Eliminate parking that restricts sight distance	•			
	• Improve visibility of intersections by providing enhanced signing and delineation	•			
	• Provide a stop bar (or provide a wider stop bar) on minor road approaches	•			
	• Install larger regulatory and warning signs at intersections	•			
	• Call attention to the intersection by installing rumble strips on intersection approaches	•			
	• Provide pavement markings with supplementary messages, such as STOP AHEAD	•			
	• Provide improved maintenance of Stop signs	•			
	• Install flashing beacons at stop-controlled intersections	•			
	• Provide all-way stop control at appropriate intersections	•			
	• Provide targeted enforcement to reduce Stop sign violations and speed enforcement			•	
	• Post appropriate speed limit on intersection approaches	•			
	• Provide turn path markings	•			
	• Provide double yellow centerline on the median opening of a divided highway at intersections	•			
Medium (1 to 2 years)	• Implement driveway closures/relocations		•		
	• Provide left-turn and right-turn lanes or at intersections		•		
	• Provide left-turn and right-turn acceleration lanes at divided highway intersections		•		
	• Provide full-width paved shoulders in intersection areas		•		
	• Convert four-leg intersections to two T-intersections				•
	• Convert offset T-intersections to four-leg intersections				•
	• Realign intersection approaches to reduce or eliminate intersection skew				•
	• Use indirect left-turn treatments to minimize conflicts at divided highway intersections		•		
	• Provide an automated real-time system to inform drivers of the suitability of available gaps for making turning and crossing maneuvers		•		
	• Provide roadside markers or pavement markings to assist drivers in judging the suitability of available gaps for making turning and crossing maneuvers	•			
	• Improve visibility of the intersection by providing lighting			•	
	• Install splitter islands on the minor-road approach to an intersection		•		
	• Provide traffic calming on intersection approaches through a combination of geometrics and traffic control devices		•		
Long (more than 2 years)	• Close or relocate high-risk intersections				•
	• Change horizontal and/or vertical alignment of approaches to provide more sight distance				•
	• Provide roundabouts at appropriate locations				•
*Relative cost to implement and operate, L = low, M = moderate, D = moderate to high, H = high.					

Table 2. Rural Expressway Intersection Safety Treatments (*40*).

Category	Subcategory	Treatment
Conflict point management techniques	Removal or reduction through access control	1. Convert entire expressway corridor to freeway 2. Isolated conversion to grade separation or interchange 3. Close low minor road volume intersections and use frontage roads to direct traffic to major intersections 4. Close median crossovers (right-in, right-out access only) 5. Convert four-leg intersection into T-intersection or initially construct T-intersections instead of four-leg intersections (offset T-intersections, use a one-quadrant interchange design if necessary)
	Replacement of high-risk conflict points	1. J-turn intersections (indirect minor road crossing and left-turns) 2. Offset T-intersections (indirect minor road crossing) 3. Jug-handle intersections (indirect left-turns off expressway) 4. Other indirect left-turn treatments (Michigan lefts) 5. Expressway semi-roundabout intersection
	Relocation or control	1. Provide left-/right-turn lanes or increase their length 2. Provide free right-turn ramps for existing expressway traffic 3. Minimize median opening length 4. Provide signalization
Gap selection aids	Vehicle detection (intersection sight distance enhancements)	1. Provide clear sight triangles 2. Modify horizontal/vertical alignments on intersection approaches 3. Realign skewed intersections to reduce or eliminate skew 4. Move minor road stop bar as close to expressway as possible 5. Provide offset right-turn lanes 6. Provide offset left-turn lanes
	Judging arrival time	1. Install intersection decision support technology or other dynamic device to communicate availability and size of gaps 2. Install roadside markers/poles (static markers at a fixed distance)
	Merging / crossing aids (promoting two-stage gap selection)	1. Provide left-turn median acceleration lanes 2. Provide right-turn acceleration lanes 3. Add expressway speed zoning/enforcement near intersections 4. Widen median to provide for adequate vehicle storage 5. Add centerline, Yield/Stop signs/bars, and other signage ("Recheck Cross Traffic Before Proceeding" or "Look" signs) in the median 6. Extend left edge lines of expressway across median opening 7. Conduct public education campaign teaching two-stage gap selection
Intersection recognition devices	Intersection treatments	1. Provide overhead control beacon reinforcing two-way stop control 2. Provide intersection lighting
	All approaches	1. Provide enhanced (overhead/larger/flashing) intersection or approach signage
	Expressway approaches	1. Provide enhanced freeway style intersection guide signs 2. Provide dynamic "Watch for Entering Traffic When Flashing" signs or other activated advance intersection warning systems 3. Use a variable median width (wider in intersection vicinity) 4. Change median type in vicinity of intersection
	Minor road approaches	1. Use "Stop Ahead" pavement marking and in-lane rumble strips 2. Provide a stop bar (or a wider one) 3. Provide divisional/splitter island at mouth of intersection 4. Provide signage/marking for prevention of wrong-way entry

Table 3. Guidance from Forbes and Garvey on Implementation (*41*).

Implement measures in the following order:
A. Increase the size of the sign. B. Provide a more reflective sign sheeting. C. Post an additional (left-side mounted) sign. D. Post a Stop Ahead warning sign. E. Add "STOP AHEAD" pavement markings. F. Add transverse rumble strips. G. Add a flashing beacon. H. Embed LEDs in the border of the sign.
Additional guidance regarding treatments:
• If the visibility of the intersection control sign on the approach to the intersection is less than the stopping sight distance (SSD) and the visibility obstruction cannot be removed, then measures A and B are not appropriate. Similarly, measure C may not be effective unless the leftside placement is such that it is visible from a point upstream that affords SSD. If the sign is not visible sufficiently far upstream, then measures G and H will also have short visibility distances, but due to the flashing operation they may improve driver performance. These measures are generally poor choices for a limited visibility condition. • Measure B should be limited to high crash frequencies or high incidences of Stop sign violations when these conditions occur during hours of darkness. • Measure F should not be used in urban areas or areas where the noise created by the rumble strips will create a disturbance for nearby residents. Further guidance on transverse rumble strips is available in *Best Practice Guidelines for the Design and Application of Transverse Rumble Strips [TAC, 2005]*. • Measures D, E, and F involve the placement of items upstream of the intersection and should be used only if there is not another intersection or major driveway located in between the subject intersection and the upstream measure. Also, these measures should be sufficiently far downstream of the last intersection encountered by the motorist so that the driver is not likely to miss the measure because of diverted attention. For this last purpose, it is suggested that these measures be at least 3 s downstream of the last intersection at the posted speed limit. • Measures F, G, and H should only be used on approaches where the traffic is 500 vehicles per day or more. Additionally, as these measures have the potential to reduce the effectiveness of static signs, these measures should not be tried until all of the static signs and marking measures have been ruled out or have been tried and found unsuccessful. • Measures G and H shall not be used at the same location/approach. The principal advantage of either measure is the flashing lights associated with each system. Installation of either flashing light system should be sufficient to attract driver attention. There is a real concern that employing both methods at one location will start an increasing spiral of lighting, which is successively more attention-getting as different arrangements of devices strive to be more conspicuous than the previous. This spiral will erode the effectiveness of the static sign in attracting the attention of motorists.

Forbes and Garvey also provided the following principles for consideration in determining the order of selection for the technique:

1. **Select the technique to suit to purpose.** For example, if a conspicuity problem exists at all times of the day, employing more reflective sign sheeting is not generally suitable, as it only addresses nighttime issues. Alternatively, if the concern seems to be attention conspicuity (i.e., not actively looking for a sign), then a flashing beacon or LETS may be preferable.
2. **Review the available evidence on technique effectiveness.** The state-of-knowledge on any particular device or technique is constantly evolving, and the practitioner should make himself/herself aware of the most up-to-date information to make informed decisions.
3. **Conform to local policies.** If an established policy or practice is used within a jurisdiction, then conformance to that practice is an important step in meeting driver expectations.
4. **Select the technique with the minimum environmental impact**. All of the available options tend to have minimal impacts. However, dark-sky policies that strive to preserve and protect nighttime environment through environmental responsible outdoor lighting may be a consideration.
5. **The lower cost option**. Both capital and operating costs of the selected option should be a factor in selecting the treatment.

SAFETY

Crash Types

A review of Minnesota's crashes for rural two-lane highway intersections by Preston and Storm (*42*) focused on identifying predominant crash types. They concluded that strategies are needed to address the issue of gap selection and intersection recognition. They observed that due to the very low frequency of occurrence of either type of crash, the most effective implementation would most likely involve a systematic approach instead of an approach focused on the very small number of locations with multiple crashes.

The purpose of a study conducted by Retting et al. (*43*) was to develop a better understanding of the crashes that occur at Stop signs and to identify potential countermeasures. They examined police reports of crashes at stop-controlled intersections during 1996–2000 in four U.S. cities in detail. The study included a total of 1788 crash reports for intersections with two-way Stop signs. Stop sign violations accounted for about 70 percent of all crashes. Typically, these crashes were angular collisions. Among crashes not involving stop violations, rear-end crashes were most common, accounting for about 12 percent of all crashes. The researchers classified Stop sign violation crashes into several subtypes—driver stopped, driver did not stop, snow/wet/ice, and other/unknown. In about two-thirds of Stop sign violation crashes, drivers said they had first come to a stop. In these cases, inability or failure to see approaching traffic often was cited as the cause of the crash. Drivers younger than 18 as well as drivers 65 and older were disproportionately found to be at fault in crashes at Stop signs. Potential countermeasures include changing traffic control and intersection design, improving intersection sight distance, and increasing conspicuity of Stop signs through supplemental pavement markings and other devices.

Kim et al. (*44*) conducted a study using data from Georgia that developed crash type models. They argued that using crash type models can provide greater insights into the relationship between factors and crashes. Crash type models are useful for three reasons:

- There is a need to identify sites that are high risk with respect to specific crash types but that may not be revealed through crash totals.
- Countermeasures are likely to affect only a subset of all crashes—usually called target crashes—and so examination of crash types will lead to improved ability to identify effective countermeasures.
- There is reason to believe that different crash types (e.g., rear-end, angle, etc.) are associated with road geometry, the environment, and traffic variables in different ways and as a result justify the estimation of individual predictive models.

Prediction Models

Several past research projects have concentrated on assessing the safety effects of crash countermeasures and the safety relationship between geometrics and crashes, including work by Vogt and Bared (*45*), Vogt (*46*), Harwood et al. (*47*), Oh et al. (*48*), Lyon et al. (*49*), and Bonneson and Pratt (*50*). These research efforts have focused on modeling the relationships between total, fatal, and injury crashes with intersection geometric characteristics, environmental factors, and traffic-related explanatory variables.

Vogt and Bared (*45*) formulated several crash models for both road segments and intersections on two-lane rural roads in the states of Minnesota and Washington. Two intersection crash models were estimated for three- and four-leg stop-controlled intersections with two lanes. In another study by Vogt (*46*), which may be regarded as a continuation of the previous study, three negative binomial crash prediction models were estimated for three- and four-leg intersections with two lanes on minor and four lanes on major rural highways. Lyon et al. (*49*) recalibrated the crash prediction models for five types of rural intersections based on validation results.

For rural intersections, the crash models developed for the Federal Highway Administration (*45, 46, 47, 49*) discussed above were incorporated in the Interactive Highway Safety Design Model (IHSDM). IHSDM is roadway design and redesign software that estimates safety effects of alternative designs, in addition to operational and other traditional aspects. In addition to these studies Harwood et al. (*47*) developed crash prediction models for two-lane rural highway sections that include road segments and three types of at-grade intersections.

The recently published *Highway Safety Manual* (HSM) includes crash models similar to the models discussed above (*51*). It also includes a crash prediction algorithm. The crash prediction algorithm consists of an approach that combines historical crash data, regression analysis, before-and-after studies, and expert judgment to develop crash modification factors (CMFs), which are then used to adjust base model (based on average annual daily traffic [AADT] only) crash predictions.

In Texas, the Project 0-4703 developed an evaluation tool that can be used by TxDOT designers to quantitatively incorporate safety analyses earlier in the project development process. The tool also includes crash prediction models. Table 4 summarizes the rural highway models included in the *Highway Safety Manual* and the models included in the Texas *Roadway Safety Design Workbook*.

Table 4. Rural Unsignalized Intersection Models Included in the Texas *Roadway Safety Design Workbook* (*50*) and the *Highway Safety Manual* (*51*).

Texas ***Roadway Safety Design Workbook*** (***50***)
$$C_{b,3U} = 0.0973 \left(\frac{ADT_{major}}{1000}\right)^{0.863} \left(\frac{ADT_{minor}}{1000}\right)^{0.497} f_{3U}$$ $$C_{b,4U} = 0.2350 \left(\frac{ADT_{major}}{1000}\right)^{0.692} \left(\frac{ADT_{minor}}{1000}\right)^{0.514} f_{4U}$$ where: $C_{b,3U}$ = base injury (plus fatal) crash frequency for three-leg, unsignalized intersections, crashes/yr. $C_{b,4U}$ = base injury (plus fatal) crash frequency for four-leg, unsignalized intersections, crashes/yr. ADT_{major} = average daily traffic volume on the major road, veh/d. ADT_{minor} = average daily traffic volume on the minor road, veh/d. f = local calibration factor.
Highway Safety Manual (***51***) Models predict intersection-related crashes for intersection of two-lane intersecting two-lanes highways
$$N_{spf,3ST} = e^{(-9.86+0.79\ln AADT_{maj}+0.49\ln AADT_{min})}$$ $$N_{b,4U} = e^{(-8.56+0.60\ln AADT_{maj}+0.61\ln AADT_{min})}$$ where: $N_{spf,3ST}$ = estimate of intersection-related predicted average crash frequency for base conditions for three-leg stop-controlled intersections, crashes/yr. $N_{spf,4ST}$ = estimate of intersection-related predicted average crash frequency for base conditions for four-leg stop-controlled intersections, crashes/yr. $AADT_{maj}$ = average annual daily traffic volume on the major road, veh/d. $AADT_{min}$ = average annual daily traffic volume on the minor road, veh/d.

A 2006 study examined the safety performance of expressway intersections (*52*). It concluded that much of the variation in safety performance is explained by minor roadway volumes, but some of the variation can be attributed to the expressway curvature at the intersection, skew of the intersection, and land use surrounding the intersection. These features affect both the crash rate and crash severity. The study also concluded that judging gaps in the far lanes was most problematic for drivers, except on horizontal curves, where drivers had equal difficulty judging gaps in both the farside and nearside lanes.

Crash Modification Factors or Crash Reduction Factors

The crash prediction algorithm proposed for the *Highway Safety Manual* and included in the Texas *Roadway Safety Design Workbook* includes crash modification factors. The CMF adjusts the base estimate to account for the effect of individual geometric design and traffic control features. Table 5 lists the crash modification factors included in the Texas *Roadway Safety Design Workbook* along with the assumed based condition.

The proposed material for consideration in the *Highway Safety Manual* suggests adjustments or consideration for the following features:

- Number of intersection legs (three or four).
- Type of traffic control (minor-road Stop, all-way Stop, minor-road Yield control, or signal).
- Intersection skew angle.
- Number of major-road approaches with intersection left-turn lanes.
- Number of major-road approaches with intersection right-turn lanes.
- Number of intersection quadrants with deficient intersection sight distance.

Follow-on work has also suggested the following:

- Lighting.

Table 5. CMFs for Unsignalized Intersections Included in the Texas *Roadway Safety Design Workbook* (*50*).

Application	Crash Modification Factor (Assumed Base Condition)
Geometric design	Left-turn lane (none) Right-turn lane (none) Number of lanes (2 lanes) Shoulder width (4 ft) Median presence (not present) Alignment skew angle (no skew)
Access control	Driveway frequency (1)
Other	Truck presence (15% trucks)

In 2007, FHWA published the *Desktop Reference for Crash Reduction Factors* which documents the estimates of crash reduction that might be expected if a specific countermeasure or group of countermeasures is implemented with respect to intersections, roadway departure and other non-intersection crashes, and pedestrian crashes (*53*). The document includes information for signs, markings, and operational countermeasures for intersection crash reduction factors.

The findings from the *Desktop Reference* document along with additional evaluations were used to develop the Crash Modification Factors Clearinghouse (*54*). The clearinghouse is a website that contains a searchable database of crash modification factors. The objective of the website is to enable transportation professionals to identify the most appropriate countermeasure for their safety needs. It is available at: http://www.cmfclearinghouse.org/. Figure 16 shows an example of the material available in the clearinghouse.

A recent *Public Roads* article provided information on the differences between crash reduction factors (CRFs) and CMFs (previously known as AMFs, for accident, rather than crash, modification factor) (*55*). The HSM uses the phrases “crash modification factors” or “crash modification functions” (CMFs) when referring to CRFs. The main difference between a CRF and a CMF is that CRFs provide an estimate of the *percentage* reduction in crashes, while CMFs are a multiplicative factor used to compute the *expected number* of crashes after implementing a given improvement. Also, the CMFs included in the HSM were “filtered” from the available literature to include only information that is deemed reliable based on accuracy, precision, and stability. Mathematically stated, CMF = 1 − (CRF/100). CRFs and CMFs are simply different conventions for expressing safety effectiveness. Note that CRFs and crash modification *factors* are constants; crash modification *functions* allow the factor to vary for different scenarios, such as for different traffic volume scenarios.

Countermeasure: Convert two-way to all-way stop control

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.25 [B]	75	★★★★★	Angle	All	Not specified	Urban	Lovell and Hauer, 1986
0.52 [B]	48	★★★★★	All	All	Not specified	Urban	Harwood et al.,
0.57 [I]	43	★★★★☆	Pedestrian	All	Not specified	Urban	Lovell and Hauer, 1986
0.3 [B]	70	★★★★☆	All	Serious injury, Minor injury	Not specified	Urban	Lovell and Hauer, 1986
0.82 [B]	18	★★★☆☆	Rear end	All	Not specified	Urban	Lovell and Hauer, 1986
0.71	29	★★☆☆☆	Angle	All	Not specified	Urban	Lovell and Hauer, 1986
0.53	47	Not Yet Rated	All	All	Not specified	All	Harkey et al., 2005
0.2	80	Not Yet Rated	Angle	All	Not specified	Urban	Polanis, 1999
0.81	19	Not Yet Rated	Vehicle/pedestrian	All	Not specified		Harkey et al., 2005

Figure 16. Sample from CMF Clearinghouse (*54*).

CHAPTER 3

CRASH CHARACTERISTICS FOR TEXAS RURAL STOP-CONTROLLED INTERSECTIONS

INTRODUCTION

This chapter starts with a review of the current knowledge regarding safety at rural stop-controlled intersections. It then documents the efforts to identify the characteristics of crashes for Texas rural stop-controlled intersections. To better identify appropriate treatments for Texas intersections, the research team reviewed Texas crash data to identify characteristics of crashes at these intersections. For example, are the concerns at stop-controlled intersections that:

- Drivers are stopping suddenly (high number of rear-end crashes)?
- Drivers are making poor gap acceptance decisions (angle crashes, especially for a particular approach)?
- Drivers are running through the Stop sign at the intersection (angle, two-vehicle crash, or single vehicle at T-intersection)?

Specific crash characteristics are also associated with the characteristics of the intersections. For example, we expect to find different crash characteristics between T-intersections and cross intersections.

LITERATURE

The researchers reviewed literature to identify similar rural stop-controlled intersection crash characteristics studies. This provides the opportunity to compare the Texas findings with other regions, along with suggesting potential classification of crash types. Several studies were found examining rural stop-controlled intersections.

Retting et al. (*56*) found that about 70 percent of all crashes were Stop sign violations. Typically these crashes were angular collisions. Among crashes not involving stop violations, rear-end crashes were most common, accounting for about 12 percent of all crashes. In about two-thirds of Stop sign violation crashes, drivers said they had first come to a stop. In these cases, inability or failure to see approaching traffic was often cited as the cause of the crash. Drivers younger than 18 as well as drivers 65 and older were disproportionately found to be at fault in crashes at Stop signs. Potential countermeasures recommended by Retting et al. include changing traffic control and intersection design, improving intersection sight distance, and increasing conspicuity of Stop signs through supplemental pavement markings and other devices.

Preston and Storm (*57*) examined Minnesota crashes for rural state highways for a three-year period. They found the following right-angle crash types:

- 57 percent involved a vehicle that stopped at the Stop sign and then pulled out.
- 26 percent involved a vehicle that ran through the Stop sign.
- 17 percent could not be identified relative to vehicle actions.

Kim, Washington, and Oh (*58*) investigated the development of crash prediction models by focusing on different crash types. The reasons for this approach included the following:

- Analysis by crash type can help to identify sites that are high risk with respect to specific crash types but that may not be revealed as high risk in overall crash totals.
- Countermeasures are likely to affect only a subset of all crashes—usually called target crashes—and so examination of crash types will lead to improved ability to identify effective countermeasures.
- There are reasons to believe that different crash types (e.g., rear-end, angle) are associated with road geometry, the environment, and traffic variables in different ways and as a result justify the estimation of individual predictive models.

The study's data set included 837 motor vehicle crashes for two-lane rural intersections in the state of Georgia. The analysis revealed that factors such as the AADT, the presence of turning lanes, and the number of driveways have a positive association with each type of crash (i.e., more crashes occur), whereas median widths and the presence of lighting are associated with fewer crashes. For the best fitting models, covariates relate to crash types in different ways, suggesting that crash types are associated with different pre-crash conditions and that modeling total crash frequency may be less helpful for identifying specific countermeasures.

Burchett and Maze (*59*) examined characteristics that affect the safety performance of rural expressway intersections in Iowa. They used data for the 100 best-performing and 100 worst-performing intersections based on crash severity rate. They also conducted a more in-depth analysis of the 30 intersections with the highest crash severity rate. Much of the variation in safety performance was explained by minor road traffic volumes, but some of the variation was attributed to the expressway curvature at the intersection, skew of the intersection, and land use surrounding the intersection. The authors concluded that it appeared that judging gaps in the far lanes was most problematic for drivers, except on horizontal curves, where drivers had equal difficulty judging gaps in both the farside and nearside lanes.

DATA COLLECTION ACTIVITIES

This section describes the data collection activities undertaken to assemble a database suitable for the safety analysis of stop-controlled intersections in Texas.

Identifying Stop-Controlled Intersections within Texas

The geometry, traffic volume, and location attributes for the Texas state highway system can be obtained using the Texas Reference Marker (TRM) system. Intersection information is maintained in the database called "Phini." An intersection in the Phini database is defined as a point entity (*60*). The intersection has a mile point value that uniquely identifies it in the database. However, since there is no unique variable that can identify the stop-controlled intersections, researchers needed supplemental approaches. The 2003–2008 TxDOT crash databases were utilized to identify signalized intersections, which were removed from the data set. A subset of sites was located in Google Earth to identify additional intersection characteristics such as number of legs.

Researchers used a number of constraints in the initial database search in order to identify intersections on rural highways. Table 6 shows the constraints applied to the 2007 Phini database. The basic constraints limited the data set to at-grade intersections in rural areas. Freeways (divided, full access control), expressways (divided, partial access control), one-way pair, and one-way (undivided) roads were eliminated. Additional constraints were applied to exclude high traffic volume intersections, intersections crossing with short connectors or driveways, and duplicate intersections.

Table 6. Constraints Used in Phini Database.

	Variables in Phini	Code	Description
Basic Constraints	RECORD_TYPE	1	Mainlanes
	INT_TYPE	'A'	At-grade intersection
	RURAL_URBAN_CODE	1	Rural area
	ROADWAY_FEAT_CODE	33	Intersection
	HIGHWAY_DESIGN1	2, 3	Eliminate freeway (divided, full access control), expressway (divided, partial access control), one-way pair, and one-way (undivided)
	INT_FEAT_TYPE	11, 21	On-system main lane and local road
Additional Constraints	ADT_ADJUST_CURRENT	<15000	Traffic volume constraint
	FEAT_NOTATION	'LR'	Remove the intersection if its crossing road is indicated with the 'LR' code
	MILEPOINT	-	Remove the intersections that have duplicate mile points

The intersections identified in the above procedure include both signalized and unsignalized intersections. The 2003–2008 TxDOT crash databases were used to isolate the stop-controlled intersections among those intersections. If a crash occurs at an intersection, the traffic control information (i.e., whether it is a signal light or a Stop sign) is recorded in the crash database. Therefore, the research team first set up 0.1 mile boundaries for all the intersections identified above and extracted all crashes of all severity levels (from fatal crashes down to PDO) within the boundary. Then, the signalized intersections were removed if at least one crash indicated that it occurred at a signal light.

The approach of identifying the unsignalized intersections using the crash database is not without limitations. First, there is a possibility that some intersections with traffic lights might have been included in the final data set if they did not experience any crashes for six years. Second, "zero" crashes at an intersection may be interpreted in two ways: one is that the intersection did not in fact experience any crashes during those six years; the other is that it experienced crashes, but the control-section information for the intersection was not recorded in the crash database. For example, a total of 41 crashes occurred during six years along State Highway "Old Spanish Road" (SH OSR) in Brazos County. However, the 2003–2008 crash database does not have the control-section or mile point information for these crashes. Therefore, the unsignalized intersections identified on SH OSR do not show any crashes in the database even though crashes might have occurred on those intersections. Third, since the analysis used a 0.1 mile boundary for identifying crashes, if the distance between two intersections is too short (i.e., less than 0.2 mile), the crashes identified for the two intersections may overlap. A check of the distance between crossing points based on the identified intersections in Table 6 revealed that about 45 percent were spaced less than 0.2 mile apart. Figure 17 shows an example of closely spaced intersections on the road identified as BU82J in the Paris TxDOT District.

Source: Google Earth™ mapping service.

Figure 17. Example of Closely Spaced Intersections (BU82J in Paris District).

In this study, therefore, crossing points identified as being on SH OSR were not included in the final data set used in the analysis. In addition, any adjacent crossing points in the data set that were less than 0.2 miles apart were removed. This step of the process resulted in a total of 34,638 crossing points with a total number of 28,251 crashes.

The complete procedure for identifying the unsignalized intersections is listed in Table 7. The number of crossing points or intersections resulting from each step is also indicated.

Additional steps were necessary to match the main road with the crossing road so that they represent one intersection rather than two crossing points. Prior to the matching process, any record that did not have cross street data was removed. Having the ADT for both the main road and the cross road is critical in a regression analysis. Therefore, if data on the cross street (e.g., roadway name or control section) are not available, the analysis would not be able to obtain the needed cross street characteristics. The remaining crossing points were then matched to form intersections. If a record did not have a match, it was removed. An example of a situation when a match would not be present is when the crossing roadway had an ADT of greater than 15,000. Those roads were eliminated in an earlier step. The resulting intersections included a few sites where two intersections had the same major street and cross street names—a situation caused by offset intersections. These sites were removed from the data set. The final data set of rural stop-controlled intersections with roads of less than 15,000 ADT included 2054 intersections.

Table 7. Procedure for Identifying Stop-Controlled Intersections.

Step	Details	Count
2007 Phini Database	Contains information where a road crosses a feature such as another road, railroad tracks, pipeline, etc.	302,991 crossing points
Basic Constraints	See Table 6	77,861 crossing points
ADT Constraint	Basic constraints and ADT_Adjust_Current < 15,000	76,707 crossing points
Remove all 'LR'	Basic and ADT constraints Feat_Notation ≠ 'LR'	69,454 crossing points
Remove duplicates in mile point	Records deleted if they had the same mile point on a segment	65,489 crossing points
Remove signalized intersections	Review 2003–2008 crash data to identify if crash occurred at a signalized intersection	63,973 crossing points 73,829 crashes
Remove closely spaced crossing points	Remove site if crossing point's mile point is within 0.2 miles of another crossing point Remove OSR crossing points	34,638 crossing points 28,251 crashes
Begin to identify cross street data	Remove if Int_Highway_Number does not have cross street information	7,430 crossing points
Check for availability of cross street data so that intersections can be identified	Delete if crossing point does not have matching cross street data within current data set	4,354 crossing points
Check for duplicates	Create intersections by matching cross streets Omit any intersections that had the same cross street name (perhaps because of offset intersections)	2,054 intersections

Supplemental Information for Stop-Controlled Intersections in Nine Districts

To expand the list of characteristics available for an intersection, intersections were located using Google Earth. Researchers selected districts in different regions of Texas because data for only a sample of Texas stop-controlled intersections could be collected. The selected districts include the nine districts listed in Table 8. The following intersection characteristics were collected:

- Intersection type (three-leg and four-leg).
- Traffic control device (none, stop, yield, all-way stop, intersection control beacon, signal).
- Number of driveways within 250 ft on each major road approach.

- Number of intersections within 250 ft on each major road approach.
- Presence of skew at intersection.
- Presence of horizontal curve on major road.
- Presence of horizontal curve on cross road.
- Number of turn lanes on major road.
- Number of turn lanes on cross road.

Related roadway characteristics for the identified intersections were available from the TRM database:

- Average ADT for six years (2003–2008) on major and minor road.
- Median width.
- Surface width.

Intersections were removed from the data set if controlled by all-way Stop signs, if there was a conflict between the number of lanes in Texas' Roadway Highway Inventory Network (Rhino) database and the satellite view on Google, if a road looped and intersected the main road twice, or if an extra long right-turn ramp created multiple intersections. Approximately 10 percent of the intersections were removed for these reasons. Table 8 lists the number of stop-controlled rural intersections by district within the final nine-district data set. This data set included a total of 595 stop-controlled intersections.

Table 8. Number of Stop-Controlled Rural Intersections for Nine Districts.

District Number	District	Number of Intersections
4	Amarillo	95
6	Odessa	41
9	Waco	102
14	Austin	70
16	Corpus Christi	84
18	Dallas	44
19	Atlanta	86
20	Beaumont	40
22	Laredo	33
Total		**595**

Table 9 provides the number of intersections with selected intersection characteristics for the nine district data set. Approximately a third of the three-leg intersections in the nine-district data set had a skew, while only about 25 percent of the four-leg intersections had a skew. The three-leg intersections also were more likely to have a horizontal curve on one of the approaches to the intersection as compared to the four-leg intersections. Both three- and four-leg intersections had similar distributions of turn lanes—about 20 percent had a turn lane on an approach. The rural stop-controlled intersections within the nine-district data set generally had very low entering volumes. More than 80 percent of the intersections had 4000 or fewer vehicles entering the intersection per day.

Table 9. Distribution of Intersection Characteristics for 595 Intersections.

Intersection Characteristic	3 Legs		4 Legs		Total	
	Number	Percent	Number	Percent	Number	Percent
Presence of skew at intersection						
90 degrees	327	69	92	76	419	70
Skew	147	31	29	24	176	30
Grand Total	474	100	121	100	595	100
Presence of Horizontal Curve on Approach						
Yes	171	36	25	21	196	33
No	303	64	96	79	399	67
Grand Total	474	100	121	100	595	100
Presence of Turn Lane on Approach						
No	372	78	96	79	468	79
Yes	102	22	25	21	127	21
Grand Total	474	100	121	100	595	100
Number of Driveways Within 250 ft of Intersection						
0	258	54	76	63	334	56
1	120	25	22	18	142	24
2	58	12	11	9	69	12
3	19	4	7	6	26	4
4	11	2	4	3	15	3
5	5	1	0	0	5	1
6	1	0	1	1	2	0
7	1	0	0	0	1	0
9	1	0	0	0	1	0
Grand Total	474	100	121	100	595	100
6-Year Average Entering Intersection Volume						
0–2000	287	61	71	59	358	60
2000–4000	100	21	27	22	127	21
4000–6000	53	11	19	16	72	12
6000–8000	19	4	4	3	23	4
8000–10,000	8	2	0	0	8	1
10,000–12,000	3	1	0	0	3	1
12,000–14,000	2	0	0	0	2	0
14,000–16,000	2	0	0	0	2	0
Grand Total	474	100	121	100	595	100

Crash Data

After the stop-controlled intersections were identified, crash data for each intersection were extracted from the TxDOT crash databases. Six years of crash data (2003–2008) were extracted, including only the crashes that occurred within a 0.1 mile boundary on each side of the mile point identified for the crossing point. The 0.1 mile distance was selected for the boundary because that was the distance used earlier when identifying suitable intersections within the Phini database. The crashes that occurred on the main road and the cross road were summed to generate the total number of crashes at an intersection. Because the 0.1 mile boundaries could include crashes where the intersection did not contribute to the crash, the crash database variable "Intersection Related" can be used to restrict the analysis to only those crashes that are identified in the crash reports as being at an intersection, related to an intersection, or at a driveway access. The following codes are available within the Intersection Related variable:

1. Intersection.
2. Intersection related.
3. Driveway access.
4. Non intersection.
5. Not reported.

For the crash severity type, all types were extracted, i.e.:

1. Incapacitating-injury (A).
2. Non-incapacitating injury (B).
3. Possible injury (C).
4. Killed (K).
5. Not injured (or PDO).

In addition to developing a regression model for total crashes, the crashes were grouped by crash type in order to explore whether prediction models could be developed for unique groups. If prediction models can be generated, it could result in an improved ability to identify specific countermeasures. The crashes were also grouped into the following types:

- One moving vehicle—vehicle going straight (OMV_VGS).
- Angle—both going straight (ANGLE_BGS).
- Angle—one straight, one left turn (ANGLE_OS_OLT).
- Opposite direction—both going straight (OD_BGS).
- Opposite direction—one straight, one left turn (OD_SD_OLT).
- Same direction—both going straight, rear end (SD_BGS_RE).
- Same direction—one straight, one left turn (SD_OS_OLT).
- Same direction—one straight, one stopped (SD_OS_OS).
- All other crashes (OTHERS).

CHARACTERISTICS OF TEXAS RURAL STOP-CONTROLLED INTERSECTIONS

Texas Rural Stop-Controlled Intersections (ADT less than 15,000)

Table 10 lists the number of crashes and number of driver records for the 2054 intersections identified. A large portion of the 2054 intersections had no crashes during the six-year period (2003–2008).

Table 11 lists the proportion of intersections by number of crashes for all crashes and intersection crashes. Within this data set, 58 percent of the intersections did not have any intersection, intersection-related, or driveway access crashes within the six-year period.

Table 10. Number of Records in the 2054 Intersection Data Set.

Type of Record	Number of Records	
	All Crashes (Intersection Related = 1, 2, 3, 4, 5)	Intersection Crashes (Intersection Related = 1, 2, or 3)
Crashes	4442	2857
Drivers	7421	5308

Table 11. Percent of the 2054 Intersections with 0, 1, 2, 3, and More than 3 Crashes between 2003 and 2008.

	Crashes	Percent of Intersections with…				
Crash Type	Number	0 crashes	1 crash	2 crashes	3 or more crashes	Total
All Crashes (intersection related = 1, 2, 3, 4, or 5)	4442	41	21	12	26	100
Intersection Crashes (intersection related = 1, 2, 3)	2857	58	17	8	16	100

Table 12 lists the number of intersection crashes by collision type. The most common collision types identified by the officers at rural stop-controlled intersections are:

- One moving vehicle—vehicle going straight (31 percent).
- Angle—both going straight (28 percent).
- Same direction—one straight and one stopped (7 percent).
- Angle—one straight and one left turn (6 percent).
- Opposite direction—one straight and one left turn (6 percent).
- Same direction—one straight and one left turn (5 percent).

Not surprisingly, several crashes (more than 17 percent) involved a left-turning vehicle. Over one-third of the crashes at rural unsignalized intersections with less than 15,000 ADT on each roadway were single-vehicle crashes.

Table 13 lists the contributing factors selected by officers for drivers involved in an intersection crash (intersection related variable = intersection, intersection-related, or driveway access) at the 2054 intersections. For almost half of the drivers, the officer selected "not applicable," indicating no contributing factor related to the driver. When a contributing factor was selected, it typically involved failure to yield right of way/disregard for the traffic control device or speeding. Alcohol was cited for 3 percent of the drivers.

Table 12. Number of Intersection Crashes (Intersection, Intersection-Related, or Driveway Access) by Collision Type for 2054 Intersections.

Collision Type		Number of Crashes	Percent
1	OMV vehicle going straight	881	31
10	angle - both going straight	791	28
22	same direction - one straight and one stopped	213	7
14	angle - one straight and one left turn	183	6
34	opposite direction - one straight and one left turn	176	6
24	same direction - one straight and one left turn	135	5
20	same direction - both going straight (rear end)	98	3
3	OMV vehicle turning left	73	3
2	OMV vehicle turning right	62	2
23	same direction - one straight and one right turn	61	2
13	angle - one straight and one right turn	46	2
21	same direction - both going straight (sideswipe)	25	1
17	angle - one right turn and one stopped	19	1
30	opposite direction - both going straight	16	1
19	angle - one left turn and one stopped	15	1
11	angle - one straight and one backing	10	0
35	opposite direction - one backing and one stopped	9	0
25	same direction - both right turn	6	0
32	opposite direction - one straight and one stopped	5	0
12	angle - one straight and one stopped	4	0
16	angle - one right turn and one left turn	4	0
18	angle - both left turn	4	0
31	opposite direction - one straight and one backing	4	0
4	OMV vehicle backing	3	0
36	opposite direction - one right turn and one left turn	3	0
26	same direction - one right turn and one left turn	2	0
27	same direction - one right turn and one stopped	2	0
28	same direction - both left turn	2	0
40	one straight - one enter or leave parking space	2	0
5	OMV other	1	0
15	angle - both right turn	1	0
33	opposite direction - one straight and one right turn	1	0
	Total	**2857**	**100**

Table 13. Distribution of Contributing Factors for Drivers Involved in an Intersection Crash (Intersection, Intersection-Related, or Driveway Access) at 2054 Intersections.

Contributing Factor (Numerical Code and Description)		Number of Drivers	Percent
0	Not applicable	2373	45
35	Failed to yield ROW – Stop sign	661	12
16	Disregard Stop sign or light	409	8
22	Failed to control speed	382	7
60	Speed – unsafe (under limit)	268	5
37	Failed to yield ROW – turning left	165	3
20	Driver inattention	147	3
67	Under influence – alcohol	141	3
(blank)	Not provided	68	1
66	Turned when unsafe	59	1
34	Failed to yield ROW – private drive	44	1
48	Impaired visibility	38	1
40	Fatigued or asleep	37	1
57	Passed in no passing lane	33	1
74	Other factor	32	1
3	Backed without safety	31	1
26	Failed to pass to left safely	25	0
63	Turned improperly – cut corner on left	25	0
41	Faulty evasive action	23	0
15	Disregard stop and go signal	19	0
29	Failed to stop at proper place	19	0
39	Failed to yield ROW – yield sign	19	0
64	Turned improperly – wide right	19	0
2	Animal on road – wild	18	0
44	Followed too closely	18	0
10	Defective or no vehicle brakes	16	0
45	Had been drinking	16	0
1	Animal on road – domestic	15	0
23	Failed to drive in single lane	13	0
61	Speed (over limit)	12	0
68	Under influence – drug	12	0
4	Changed lane when unsafe	11	0
33	Failed to yield ROW – open intersection	11	0
27	Failed to pass to right safely	10	0
47	Ill	10	0
49	Improper start from parked position	10	0
	Other contributing factors that had less than 10 records	99	6
	Grand Total	5308	100

Subset of Texas Rural Stop-Controlled Intersections (Daily Entering Volume Less than 15,000)

Supplemental roadway characteristics were gathered for a subset of intersections. Table 14 lists the number of crashes and driver records for the 595 intersections identified within the nine districts. Most of the 595 intersections had no crashes during the six-year period (2003–2008). Table 15 lists the number (or proportion) of intersections by number of crashes for presence of skew, number of legs, number of driveways, or presence of horizontal curve. The potential impact of a horizontal curve on the approach to the intersection or the presence of a skew can be seen in Table 15. When a horizontal curve is present on approach to the intersection, over half of the intersections had one crash or more. When a horizontal curve is not present, only 41 percent of the intersections had one crash or more. Only 44 percent of the intersections with two or more driveways had zero crashes in the six-year period, while 58 percent of the intersections with no driveways within 250 ft had no crashes.

Table 14. Number of Records in Nine-District Data Set of 595 Intersections.

Type of Record	Number of Records		
	All Crashes (Intersection Related = 1, 2, 3, 4, 5)	Intersection Crashes (Intersection Related = 1, 2, or 3)	
Crashes	1189	758	
Drivers	1952	1382	
Drivers/Crash	1.64	1.82	
Legs		3	4
Crashes	Not obtained	550	208
Drivers	Not obtained	939	443
Drivers/Crash	Not obtained	1.71	2.13

The crash database includes information about each driver involved in a crash. For the 1189 crashes available for the 595 intersections, data were available for 1952 drivers. The data were reviewed to identify trends or characteristics of low-volume stop-controlled rural intersections. Data were grouped into four-leg versus three-leg intersections.

Similar to the findings for the 2054 intersections, a contributing factor was not identified for more than 40 percent of the crashes (see Table 16). Failure to yield right of way (Stop sign or turning left) or disregard of the Stop sign was cited more often at four-leg (31 percent) than at three-leg intersections (21 percent). There is more opportunity at a four-leg as compared to a three-leg intersection to violate a Stop sign since there are a greater number of approaches. Speed (speed unsafe [under limit] or failure to control speed) was cited more often at three-leg intersections (17 percent) than at four-leg intersections (4 percent). More of the drivers involved in a crash at three-leg intersections (6 percent) were identified as being affected by alcohol than drivers at four-leg intersections (3 percent).

The majority of the crashes at four-leg intersections were angle crashes where both drivers were going straight (see Table 17). At three-leg intersections, the majority of the crashes were single-vehicle crashes.

Table 15. Number of Crashes by Intersection Characteristics.

Characteristic	Number or Percent of Intersections with the following Number of Intersection, Intersection-Related, or Driveway Access Crashes				
	0 Crash	1 to 2 Crashes	3 to 4 Crashes	>4 Crashes	Total
Number of Intersections	333	167	52	43	595
Percent of Intersections (%)					
All intersections	56	28	9	7	100
Percent of Intersections (%) with and without Skew					
No skew	57	19	9	15	100
With skew	54	18	11	17	100
Percent of Intersections (%) with Horizontal Curve Present on Any Approach					
No	59	26	9	6	100
Yes	50	32	8	10	100
Percent of Intersections (%) by Number of Legs					
4 Legs	46	32	13	9	100
3 Legs	58	27	8	7	100
Percent of Intersections (%) by Number of Driveways within 250 ft of Intersection					
0	58	27	8	7	100
1	56	27	9	4	100
2	55	30	7	8	100
>2	44	34	14	8	100

Table 16. Distribution of Contributing Factors for Drivers Involved in Intersection Crashes (Intersection, Intersection-Related, Driveway Access) at 595 Intersections.

Contributing Factor 1 (Code and Description)		3 Legs		4 Legs		Grand Total	
		Num	Percent	Num	Percent	Num	Percent
0	Not applicable	383	41	226	51	609	44
35	Failed to yield ROW – Stop sign	81	9	97	22	178	13
22	Failed to control speed	86	9	12	3	98	7
16	Disregard Stop sign or light	73	8	24	5	97	7
60	Speed – unsafe (under limit)	76	8	5	1	81	6
37	Failed to yield ROW – turning left	35	4	16	4	51	4
67	Under influence – alcohol	38	4	7	2	45	3
20	Driver inattention	23	2	10	2	33	2
	Not provided	10	1	7	2	17	1
66	Turned when unsafe	10	1	2	0	12	1
57	Passed in no passing lane	9	1	2	0	11	1
2	Animal on road – wild	6	1	4	1	10	1
	Other contributing factors that had less than 10 records each	109	12	31	7	140	10
Grand Total		**939**	**100**	**443**	**100**	**1382**	**100**

Table 17. Distribution of Contributing Factors for Drivers Involved in Intersection Crashes (Intersection, Intersection-Related, Driveway Access) at 595 Intersections.

COLLISION (Code and Description)		3 Legs		4 Legs		Grand Total	
		Num	Percent	Num	Percent	Num	Percent
10	Angle - both going straight	130	14	264	60	394	29
1	OMV vehicle going straight	249	27	35	8	284	21
14	Angle - one straight and one left turn	116	12	22	5	138	10
22	SD one straight and one stopped	97	10	19	4	116	8
34	OD one straight and one left turn	76	8	38	9	114	8
24	SD one straight and one left turn	67	7	19	4	86	6
20	SD both going straight - rear end	44	5	8	2	52	4
2	OMV vehicle turning right	28	3	3	1	31	2
23	SD one straight and one right turn	18	2	10	2	28	2
3	OMV Vehicle turning left	24	3	3	1	27	2
13	Angle - one straight and one right turn	18	2	6	1	24	2
21	SD both going straight - sideswipe	14	1	2	0	16	1
17	Angle - one right turn and one stopped	13	1	0	0	13	1
19	Angle - one left turn and one stopped	8	1	4	1	12	1
35	OD one backing and one stopped	9	1	0	0	9	1
36	OD one right turn and one left turn	6	1	0	0	6	0
16	Angle - one right turn and one left turn	4	0	2	0	6	0
30	OD both going straight	4	0	2	0	6	0
11	Angle - one straight and one backing	2	0	2	0	4	0
25	SD both right turn	3	0	0	0	3	0
28	SD both left turn	3	0	0	0	3	0
12	Angle - one straight and one stopped	0	0	3	1	3	0
15	Angle - both right turn	2	0	0	0	2	0
18	Angle - both left turn	2	0	0	0	2	0
31	OD one straight one backing	2	0	0	0	2	0
4	OMV Vehicle backing	0	0	1	0	1	0
Grand Total		**939**	**100**	**443**	**100**	**1382**	**100**

The distribution of crashes by day of the week varies for a four-leg versus a three-leg intersection. More of the crashes at three-leg intersections occurred on the weekend as compared to four-leg intersections (see Table 18). Table 19 shows the distribution by weather conditions. Interesting is that 6 percent of the crashes at three-leg intersections occurred in fog conditions. Reviewing the 34 crashes occurring in fog condition shows that about half of the crashes happened at an intersection that had a skew and half happened at a 90 degree angle intersection. All districts were represented; therefore, fog is not a specific location, rather these types of crashes are occurring across the state. Table 20 shows the distribution by light conditions. The majority of crashes occurred during daylight. A large difference for three-leg and four-leg intersections is shown in the distribution. Almost a third of the crashes occurred during nighttime conditions at the three-leg intersections as compared to only 10 percent for the four-leg intersections.

Table 18. Distribution of Day of Week for Intersection Crashes at 595 Intersections.

Day of Week		3 Legs		4 Legs		Grand Total	
		Num	Percent	Num	Percent	Num	Percent
1	Sunday	86	16	28	13	114	15
2	Monday	79	14	36	17	115	15
3	Tuesday	59	11	25	12	84	11
4	Wednesday	79	14	29	14	108	14
5	Thursday	69	13	36	17	105	14
6	Friday	95	17	29	14	124	16
7	Saturday	83	15	25	12	108	14
Grand Total		**550**	**100**	**208**	**100**	**758**	**100**

Table 19. Distribution of Weather Conditions for Intersection Crashes at 595 Intersections.

Weather Conditions		3 Legs		4 Legs		Grand Total	
		Num	Percent	Num	Percent	Num	Percent
1	Clear/Cloudy	459	83	197	95	656	87
2	Rain	46	8	5	2	51	7
3	Sleet/Hail	0	0	1	0	1	0
4	Snow	1	0	0	0	1	0
5	Fog	33	6	1	0	34	4
	Unknown	11	2	4	2	15	2
Grand Total		**550**	**100**	**208**	**100**	**758**	**100**

Table 20. Distribution of Light Conditions for Intersection Crashes at 595 Intersections.

Light Conditions		3 Legs		4 Legs		Grand Total	
		Num	Percent	Num	Percent	Num	Percent
0	Unknown	1	0		0	1	0
1	Daylight	330	60	171	82	501	66
2	Dawn	16	3	5	2	21	3
3	Dark (Not Lighted)	159	29	21	10	180	24
4	Dark (Lighted)	18	3	3	1	21	3
5	Dusk	10	2	3	1	13	2
6	Dark (Unknown Lighting)	2	0	1	0	3	0
8	Other	1	0		0	1	0
	Unknown	13	2	4	2	17	2
Grand Total		**550**	**100**	**208**	**100**	**758**	**100**

Regression Analysis

Researchers used negative binomial (NB) regression models to estimate the safety of rural intersections. An important characteristic associated with the development of NB models is the choice of the functional form linking crashes to the covariates. Flow to a power has been a common functional form used by transportation safety analysts in recent studies. For this study, the functional form in Equation 1 was used.

$$\mu_i = t_i \times F_{maj}^{\alpha 1} \times F_{\min}^{\alpha 2} e^{\beta_0 + \sum_{k=1}^{K} x_i \beta_k} \tag{1}$$

where,

μ_i = The estimated number of crashes for t_i period for site i.

t_i = Time period for modeling (six years in this study).

F_{maj} = Flow in vehicles per day (ADT) for major road (average of six years).

$F_{\min}$ = Flow in vehicles per day (ADT) for minor road (average of six years).

x = A series of covariates.

$\alpha 1, \alpha 2, \gamma_0, \beta_0, \beta_1, \ldots, \beta_K$ = Coefficients to be estimated.

For model estimation the generalized linear model procedure (GENMOD) in SAS (*61*) was utilized. As the log-likelihood, the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) values are directly available from the GENMOD procedure; they were used to assist in selecting the best model within each model category.

The intersection characteristics along with the number of crashes by crash type were used with regression to determine additional relationships between crash type and intersection characteristics. Initially the crashes were classified into nine different types for evaluation:

- One moving vehicle—vehicle going straight (OMV_VGS).
- Angle—both going straight (ANGLE_BGS).
- Angle—one straight, one left turn (ANGLE_OS_OLT).
- Opposite direction—both going straight (OD_BGS).
- Opposite direction—one straight, one left turn (OD_SD_OLT).
- Same direction—both going straight-rear end (SD_BGS_RE).
- Same direction—one straight, one left turn (SD_OS_OLT).
- Same direction—one straight, one stopped (SD_OS_OS).
- All other crashes (OTHERS).

Usable models could not be determined for these conditions due to small sample mean value. It should be noted that the results of the NB regression models are unduly influenced by small sample size and small sample mean value (*62*). In this study, a usable model was determined for the 595 intersections when all crash types were combined. Table 21 shows the results for the best model. As expected, the ADT of the major and the ADT of the minor road were significant variables.

Also significant were:

- Presence of horizontal curve on an approach (crashes increase when horizontal curve is present).
- Presence of turn lane on an approach (crashes decrease when a turn lane is present).

Other studies have also identified intersection skew and number of driveways as contributing elements when predicting the number of crashes at an intersection. Both of these variables were not significant in the final models. The presence of a horizontal curve may explain some of the variance that the skew variable indicates. The non-significance of number of driveways may be more of a reflection of the limited number of driveways observed in this study.

Table 21. Regression Model of All Types of Crashes at Rural Stop-Controlled Intersections.

Parameter		Estimate	Standard Error	P-value	Criteria
Intercept		−7.5109	0.4139	<0.0001	Deviance value = 593.18
Flow_major		0.4992	0.0541	<0.0001	Deviance/DF = 1.00
Flow_minor		0.4459	0.0527	<0.0001	Pearson Chi-Square = 631.41
Horizontal Curve	Yes	0.2610	0.1018	0.0104	Pearson Chi-Square/DF = 1.07
Turn Lane	Yes	−0.2762	0.1206	0.0220	2 × log-likelihood = –2007.17
Dispersion		0.7209	0.0822		AIC = 2019.17, BIC = 2045.50

Using the coefficients from the regression model provides the following equation for predicting the number of crashes at rural stop-controlled intersection when the major and minor roads each have less than 15,000 ADT:

$$\mu_i = 6 \times F_{maj}^{0.4992} \times F_{\min}^{0.4459} e^{-7.5109 + 0.2610 \times HC - 0.2762 \times TL} \quad (2)$$

where

μ_i = The estimated number of total crashes for t_i period for site i.

F_{maj} = Flow in vehicles per day (ADT) for major road (average of six years).

$F_{\min}$ = Flow in vehicles per day (ADT) for minor road (average of six years).

HC = 1 if horizontal curve exists on any approach, 0 = if horizontal curve is not present on all approaches.

TL = 1 if turn lane exists on any approach, 0 = if turn lane is not present on all approaches.

FINDINGS

Task 2 of TxDOT Project 0-6462 investigated the characteristics of crashes for Texas rural stop-controlled intersections and current knowledge regarding safety at rural stop-controlled intersection. A review of the literature identified the following variables as important to include in a safety evaluation of rural stop-controlled intersections: major and minor road ADT, presence of turning lanes, number of driveways, presence of skew, median width, and presence of lighting.

To better identify appropriate treatments for Texas intersections, the research team reviewed the Texas crash data to identify characteristics of crashes at these intersections. Key findings regarding rural stop-controlled intersections with daily entering volumes of less than 16,000 include the following:

- The majority of intersections had less than one intersection crash (intersection, intersection related, or driveway access) in six years.
- The presence of a horizontal curve on an approach resulted in an increase in crashes.
- The presence of a turn lane on an approach resulted in a decrease in crashes.
- The two most common types of crash were (a) one moving vehicle going straight and (b) angle crashes. These crash types represented about half of the crashes. When subdivided by number of legs on the approach, a slightly different pattern is revealed. Angle crashes are within the top two crash types for both three-leg and four-leg intersections; however, for four-leg intersections they represent 60 percent of crashes while they only represent 14 percent of the crashes at three-leg intersections. For three-leg intersections, the most common crash type was one moving vehicle going straight (27 percent). A broader distribution of crash type existed at three-leg intersections with angle (straight/left) and same direction (straight/stopped) also representing more than 10 percent of the crashes.
- A code is available in the crash database for the variable "contributing factor" for about half of the drivers. When a contributing factor was selected, it typically involved failure to yield right of way/disregard for the traffic control device or speeding. Alcohol was cited for 3 percent of the drivers. A comparison of the distributions of contributing factors for four-leg and three-leg intersections showed that speed-related contributing factors were selected more often for three-leg intersections. For four-leg intersections, the speed-related contributing factors were selected for approximately 4 percent of the crashes as compared to 17 percent of the crashes at three-leg intersections.
- Almost a third of the crashes occurred during nighttime conditions at the three-leg intersections as compared to only 10 percent for the four-leg intersections.

In general for rural intersections in Texas with entering volumes of less than 16,000 vehicles per day this evaluation revealed different focus areas for three-leg and four-leg intersections.

For three-leg intersections, especially if one of the approaches has a horizontal curve, countermeasures that address the following crash conditions or categories are appropriate:

- Nighttime crashes.
- Crashes that involve speeding.
- Single-vehicle crashes.

A general conclusion for the four-leg intersections is to identify countermeasures that focus on angle crashes with an emphasis on communicating to drivers the presence of the stop-controlled condition.

CHAPTER 4

TXDOT DISTRICT SURVEY TO EXPAND KNOWLEDGE OF SELECTED TRAFFIC CONTROL DEVICE ALTERNATIVES

INTRODUCTION

This chapter documents the efforts to collect additional information for traffic control devices selected for evaluation. This additional information included costs, maintenance experience, and safety experience and was obtained by conducting a survey of selected TxDOT districts. The survey also collected the order in which improvements are made to TCDs by TxDOT districts to improve safety at intersections. Some vendors were surveyed to obtain material and maintenance costs of TCDs. Additional applicable findings regarding these TCDs from other Texas Transportation Institute (TTI) research projects were also added to the data.

TRAFFIC CONTROL DEVICES EVALUATED

The Task 1 literature review, described in Chapter 2, summarized the TCDs being used by various agencies and their effectiveness to improve safety at rural intersections. Task 2, described in Chapter 3, evaluated characteristics of crashes at rural intersections and identified variables impacting the crash rates at rural intersections. Based on the results of these two tasks and discussion with the project panel, the Stop sign and the Intersection Ahead sign were selected for further evaluation. The survey collected information on improvements made to the Stop sign and Intersection Ahead sign.

Stop Sign (R-1)

Stop sign improvements identified for evaluation based on experience of TxDOT districts included increasing the size of Stop signs from 36 in. to 48 in., adding an additional Stop sign on either side of the approach at the intersection, adding flags, adding a reflective post, or adding 12-in. beacons in various arrangements. Some of the improvements also included the use of signs embedded with LEDs and installation of intersection overhead beacons. Enhancements to the Stop signs that were evaluated in the TxDOT district survey are illustrated in Figure 21.

Intersection Ahead Sign (W2-1)

Along with the Stop signs, improvements made to the Intersection Ahead signs (W2-1) were also evaluated. TxDOT districts have varying policies about the use of the W2-1 sign. Improvements to the W2-1 signs include adding flags, reflective posts, beacons, and LEDs. Enhancements to the Intersection Ahead signs that were evaluated are illustrated in Figure 19.

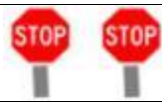
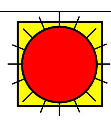
	Symbol	Treatment	Description
Additional Treatment		Oversized Stop sign	• 48 × 48 in.
		Two Stop signs	• Signs used on both sides of the roadway
		Stop sign with flags	• Flags added to Stop signs made of cloth (temporary) or metal
		Stop signs with a reflective post	• Reflective tape added to sign post
		Stop sign with a single beacon	• Beacon added to sign • Usually beacon flashes continuously • Beacon continuously ON (rare)
		Stop sign with two horizontal beacons	• Two beacons in a horizontal arrangement • Beacons flash all the time • Beacons flash in a simultaneous pattern • Beacons flash in an alternate pattern • Beacons continuously ON (rare)
		Stop sign with two vertical beacons	• Two beacons in a vertical arrangement • Beacons flash all the time • Beacons flash in an alternate pattern • Beacons flash in a simultaneous pattern • Beacons continuously ON (rare)
		Stop sign with embedded LEDs	• LEDs embedded within the perimeter of the sign • LEDs ON all the time • LEDs flash in a specific pattern
		Intersection overhead beacon	• Overhead beacon flashing continuously

Figure 18. Stop Sign Treatments.

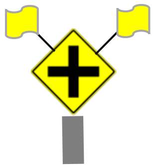
	Symbol	Treatment	Description
Additional Treatment		Intersection Ahead sign with flags	• Flags added to Intersection Ahead sign made of cloth (temporary) or metal
		Intersection Ahead sign with a reflective post	• Reflective tape added to sign post
		Intersection Ahead sign with a single beacon	• Beacon added to sign • Beacon flashes continuously • Beacon is continuously ON (rare)
		Intersection Ahead sign with two horizontal beacons	• Two beacons in a horizontal arrangement • Beacons flash all the time • Beacons flash in a simultaneous pattern • Beacons flash in an alternate pattern • Beacons continuously ON (rare)
		Intersection Ahead sign with two vertical beacons	• Two beacons in a vertical arrangement • Beacons flash all the time • Beacons flash in an alternate pattern • Beacons flash in a simultaneous pattern • Beacons continuously ON (rare)
		Intersection Ahead sign with embedded LEDs	• LEDs embedded within the perimeter of the sign • LEDs ON all the time • LEDs Flash in a specific pattern

Figure 19. Intersection Ahead Sign Treatments.

SURVEY/QUESTIONNAIRE FOR TXDOT

Researchers developed a questionnaire for TxDOT districts to evaluate their experiences with the use of the Stop sign and the Intersection Ahead sign. This questionnaire consisted of 10 questions. In consultation with the project panel, the questionnaire was sent to the following 11 districts: Abilene, Atlanta, Corpus Christi, Dallas, Fort Worth, Houston, Laredo, Lubbock, Paris, San Antonio, and Waco.

Four of the 11 districts indicated they could not provide this information, as they did not have the information readily available. Thus, three additional districts (Lufkin, Odessa, and Yoakum) were asked to complete the survey; one of those three agreed.

SURVEY FINDINGS

Sign Treatments

The survey responses illustrated significant variability in the application of treatments for these two TCDs among the responding districts. While one district used as few as three treatments for improving the effectiveness of Stop signs, another district used as many as six different treatments. For the Intersection Ahead sign (W2-1), most districts used one or two treatment variations and one district used five different treatments with the sign. Table 22 summarizes the results regarding Stop sign treatments, while Table 23 provides the results for Intersection Ahead signs.

Table 22. Treatments Used for Stop Signs across the Districts Surveyed.

Treatment	Atlanta	Corpus Christi	Lufkin	Laredo	Lubbock	San Antonio	Waco
Oversized	93.6%	60.0%	80.3%	10.0%	0.0%	13.0%	55.6%
Two Signs	1.2%	5.0%	0.0%	10.0%	0.0%	13.0%	0.0%
Flags	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Reflective Post	1.5%	0.0%	0.0%	0.0%	0.0%	8.0%	0.0%
Single Top Beacon	0.6%	3.0%	0.9%	0.0%	0.0%	0.0%	5.6%
Two Horizontal Beacons	0.0%	0.0%	1.4%	0.0%	3.4%	0.0%	1.1%
Two Vertical Beacons	0.9%	25.0%	3.7%	80.0%	69.0%	26.0%	3.9%
Embedded LEDs	3.1%	0.0%	0.0%	0.0%	10.3%	0.0%	0.0%
Intersection Overhead Sign	0.0%	7.0%	13.8%	0.0%	17.2%	40.0%	33.7%

Table 23. Treatments Used for Intersection Ahead Signs across the Districts Surveyed.

Treatment	Atlanta	Corpus Christi	Lufkin	Laredo	Lubbock	San Antonio	Waco
Intersection Ahead Sign (W2-1)	24%	70%	80%	0%	0%	94%	98%
With Reflective Post	24%	0%	0%	0%	0%	0%	0%
With Single Top Beacon	24%	0%	5%	0%	0%	0%	0%
With Two Vertical Beacons	24%	30%	16%	100%	100%	6%	2%
With Embedded LEDs	6%	0%	0%	0%	0%	0%	0%

There were clearly differences among the responding districts regarding their selection of enhancements to the Stop sign. As can be seen in Figure 20, Atlanta District uses oversized Stop signs at a very high proportion of its sign-controlled intersections. On the other hand, as illustrated in Figure 21, Laredo District uses two vertical beacons as the predominant Stop sign treatment. As shown in Table 22, the predominant treatments for Stop signs are:

- Oversized Stop sign.
- Two vertical beacons.
- Intersection overhead beacon.

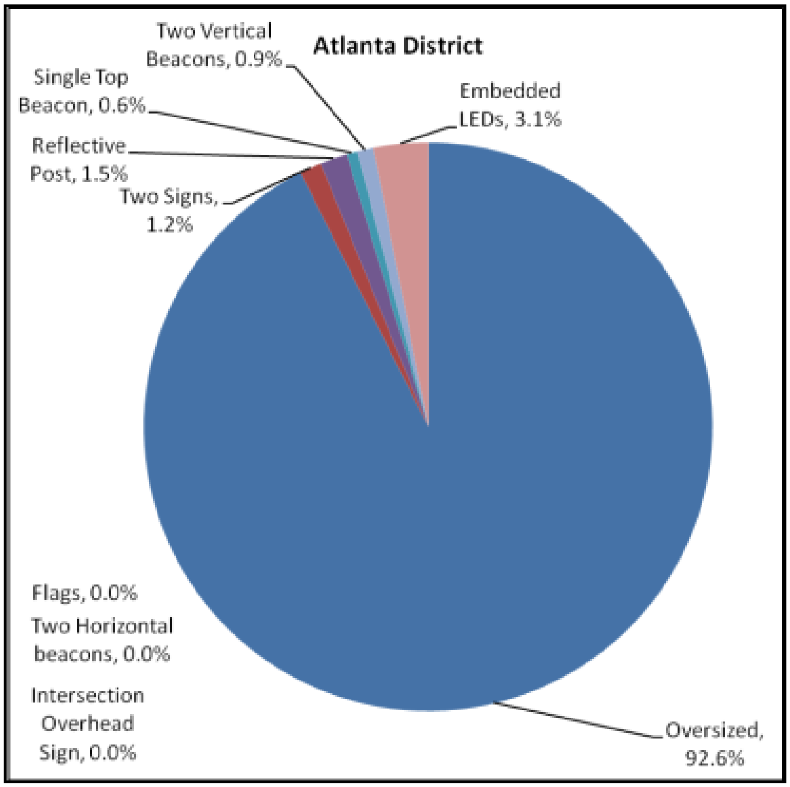


Figure 20. Example of the Use of Stop Sign Treatments in Atlanta District.

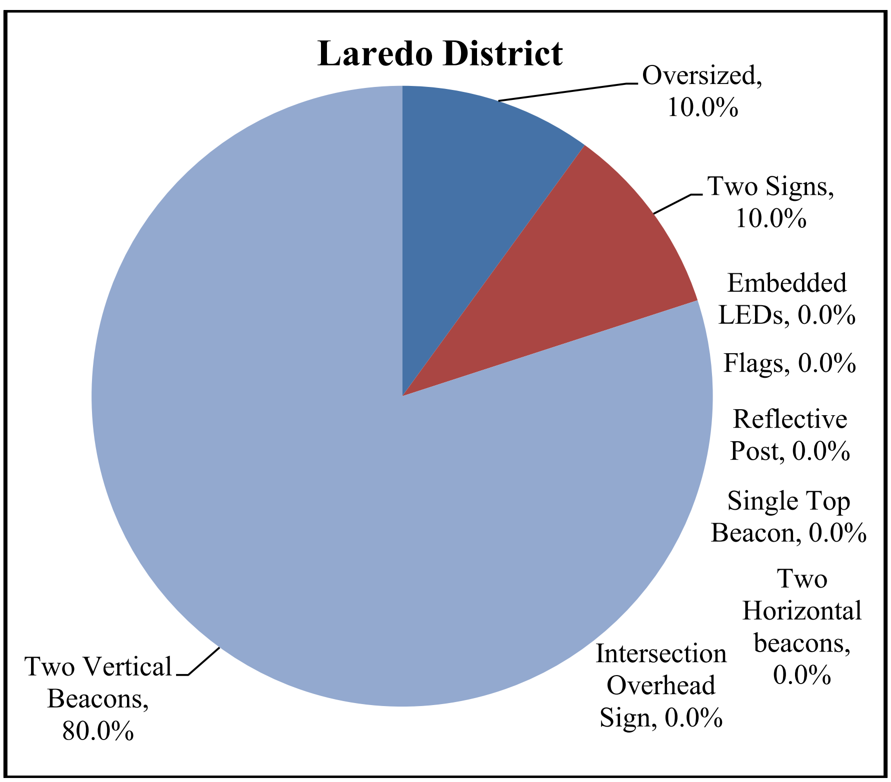


Figure 21. Example of the Use of Stop Sign Treatments in Laredo District.

With respect to the Intersection Ahead sign, most districts used one treatment predominantly, i.e., most districts either used the Intersection Ahead sign by itself or used the sign with two beacons in a vertical arrangement as shown in Table 23.

Beacons and LEDs on the signs improve their attention value. Beacon assemblies can consist of a single beacon or two beacons either in a horizontal arrangement or a vertical arrangement. Beacons and LEDs can either be steadily ON, or they can flash either simultaneously or alternately. The districts appear to have some consistency in the application and operations of these beacons and LEDs. None of the districts operated the beacon in a steady ON manner. Beacon operation by TxDOT districts is summarized below.

- In single beacon installation, the beacon flashes continuously.
- When two beacons are arranged horizontally, the beacons flash simultaneously.
- When two beacons are arranged vertically, the beacons flash alternately.
- When LEDs are embedded in the sign, LEDs flash simultaneously.

These practices for operating flashing beacons and LEDs were common for both the Stop sign and the Intersection Ahead sign. Table 24 and Table 25 provide the flashing pattern summary from the survey responses for Stop signs and Intersection Ahead signs.

Table 24. Flashing Pattern Summary at Stop Signs.

Treatment	Single Beacon	Two Horizontal Beacons	Two Vertical Beacons	Embedded LEDs	Intersection Overhead sign
Steady Burn	No	No	No	No	No
Simultaneous Flash	A few	Almost All	No	Almost All	A few
Alternating Flash	N/A	No	Almost all	No	Almost all

Table 25. Flashing Pattern Usage Summary at Intersection Ahead Signs.

Treatment	Single Beacon	Two Horizontal Beacons	Two Vertical Beacons	Embedded LEDs
Steady Burn	No	N/A	No	No
Simultaneous Flash	Almost all	N/A	No	Almost
Alternating Flash	N/A	N/A	Almost all	No

TCD Suitability

The districts were asked about the effectiveness of each treatment both during day and night and if their experience prompted them to use those treatments again. An important question was asked about the sequence or the order of the application of these treatments. Almost all the districts that responded to the survey were contacted with a phone call to clarify their responses to these questions. Effectiveness of the improvements to Stop signs as reported by districts is summarized below.

- Flags were almost never used as an improvement to a Stop sign. One district, however, routinely used flags temporarily on new sign installations.
- Stop signs with reflective posts and Stop signs with horizontal beacons were occasionally used. While most districts found the reflective post effective, one district has made further improvements in addition to the reflective post, such as flashing beacons. Stop signs with horizontal beacons, though rarely used, were believed to be effective.
- Stop signs with a single beacon and Stop signs with embedded LEDs were used by half of the districts that responded and are believed to be effective. Some districts, however, made improvements to Stop signs with a single beacon by adding an additional beacon. Some districts are also choosing LED embedded signs to reduce operating costs by retrofitting an existing installation or selecting them for new installations in place of adding beacons.
- Stop signs with beacons in a vertical arrangement and intersection overhead beacons were used by almost all districts and are believed to be the most effective in improving intersection safety. However, one district was moving from a vertical beacon arrangement to two horizontal beacons or a single beacon due to frequent vandalism of the lower beacon.
- A common theme from almost all districts observed was that the large Stop sign was in most cases the first treatment deployed to improve safety. In almost all cases, a Stop sign with beacons or the intersection overhead beacon was the final treatment to improve safety.

TCD Costs

The cost of implementing these treatments was found to vary significantly for each district. Not all districts use all treatments. Secondly, different districts use different methods to install these signs. While some use state personnel to install signs, others use maintenance contractors. For installations requiring power, some districts (e.g., west Texas districts) use solar, which is expensive initially. Power, however, is not available nearby for these installations due to the remoteness of the locations in the district. Some east Texas districts, however, use electrical power because electricity is usually available in the vicinity of the intersection. The monthly operating costs when using electrical power was not always accurately identified because in some cases, the monthly power consumption also included power for the street lights at the intersection. Thus the installation and operation costs obtained from the districts vary significantly between the districts. Table 26 and Table 27 list the installation and operational costs for Stop signs and Intersection Ahead signs and their treatments as provided by the TxDOT districts.

Table 26. Average Installation and Operation Costs from Districts for Stop Signs and Their Treatments.

	Power Type	Material Cost	Labor Costs	Monthly Costs	# Visits per Year	Vandalism
Oversized Stop Sign	N/A	$190	$180	$24	11	Sometimes to often
Two Stop Signs	N/A	$355	$346	$48	9	Sometimes
Stop Sign with Flags	N/A	$278	$165	NP	NP	Rarely
Stop Sign with Reflective Post	N/A	$325	$200	$50	NP	Rarely to sometimes
Stop Sign with Single Beacon	Electric	$816	$614	$10	1	Sometimes
	Solar	$3275	$925	$167	7	Sometimes
Stop Sign with Two Horizontal Beacons	Electric	$728	$307	$755	4	Sometimes
	Solar	NP	NP	NP	NP	NP
Stop Sign with Two Vertical Beacons	Electric	$1053	$614	$15	1	Sometimes to often
	Solar	$2800	$925	$170	6	Sometimes to often
Stop Sign with Embedded LEDs	Electric	$5894	$200	$905	6	Rarely to sometimes
	Solar	NP	NP	NP	NP	NP
Intersection Overhead Beacon	Electric	$6000	$12,250	$120	1	Rarely to sometimes
	Solar	$10,020	$300	$1273	3	Rarely to sometimes

N/A = not applicable.
NP = none provided.

Table 27. Average Installation and Operation Costs from Districts for Intersection Ahead Signs and Their Treatments.

	Power Type	Material Cost	Labor Costs	Monthly Costs	# of visits per year	Vandalism
Intersection Ahead Sign with Reflective Post	N/A	$300	$200	$10	12	Sometimes
Intersection Ahead sign with Single Beacon	Electric	$2158	$1057	$30	6	Sometimes
	Solar	$3000	$350	$279	2	NP
Intersection Ahead sign with Two Vertical Beacons	Electric	$1969	$1057	$28	6	Depends on district
	Solar	$2675	$350	$292	3	
Intersection Ahead sign with Embedded LEDs	Electric	NP	NP	NP	NP	NP
	Solar	$1500	$200	$10	12	Sometimes

NP = none provided.

TCD Costs from Vendors

Costs obtained from vendors were combined from multiple sources. Traffic control device vendors for TxDOT assemble systems from multiple sources. For example, a vendor may provide the sign but will not have the hardware for installing the sign. The hardware required for each district also varies. Some districts may use a particular hardware, while others may use different hardware due to the practice adopted by their districts. This variation can range from a different type of foundation system to a different type of installation hardware. This variation obviously has an impact on the material cost. Therefore, the TTI researchers contacted multiple vendors and obtained estimates for various Stop sign and Intersection Ahead sign assemblies. These costs are illustrated in Table 28 for Stop signs and Table 29 for Intersection Ahead signs.

Table 28. Material Costs of Stop Sign Installations (from Vendors).

Sign Type	Power Type	Material Cost
Oversized Stop Sign	N/A	$197
Two Stop Signs	N/A	$394
Stop Sign with Flags	N/A	Not available
Stop Sign with Reflective Post	N/A	$230
Stop Sign with Single Beacon	Electric	$1100
	Solar	$2900
Stop Sign with Two Horizontal Beacons	Electric	$1600
	Solar	$3800
Stop Sign with Two Vertical Beacons	Electric	$1600
	Solar	$3750
Stop Sign with Embedded LEDs	Electric	Not available
	Solar	$1853
Intersection Overhead Beacon	Electric	$2800
	Solar	Not provided

Table 29. Material Costs of Intersection Ahead Sign Assemblies (from Vendors).

Sign Type	Power Type	Material Cost
Intersection Ahead Sign with Reflective Post	N/A	$152
Intersection Ahead Sign with Single Beacon	Electric	$1100
	Solar	$2900
Intersection Ahead Sign with Two Horizontal Beacons	Electric	$1600
	Solar	$3800
Intersection Ahead Sign with Two Vertical Beacons	Electric	$1600
	Solar	$3750
Intersection Ahead Sign with Embedded LEDs	Electric	Not available
	Solar	$1575

DISCUSSION

This task evaluated the enhancements to Stop sign and Intersection Ahead signs used by TxDOT districts. The objective was to determine the treatments used by TxDOT practitioners, their experiences in using those treatments, and their rationale for selection of the treatments. While our objective was to obtain responses from about 10 districts, seven districts provided information.

Almost all enhancements for the Stop sign seem to improve safety at some intersections. Districts appear to use the large Stop sign as the first treatment to improve safety at the intersection. However, if safety problems persist, districts implement further improvements. For certain types of intersections, like intersections with high-speed approaches, some districts implemented the Stop sign with flashing beacons as the first traffic control device enhancement. Stop signs with flags are rarely used as a permanent improvement. However, one district routinely uses flags on new installations of Stop signs. Some districts use Stop signs with reflective tape. There are very few intersections using two Stop signs per approach. Districts more frequently use two Stop signs to accommodate unique geometric conditions than to specifically improve safety. The districts believe that the use of beacons has definitely improved intersection safety. Districts tend to prefer to use beacons in a vertical arrangement than the horizontal arrangement. Some of the survey participants expressed concerns regarding vandalism to the lower beacon in a vertical arrangement.

Intersection Ahead signs are being used to improve safety on high-speed approaches. Sometimes beacons are used on these signs to improve intersection visibility. The beacons for the Intersection Ahead sign flash in the same pattern as the beacons at the Stop sign.

Cost of the sign assemblies was only an issue with the use of solar panels. Some districts have started to use Stop signs with embedded LEDs. Solar panels are used as power sources by some districts when power is not closely available. Electricity is used when a power source is easily available because the start-up cost for solar power is higher.

CHAPTER 5

LAB STUDY TO IDENTIFY DRIVER REACTION TO TRAFFIC CONTROL DEVICES WITH LEDS OR BEACONS

INTRODUCTION

This chapter documents a laboratory study that examined driver reaction to selected modern traffic control devices. The selected devices have various features that purport to enhance driver visibility, comprehension, and compliance. The study was structured as a survey in which participants viewed images and video clips of these devices and answered questions about those devices.

The signs used in this study are listed below. Also provided is the Manual of Uniform Traffic Control Devices (MUTCD) designation in parentheses and the abbreviation used in this chapter in brackets.

- Stop sign (R1-1).
- Yield sign (R1-2).
- Pedestrian Crossing sign (W11-2) [Ped].
- Do Not Enter (a variation of the MUTCD sign without the legend was used).
- Speed Limit sign (R2-1).
- Intersection Ahead sign (W2-1).
- Two-Direction Large Arrow sign (W1-7) [Arrow].
- Stop sign (circular, created for this study).

Added to these signs were beacons or embedded LEDs as points (called dots in this chapter) or as bars that flashed at different rates and/or patterns.

PARTICIPANTS

The research team recruited a total of 48 participants to complete the survey. Recruiting efforts targeted four demographic groups (male under 55, male 55 and older, female under 55, and female 55 and older) with a goal of having 12 participants in each group. Table 30 lists the final breakdown by gender and age of the participants. The participants represented the following distribution regarding how often they drove on rural roadways:

- Almost never = 7 participants.
- Once a week = 14 participants.
- Several times a week = 7 participants.
- Almost every day = 7 participants.
- Several times a day = 13 participants.

TTI maintains a participant pool database that contains contact and basic demographic information of people who have previously participated in TTI studies. Researchers referred to this database for much of the recruiting for this survey, in addition to word-of-mouth recruiting.

Upon arrival for survey participation, participants were assigned a participant number for anonymity purposes. The survey took approximately 45 minutes for each participant; participants were paid $30 for their time.

Table 30. Demographic Breakdown of All Participants.

Demographic Group	Number of Participants	
Age	Female	Male
18–29	6	4
30–39	4	3
40–49	1	1
50–59	4	5
60–69	7	7
70–79	2	3
80+	0	1
TOTAL	**24**	**24**

FACILITIES

The lab study was conducted in the new Visibility Research Laboratory (VRL) in the recently opened TTI State Headquarters and Research Building. The 125-ft tunnel-shaped facility allows researchers to run night simulations under controlled conditions at any time during the day. The walls, ceiling, and the floor are covered by black nonreflective material to create a pitch black environment to simulate nighttime studies. For the purpose of this study, at one end of the long room a flat screen monitor was placed on a table and was connected to a laptop computer at the other end. Images of traffic signs generated on the laptop were displayed on the flat screen liquid crystal display (LCD) monitor. Figure 22 shows a plan view of the lab.

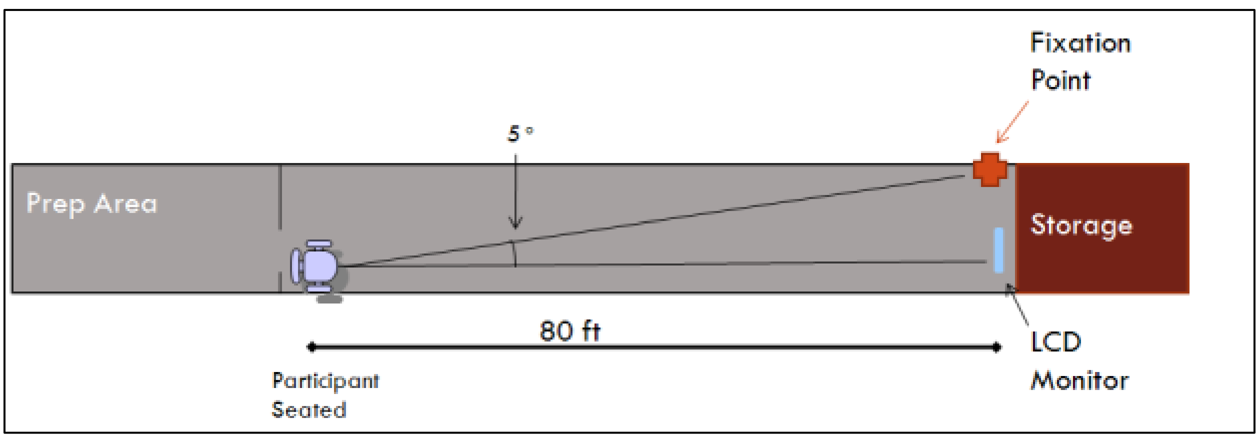


Figure 22. Plan View of Visibility Research Laboratory along with Geometry of the Focus Point for Peripheral Response Questions.

SURVEY STRUCTURE

The experiment-running software—SuperLab™—was used in this study. SuperLab can present photographs, video clips, and/or text for a set amount of time and measure the response time of viewers. Researchers inserted images and video clips of the selected TCD signs with various features. The survey had three main groups as described in Table 31. Within group A were 47 events with five types of questions. These 47 events did not occur in chronological order. For Sections 1 to 5, all events were randomized. Following these 47 events, the 24 events of Section 5.1 were randomized and presented. Finally, Section 6 ended the survey. Table 32 shows the events and questions for Sections 1 to 4, while Table 33 shows the events and questions for Sections 5 and 5.1. Due to randomization by the survey software, the event order varied for each participant.

Table 31. Structure of Survey Questions.

Order	Section		Question Type	View	# of Events
A – Events randomized	1	Stop sign comparisons of same sized signs	Is sign size same or different?	Straight	9
	2	White versus yellow colored lights comparisons	Response time to shape, color, type recognition	Peripheral	6
	3	Stop signs with beacon(s) comparisons	Response time to shape, color, type recognition	Peripheral	4
	4	Stop sign comparisons of varying sized signs	Is sign size same or different?	Straight	4
	5	All remaining sign variations	Response time to shape, color, type recognition	Peripheral	24
B	5.1	Section 5 repeated to gather baseline data	Response time to shape, color, type recognition	Straight	24
C	6	Opinions and feedback	Open-ended responses	Straight	3

Within Section 1 and Section 4, the participant looked directly at the screen and viewed two Stop sign variations back to back for 4000 milliseconds (ms) each. The participants were asked to answer the following questions:

- Were the two signs you saw the same or different in size?
- If they were different, was the second sign bigger or smaller than the first?

The order of each Stop sign pairing was reversed and repeated within the survey.

Section 5.1 consisted of the exact same sign stimuli seen in Section 5, although for 5.1 participants looked straight ahead at the screen to provide baseline response time data. For Sections 2, 3, and 5, the participant looked at a point on the side wall and viewed the stimuli peripherally.

For Sections 2, 3, 5, and 5.1, the participants pressed a button on a keypad as soon as they were able to identify the shape, color, and type of sign. They then provided the following:

- Sign shape.
- Sign color.
- Sign type or sign legend.

Researchers also recorded any other comments the participant may have had about what they saw.

The survey ended with Section 6, which included three questions about the participant's understanding of and opinions on some of the signs. The questions were as follows:

- For a flashing Stop sign, are the lights on all the time or are they turned on by an approaching vehicle? Why?
- Which sign do you like the most? Why?
- How should TxDOT decide where to put signs like these?

Table 32. Events for Section 1 to Section 4.

Section [Question Type]	View*	Stimulus Code	Sign Description
1. Stop sign comparisons of same-sized signs [Is sign size same or different?]	S	1C – 1A	Stop 36 in. – Stop w/ 8 red dots flash 1:9
		1C – 1B	Stop 36 in. – Stop w/ 8 red dots flash 2:8
		1C – 1C	Stop 36 in. – Stop 36 in.
		1A – 1A	Stop w/ 8 red dots flash 1:9 – Stop w/ 8 red dots flash 1:9
		1A – 1B	Stop w/ 8 red dots flash 1:9 – Stop w/ 8 red dots flash 2:8
		1A – 1C	Stop w/ 8 red dots flash 1:9 – 36 in. stop
		1B – 1A	Stop w/ 8 red dots flash 2:8 – Stop w/ 8 red dots flash 1:9
		1B – 1B	Stop w/ 8 red dots flash 2:8 – Stop w/ 8 red dots flash 2:8
		1B – 1C	Stop w/ 8 red dots flash 2:8 – 36 in. stop
2. White versus sign-colored lights comparisons [Response time to shape, color, type recognition]	P	1C	Stop 36 in.
		1A	Stop w/ 8 red dots flash 1:9
		2A	Stop w/ 8 white dots flash 1:9
		2B	Ped 36 in.
		2C	Ped w/ 8 yellow dots flash 1:9
		2D	Ped w/ 8 white dots flash 1:9
3. Stop signs with beacon(s) comparisons [Response time to shape, color, type recognition]	P	3A	Stop w/ one top beacon
		3B	Stop w/ top and bottom beacons
		3C	Stop w/ rapid flash bottom beacons
		3D	Stop w/ two top beacons
4. Stop sign comparisons of varying sized signs [Is sign size same or different?]	S	4A – 4A	Stop 48 in. – Stop 48 in.
		4A – 1A	Stop 48 in. – Stop w/ 8 red dots flash 1:9
		1A – 1A	Stop w/ 8 red dots flash 1:9 – Stop w/ 8 red dots flash 1:9
		1A – 4A	Stop w/ 8 red dots flash 1:9 – Stop 48 in.

*Stimuli viewed from participant's peripheral vision (P) or straight (S).

Table 33. Events for Section 5 and Section 5.1.

Sections	Question Type	Event	Stimulus Code	Sign Description
5. All remaining sign variations 5.1. Section 5 repeated	Response time to shape, color, type recognition	5-1	1C	Stop 36 in.
		5-2	1A	Stop w/ 8 red dots flash 1:9
		5-3a	5A1	Stop w/ 8 white bars flash 1:9
		5-3b	5A2	Stop w/ 4 white bars flash 1:9
		5-4a	5B1	Stop w/ 8 red bars flash 1:9
		5-4b	5B2	Stop w/ 4 red bars flash 1:9
		5-5	5C	Stop w/ 4 red dots flash 1:9
		5-6	5D	Yield 36 in.
		5-7	5E	Yield w/ 3 red dots flash 1:9
		5-8	5F	Yield w/ 3 red bars flash 1:9
		5-9	5G	Do Not Enter 36 in.
		5-10a	5H1	Do Not Enter w/ 8 red dots flash 1:9
		5-10b	5H2	Do Not Enter w/ 8 red dots flash rotating
		5-11	5I	Do Not Enter w/ 4 white bars flash 1:9
		5-12	5J	Intersection Ahead 36 in.
		5-13	5K	Intersection Ahead w/ 4 yellow dots flash 1:9
		5-14	5L	Intersection Ahead w/ 8 yellow dots flash 1:9
		5-15	5M	Speed Limit 36 × 48
		5-16	5N	Speed Limit w/ 4 white dots flash 1:9
		5-17	5O	Speed Limit w/ 4 white bars flash 1:9
		5-18	5P	Two-Direction Large Arrow 36 × 18
		5-19	5Q	Two-Direction Large Arrow w/ 4 yellow dots flash 1:9
		5-20	6C	Circular Stop 36 in.
		5-21	6B	Circular Stop w/ 8 red dots flash 1:9
Note: Event and sign stimuli have variations in nomenclature such as 5-3a or 5A1 due to additions made to the experimental design after the initial design had already been created.				

SIGN CREATION

Creation of the virtual signs for the survey stimuli began with the typical signs found in the MUTCD. Pictures of the signs were created in Photoshop®, with color and exposure levels adjusted to simulate how the signs would look during nighttime driving. Several alternatives were tested in the lab before finalizing the look of the signs.

For all of the flashing signs, a glowing effect was added to mimic the illumination of the sign by the light sources, along with GIF animations of the light sources (beacons or LEDs) themselves.

The final step was to determine the sizes of the sign images so that they resembled actual road sign dimensions when viewed from a distance. As described previously, a large LCD monitor was placed at the end of the corridor of the Visibility Research Lab (see Figure 22 and Figure 23). The objective was to simulate a 36-in. sign seen from 500 ft away, using an image on a monitor located 80 ft from the participant. Figure 24 illustrates that a 36-in. sign at 500 ft can be represented by a 5.76-in. sign on the monitor for a participant viewing the monitor from a distance of 80 ft. A 48-in. Stop sign was simulated with a sign image that was 7.68 in. in height on the monitor screen. In the rest of this chapter, the sign sizes specified (36 or 48 in.) are the apparent sizes simulated as described above.

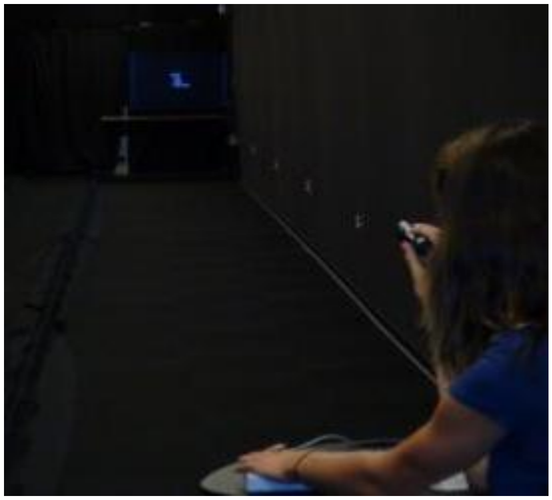


Figure 23. Setup for Surveys in the Visibility Research Lab.

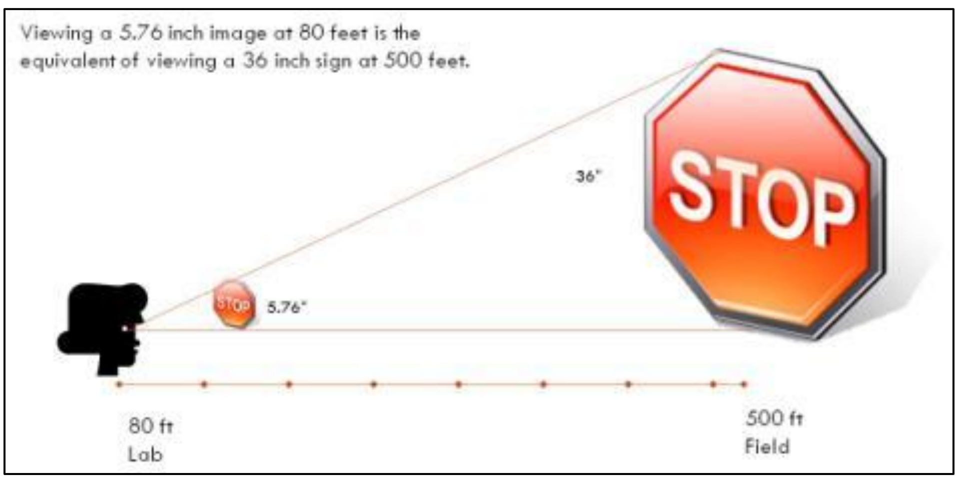


Figure 24. Proper Sign Perspective of Signs Viewed in the Visibility Research Lab.

PROCEDURES

When a participant arrived for their appointment time, he/she read and agreed to the consent form. A color vision test was administered and the results were recorded on the participant's data sheet. The participant was then led into the lab to complete the survey. Figure 25 shows the instructions that were read to the participants.

Each participant sat in a chair at the opposite end of the corridor, facing the monitor (see Figure 22 and Figure 23). The location of the chair was marked on the ground so that it remained in the same spot for all participants. A small table was placed in front of the participant's chair that held a flashlight; a keypad the participant pressed when they were able to identify the shape, color, and type of sign; and a handout that provided example sign shapes (see Figure 26).

Thanks for participating today. Did you have any questions from your consent form? Feel free to interrupt me at anytime if you have a question.

You will be sitting in this chair, and viewing signs on the monitor at the end of this hall. [*Have the subject get settled in the chair and provide them with the red flash light and show them how to use it.*] The lights will be out for this study. Sometimes you will be asked to turn your chair to look at that spot on the wall to your left, and sometimes you will be asked to look straight ahead at the monitor at the end of the hall. [*Point out the spot on the wall, and have them practice aiming the flashlight.*]

You will use this button box for several questions. You can leave it sitting on the table in front of you during the study. When you need to hit a button, it is okay for you to hit any of the buttons.

Let's start out by asking you a few questions about yourself. You don't have to press any buttons for these questions because I will enter them for you. [*Ask them the demographic questions and enter their responses using the number keys.*]

Now we'll move on to the main set of questions. There are 2 sections: the first section has a total of 47 questions and the second section has 24 questions. I will offer you a break in between the two sections if you need it.

- **First Section –** 47 questions total; 2 types of questions; the questions will be all mixed up and presented in a random order. Because the monitor is so far away, I will tell you which type of question you are about to be asked so that you don't have to read it yourself. Let's do some practice questions so that I can show you each of the two types of questions:
  - **Same/Different** – You will look straight ahead, directly at the screen at the end of the hall. You will see two signs back to back. You will then be asked if the two signs were the same size or different sizes. You don't need to press any buttons for this type of question.
  - **Color/Shape/Sign Type** – For this type of question, you will stare at the reflective cross symbol on the wall to the left of the screen so that you are not looking directly at the screen. You will be shown only one sign and you will press any button on the button box as soon as you are able to tell me what color, shape, and type of sign you think it is. (For example: red, octagon, Stop sign). Please let me know if you accidentally peek at the screen. And also try not to leave the sign up there for more than 5 or so seconds.
- **Second Section –** 24 questions total; 1 type of question
  - **Color/Shape/Sign Type** – Now you will look directly at the screen. And just like in the previous section, you will be shown only one sign and you will press any button on the button box as soon as you are able to tell me what color, shape, and type of sign you think it is. (For example: red, octagon, Stop sign)

At the end of the study you will be asked a few more questions about what you think the signs mean, and which was your preference. Do you have any questions?

Figure 25. Instructions for Participants.

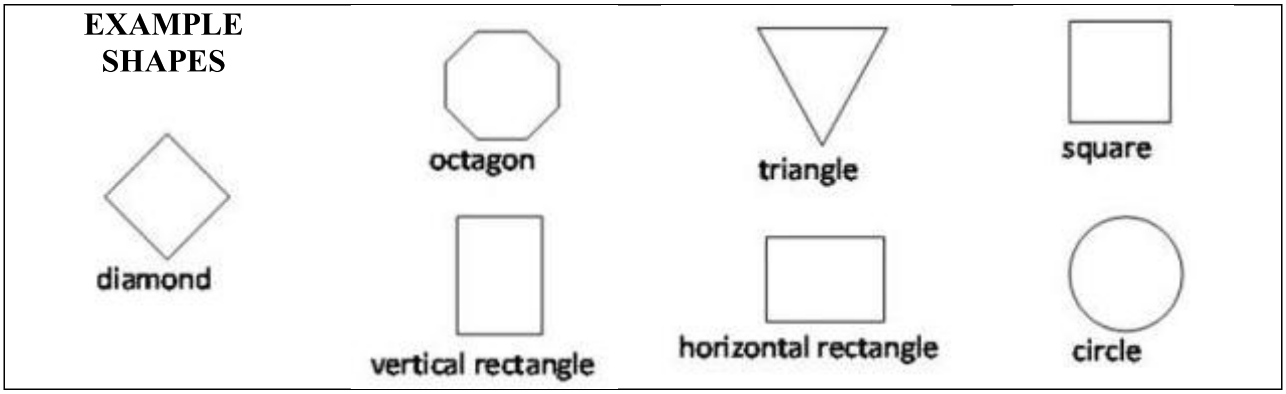


Figure 26. Example of Shapes Provided to Participants.

As previously mentioned, Sections 1, 4, 5.1, and 6 required the participant to look directly at the monitor, while Sections 2, 3, and 5 required the participant to look off-screen at a reflective "plus-sign" shaped marking on the wall to the left of the monitor (see Figure 27). This allowed participants to see the displayed signs using their peripheral vision. The plus-sign marking location was placed 5 degrees off of the screen from where the participant was sitting (see Figure 22).

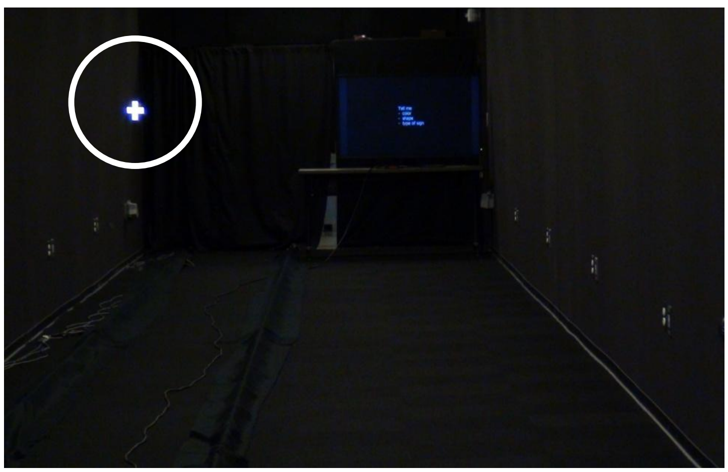


Figure 27. Focus Point for Peripheral Response Questions.

For the peripheral response questions, participants were asked to focus their eyes on the reflective plus sign and then press a button on the keypad as soon as they felt that they could tell the experimenter the shape, color, and type of sign. Participants were asked not to let the sign linger on the screen for more than a few seconds if possible. Participants' compliance with these instructions is reflected in the modal response times to peripherally presented signs of 1.5 to 2.5 s (see Figure 28).

DATA REDUCTION

The individual signs tested in the study were assigned a stimuli code and an event number to aid in data reduction and analysis.

Response Time

Response times were measured in milliseconds and represent the time between when the sign first appeared on the screen and when the participant pressed a button to indicate that they could provide the shape, color, and type of the sign. As is typical with response time data, the resulting distribution of scores was not normally distributed (see Figure 28). Thus, in order to make the data suitable for statistical analysis, three steps were taken. First, 36 of the response times (approximately 1 percent of the response time data) were removed from evaluation due to concerns that the participants' response time was compromised. These were identified by researcher notes made during the surveys, indicating instances when a participant forgot to press the button, answered the questions before pressing the button, or looked directly at the screen when they were to be looking at the side wall. Second, outliers were trimmed within each experimental factor using Tukey's interquartile range method. This is the same procedure used to flag outliers in traditional box plots and identifies outliers in a manner that is robust to the skewness of a distribution. Third, once these outliers were removed, all data were log transformed so that their shape approximated a normal distribution (see Figure 29). A primary danger of failing to take these precautionary steps would have been an increased occurrence of Type 1 errors (e.g., the increased likelihood of finding a significant difference when one did not, in fact, exist). The numbers of data points that were classified as outliers and removed from analysis are included in Table 34 and Table 35.

Table 34 provides the response time data when participants viewed signs peripherally, while Table 35 provides the response time data when participants viewed signs focally. These tables list the average and standard deviation of the response times after the compromised response times and outliers were removed.

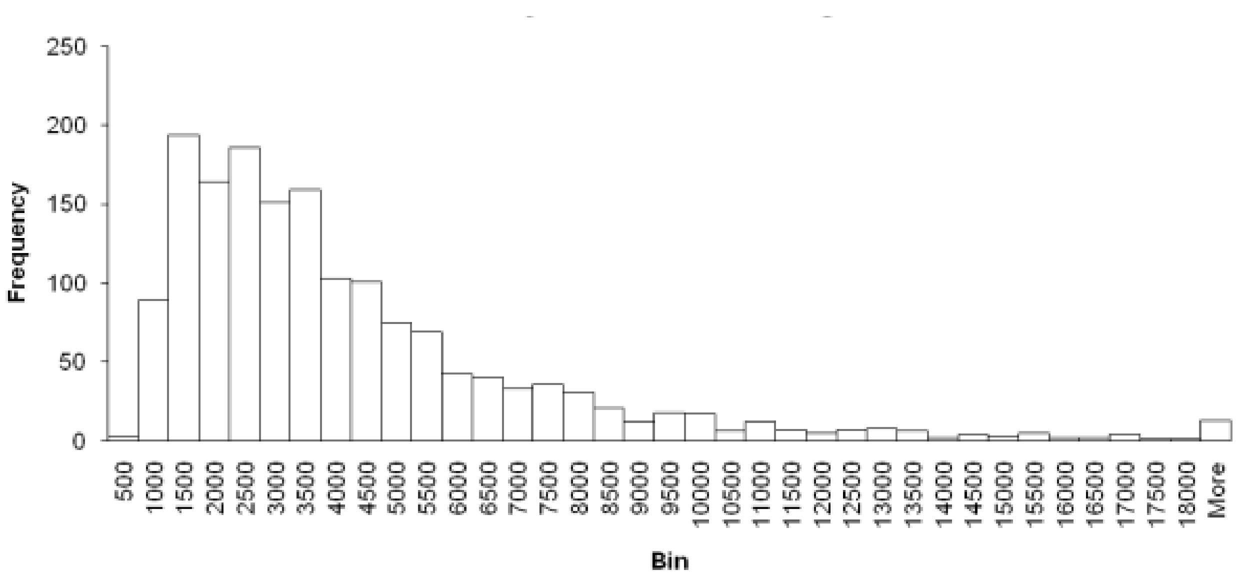


Figure 28. Histogram of All Response Times to Peripherally Presented Signs. Note the Extreme Skew.

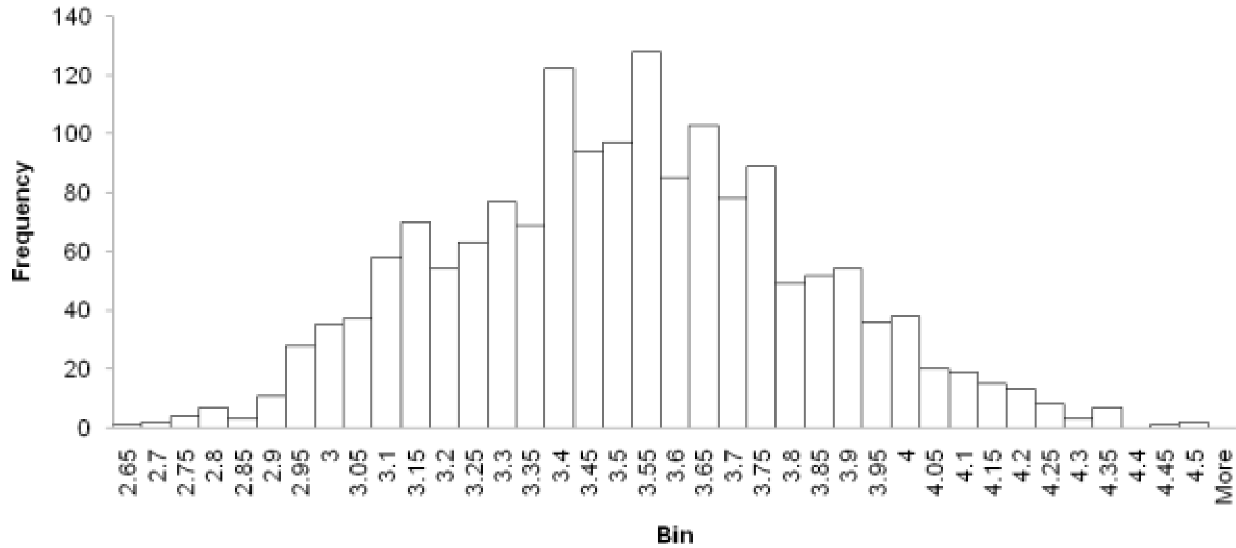


Figure 29. Histogram of the Log Transformed Response Times to Peripherally Presented Signs. Note the Near-Perfect Normal Distribution.

Color, Shape, Type

The frequency and percent responses of participants within each category are provided in the following tables:

- Table 36. Frequency Response to Sign Type Question when Viewing Peripherally.
- Table 37. Percentage Response to Sign Type Question when Viewing Peripherally.
- Table 38. Frequency Response to Sign Type Question when Viewing Straight.
- Table 39. Percentage Response to Sign Type Question when Viewing Straight.
- Table 40. Response to Sign Color Question when Viewing Peripherally.
- Table 41. Response to Sign Color Question when Viewing Straight.
- Table 42. Frequency Response to Sign Shape Question when Viewing Peripherally.
- Table 43. Percentage Response to Sign Shape Question when Viewing Peripherally.
- Table 44. Frequency Response to Sign Shape Question when Viewing Straight.
- Table 45. Percentage Response to Sign Shape Question when Viewing Straight.

Table 34. Mean Response Time Results when Viewing Peripherally.

Code	Event	Sign Description	Num*	Average Response Time (ms)	SD Response Time (ms)	Average Log Response Time	SD Log Response Time	Out*
1C	5-1	Stop 36 in.	43	2763	1591	3.38	0.24	5
1A	5-2	Stop w/8 red dots flash 1:9	43	3080	1583	3.43	0.24	5
5A1	5-3a	Stop w/8 white bars simultaneous flash 1:9	45	4010	2317	3.53	0.26	2
5A2	5-3b	Stop w/4 white bars alternating flash 1:9	44	5362	2833	3.67	0.22	2
5B1	5-4a	Stop w/8 red bars simultaneous flash 1:9	43	2725	979	3.41	0.17	5
5B2	5-4b	Stop w/4 red bars alternating flash 1:9	44	4924	3057	3.62	0.26	3
5C	5-5	Stop w/4 red dots simultaneous flash 1:9	44	3642	2361	3.47	0.29	3
5D	5-6	Yield 36 in.	41	2440	1774	3.29	0.28	5
5E	5-7	Yield w/3 red dots flash 1:9	43	2619	1177	3.37	0.21	4
5F	5-8	Yield w/3 red bars flash 1:9	46	3477	2198	3.45	0.29	2
5G	5-9	Do Not Enter 36 in.	43	3709	2494	3.47	0.31	2
5H1	5-10a	Do Not Enter w/8 red dots flash 1:9	45	3450	2163	3.45	0.29	2
5H2	5-10b	Do Not Enter w/8 red dots flash rotating	45	4367	2559	3.55	0.30	2
5I	5-11	Do Not Enter w/4 white bars flash 1:9	42	4523	2396	3.59	0.27	4
5J	5-12	Intersection Ahead 36 in.	45	1,900	1,039	3.22	0.23	3
5K	5-13	Intersection Ahead w/4 yellow dots flash 1:9	46	2,935	1,945	3.37	0.30	2
5L	5-14	Intersection Ahead w/8 yellow dots flash 1:9	44	2,466	1,496	3.31	0.27	4
5M	5-15	Speed Limit 36 × 48 in.	44	2400	1361	3.32	0.23	3
5N	5-16	Speed Limit w/4 white dots flash 1:9	44	3475	1989	3.47	0.25	4
5O	5-17	Speed Limit w/4 white bars flash 1:9	43	2982	1806	3.38	0.31	3
5P	5-18	Double Arrow 36 × 18 in.	43	2736	1625	3.37	0.25	4
5Q	5-19	Double Arrow w/4 yellow dots flash 1:9	45	2914	1594	3.40	0.25	3
6C	5-20	Circular Stop 36 in.	40	3493	1600	3.50	0.21	7
6B	5-21	Circular Stop w/8 red dots flash 1:9	45	3649	1622	3.52	0.20	2

*Num = number of participants, Out=number of outliers, SD = standard deviation.

Table 35. Mean Response Time Results when Viewing Straight.

Code	Event	Sign Description	Num*	Average Response Time (ms)	SD Response Time (ms)	Average Log Response Time	SD Log Response Time	Out*
1C	5.1-1	Stop 36 in.	44	1276	828	3.02	0.27	3
1A	5.1-2	Stop w/8 red dots flash 1:9	45	1589	903	3.13	0.25	3
5A1	5.1-3a	Stop w/8 white bars simultaneous flash 1:9	44	1388	847	3.08	0.23	4
5A2	5.1-3b	Stop w/4 white bars alternating flash 1:9	43	2577	1119	3.37	0.19	5
5B1	5.1-4a	Stop w/8 red bars simultaneous flash 1:9	46	1425	777	3.09	0.23	2
5B2	5.1-4b	Stop w/4 red bars alternating flash 1:9	42	2859	1341	3.41	0.20	6
5C	5.1-5	Stop w/4 red dots simultaneous flash 1:9	44	1477	938	3.10	0.25	4
5D	5.1-6	Yield 36 in.	44	1077	563	2.98	0.20	4
5E	5.1-7	Yield w/3 red dots flash 1:9	45	1448	760	3.11	0.22	3
5F	5.1-8	Yield w/3 red bars flash 1:9	45	1487	947	3.10	0.24	3
5G	5.1-9	Do Not Enter 36 in.	43	1535	836	3.12	0.25	5
5H1	5.1-10a	Do Not Enter w/8 red dots flash 1:9	46	1824	1054	3.19	0.25	2
5H2	5.1-10b	Do Not Enter w/8 red dots flash rotating	45	1846	1073	3.20	0.25	3
5I	5.1-11	Do Not Enter w/4 white bars flash 1:9	45	1700	1021	3.16	0.26	3
5J	5.1-12	Intersection Ahead 36 in.	46	1,139	638	2.99	0.23	2
5K	5.1-13	Intersection Ahead w/4 yellow dots flash 1:9	45	1,540	1,015	3.10	0.27	2
5L	5.1-14	Intersection Ahead w/8 yellow dots flash 1:9	46	1,631	1,079	3.13	0.26	1
5M	5.1-15	Speed Limit 36 × 48 in.	47	1244	684	3.03	0.23	1
5N	5.1-16	Speed Limit w/4 white dots flash 1:9	46	1387	803	3.08	0.23	2
5O	5.1-17	Speed Limit w/4 white bars flash 1:9	42	1347	710	3.08	0.21	5
5P	5.1-18	Double Arrow 36 × 18 in.	45	1230	605	3.04	0.21	3
5Q	5.1-19	Double Arrow w/4 yellow dots flash 1:9	46	1959	1301	3.20	0.28	2
6C	5.1-20	Circular Stop 36 in.	46	1401	953	3.05	0.29	2
6B	5.1-21	Circular Stop w/8 red dots flash 1:9	44	1455	860	3.10	0.24	4

*Num = number of participants, Out=number of outliers, SD = standard deviation.

Table 36. Frequency Response to Sign Type Question when Viewing Peripherally.

ID	Correct Sign Type	Frequency Response to Sign Type Question*										
		A	D	I	O	P	RR	SL	Stop	U	Y	Total
1A	Stop				7		1	1	70	17		96
1C	Stop		1	1	5				75	14		96
2A	Stop				1		2		35	10		48
2B	Ped			1	20	13			2	9	3	48
2C	Ped			1	19	16				11	1	48
2D	Ped			1	20	10	1			12	4	48
3A	Stop		1		2		1	1	35	8		48
3B	Stop				6		7	1	22	11	1	48
3C	Stop				5		2		22	17	2	48
3D	Stop			2	6		2		32	6		48
5A1	Stop				5		1		32	10		48
5A2	Stop		3		9		7	1	8	20		48
5B1	Stop				3		1		39	4	1	48
5B2	Stop				4		3		21	20		48
5C	Stop				2		2		33	11		48
5D	Yield				4				1	10	33	48
5E	Yield				6				5	5	32	48
5F	Yield				6				4	9	29	48
5G	Do Not		11		11			3	3	20		48
5H1	Do Not		6		12	1		6	5	18		48
5H2	Do Not		12		5			1	4	23	3	48
5I	Do Not		9		10			2	7	20		48
5J	Int	2		9	20	2	1			12	2	48
5K	Int	2		15	15	4				12		48
5L	Int	1		14	17	1	1			12	2	48
5M	SL				16			23		9		48
5N	SL				12			18		18		48
5O	SL				13			22		13		48
5P	Arrow	8			23					16	1	48
5Q	Arrow	5		1	19				1	21	1	48
6B	Stop				1		1	1	36	8	1	48
6C	Stop				1				35	10	2	48

*A = Arrow, D or Do Not = Do Not Enter sign (without words on sign face),
I or Int = Intersection Ahead, O = other, P or Ped = Pedestrian Crossing, RR = Railroad,
SL = Speed Limit, Stop = Stop, U = did not know or offer a guess, Y = Yield.

Blank cell = 0 responses.
Shaded cell = correct response.

Table 37. Percentage Response to Sign Type Question when Viewing Peripherally.

ID	Correct Sign Type	Percent (%) Response to Sign Type Question*										
		A	D	I	O	P	RR	SL	Stop	U	Y	Frequency Total
1A	Stop	0	0	0	7	0	1	1	73	18	0	96
1C	Stop	0	1	1	5	0	0	0	78	15	0	96
2A	Stop	0	0	0	2	0	4	0	73	21	0	48
2B	Ped	0	0	2	42	27	0	0	4	19	6	48
2C	Ped	0	0	2	40	33	0	0	0	23	2	48
2D	Ped	0	0	2	42	21	2	0	0	25	8	48
3A	Stop	0	2	0	4	0	2	2	73	17	0	48
3B	Stop	0	0	0	13	0	15	2	46	23	2	48
3C	Stop	0	0	0	10	0	4	0	46	35	4	48
3D	Stop	0	0	4	13	0	4	0	67	13	0	48
5A1	Stop	0	0	0	10	0	2	0	67	21	0	48
5A2	Stop	0	6	0	19	0	15	2	17	42	0	48
5B1	Stop	0	0	0	6	0	2	0	81	8	2	48
5B2	Stop	0	0	0	8	0	6	0	44	42	0	48
5C	Stop	0	0	0	4	0	4	0	69	23	0	48
5D	Yield	0	0	0	8	0	0	0	2	21	69	48
5E	Yield	0	0	0	13	0	0	0	10	10	67	48
5F	Yield	0	0	0	13	0	0	0	8	19	60	48
5G	Do Not	0	23	0	23	0	0	6	6	42	0	48
5H1	Do Not	0	13	0	25	2	0	13	10	38	0	48
5H2	Do Not	0	25	0	10	0	0	2	8	48	6	48
5I	Do Not	0	19	0	21	0	0	4	15	42	0	48
5J	Int	4	0	19	42	4	2	0	0	25	4	48
5K	Int	4	0	31	31	8	0	0	0	25	0	48
5L	Int	2	0	29	35	2	2	0	0	25	4	48
5M	SL	0	0	0	33	0	0	48	0	19	0	48
5N	SL	0	0	0	25	0	0	38	0	38	0	48
5O	SL	0	0	0	27	0	0	46	0	27	0	48
5P	Arrow	17	0	0	48	0	0	0	0	33	2	48
5Q	Arrow	10	0	2	40	0	0	0	2	44	2	48
6B	Stop	0	0	0	2	0	2	2	75	17	2	48
6C	Stop	0	0	0	2	0	0	0	73	21	4	48

*A = Arrow, D or Do Not = Do Not Enter sign (without words on sign face),
I or Int = Intersection Ahead, O = other, P or Ped = Pedestrian Crossing, RR = Railroad,
SL = Speed Limit, Stop = Stop, U = did not know or offer a guess, Y = Yield.

Shaded cell = correct response.

Table 38. Frequency Response to Sign Type Question when Viewing Straight.

ID	Correct Sign Type	Frequency Response to Sign Type Question*									
		A	D	I	O	RR	SL	Stop	U	Y	Total
1A	Stop							47	1		48
1C	Stop							47	1		48
5A1	Stop							47	1		48
5A2	Stop				4	5		32	6		47
5B1	Stop							48			48
5B2	Stop				3	7		35	3		48
5C	Stop		1		1			46	1		49
5D	Yield				3				5	40	48
5E	Yield				1				6	41	48
5F	Yield				3				4	41	48
5G	Do Not		32		6			4	4	1	47
5H1	Do Not		33		2			7	4	1	47
5H2	Do Not		34		3	1		3	7	1	49
5I	Do Not		31		4	2		5	5	1	48
5J	INT			43	3				2		48
5K	INT			43	3				2		48
5L	INT			44	3				1		48
5M	SL				1		45		2		48
5N	SL				1		47				48
5O	SL				1		47				48
5P	Arrow	27			19			1	1		48
5Q	Arrow	25			22				1		48
6B	Stop			1				46		1	48
6C	Stop							48			48

*A = Arrow, D or Do Not = Do Not Enter sign (without words on sign face), I or Int = Intersection Ahead, O = other, P or Ped = Pedestrian Crossing, RR = Railroad, SL = Speed Limit, Stop = Stop, U = did not know or offer a guess, Y = Yield.

Blank cell = 0 responses.
Shaded cell = correct response.

Table 39. Percentage Response to Sign Type Question when Viewing Straight.

ID	Correct Sign Type	Percent (%) Response to Sign Type Question*									
		A	D	I	O	RR	SL	Stop	U	Y	Frequency Total
1A	Stop	0	0	0	0	0	0	98	2	0	48
1C	Stop	0	0	0	0	0	0	98	2	0	48
5A1	Stop	0	0	0	0	0	0	98	2	0	48
5A2	Stop	0	0	0	9	11	0	68	13	0	47
5B1	Stop	0	0	0	0	0	0	100	0	0	48
5B2	Stop	0	0	0	6	15	0	73	6	0	48
5C	Stop	0	2	0	2	0	0	94	2	0	49
5D	Yield	0	0	0	6	0	0	0	10	83	48
5E	Yield	0	0	0	2	0	0	0	13	85	48
5F	Yield	0	0	0	6	0	0	0	8	85	48
5G	Do Not	0	68	0	13	0	0	9	9	2	47
5H1	Do Not	0	70	0	4	0	0	15	9	2	47
5H2	Do Not	0	69	0	6	2	0	6	14	2	49
5I	Do Not	0	65	0	8	4	0	10	10	2	48
5J	INT	0	0	90	6	0	0	0	4	0	48
5K	INT	0	0	90	6	0	0	0	4	0	48
5L	INT	0	0	92	6	0	0	0	2	0	48
5M	SL	0	0	0	2	0	94	0	4	0	48
5N	SL	0	0	0	2	0	98	0	0	0	48
5O	SL	0	0	0	2	0	98	0	0	0	48
5P	Arrow	56	0	0	40	0	0	2	2	0	48
5Q	Arrow	52	0	0	46	0	0	0	2	0	48
6B	Stop	0	0	2	0	0	0	96	0	2	48
6C	Stop	0	0	0	0	0	0	100	0	0	48

*A = Arrow, D or Do Not = Do Not Enter sign (without words on sign face),
I or Int = Intersection Ahead, O = other, P or Ped = Pedestrian Crossing, RR = Railroad,
SL = Speed Limit, Stop = Stop, U = did not know or offer a guess, Y = Yield.

Shaded cell = correct response.

Table 40. Response to Sign Color Question when Viewing Peripherally.

ID	Correct Color	Responses										
		Frequency					Percent (%)					Frequency Total
		O	RWR	U	W	Y	O	RWR	U	W	Y	
1A	RWR	3	80	2	1	10	3	83	2	1	10	96
1C	RWR	3	86	3		4	3	90	3	0	4	96
2A	RWR	2	37	4	4	1	4	77	8	8	2	48
2B	Y	2		1		45	4	0	2	0	94	48
2C	Y	3		1		44	6	0	2	0	92	48
2D	Y	3				45	6	0	0	0	94	48
3A	RWR		40	1	5	2	0	83	2	10	4	48
3B	RWR	3	32	3	3	7	6	67	6	6	15	48
3C	RWR	3	34	3	2	6	6	71	6	4	13	48
3D	RWR	5	36	1	2	4	10	75	2	4	8	48
5A1	RWR	2	37	3	4	2	4	77	6	8	4	48
5A2	RWR	1	20	2	24	1	2	42	4	50	2	48
5B1	RWR	2	44	1	1		4	92	2	2	0	48
5B2	RWR	9	32	1	4	2	19	67	2	8	4	48
5C	RWR	2	40	1	4	1	4	83	2	8	2	48
5D	RWR	1	37	2	2	6	2	77	4	4	13	48
5E	RWR	2	32	3	2	9	4	67	6	4	19	48
5F	RWR	2	37	3	2	4	4	77	6	4	8	48
5G	RWR	1	16	2	29		2	33	4	60	0	48
5H1	RWR	2	22	1	23		4	46	2	48	0	48
5H2	RWR	3	23	3	14	5	6	48	6	29	10	48
5I	RWR		21	1	25	1	0	44	2	52	2	48
5J	Y	3				45	6	0	0	0	94	48
5K	Y	3		1		44	6	0	2	0	92	48
5L	Y	2				46	4	0	0	0	96	48
5M	W	5		2	41		10	0	4	85	0	48
5N	W	3		2	43		6	0	4	90	0	48
5O	W	2		1	45		4	0	2	94	0	48
5P	Y	8	1			39	17	2	0	0	81	48
5Q	Y	6	1			41	13	2	0	0	85	48
6B	RWR	3	43		2		6	90	0	4	0	48
6C	RWR	2	38	2	5	1	4	79	4	10	2	48

O = orange, RWR = red and white or red, U = did not know or did not answer, W = white, Y = yellow.

Blank cell = 0 responses.
Shaded cell = correct response.

Table 41. Response to Sign Color Question when Viewing Straight.

ID	Correct Color	Responses										
		Frequency					Percent (%)					Frequency Total
		O	RWR	U	W	Y	O	RWR	U	W	Y	
1A	RWR		48				0	100	0	0	0	48
1C	RWR		47	1			0	98	2	0	0	48
5A1	RWR		47	1			0	98	2	0	0	48
5A2	RWR		43	1	2	1	0	91	2	4	2	47
5B1	RWR		46	2			0	96	4	0	0	48
5B2	RWR	4	42	1		1	8	88	2	0	2	48
5C	RWR		49				0	100	0	0	0	49
5D	RWR		47	1			0	98	2	0	0	48
5E	RWR		48				0	100	0	0	0	48
5F	RWR		47	1			0	98	2	0	0	48
5G	RWR		40	1	6		0	85	2	13	0	47
5H1	RWR		40	1	6		0	85	2	13	0	47
5H2	RWR		41	2	6		0	84	4	12	0	49
5I	RWR		37	2	9		0	77	4	19	0	48
5J	Y	2				46	4	0	0	0	96	48
5K	Y	3		1		44	6	0	2	0	92	48
5L	Y	2				46	4	0	0	0	96	48
5M	W	1		1	46		2	0	2	96	0	48
5N	W	3		1	44		6	0	2	92	0	48
5O	W	2		2	44		4	0	4	92	0	48
5P	Y	5				43	10	0	0	0	90	48
5Q	Y	6				42	13	0	0	0	88	48
6B	RWR		48				0	100	0	0	0	48
6C	RWR		46	2			0	96	4	0	0	48

RWR = red and white, O = orange, RWR = red and white or red, U = did not know or did not answer, W = white, Y = yellow.

Blank cell = 0 responses.
Shaded cell = correct response.

Table 42. Frequency Response to Sign Shape Question when Viewing Peripherally.

ID	Correct Shape*	Frequency Response to Sign Shape*								
		C	D	H	O	S	T	U	V	Total
1A	**O**	21		1	66	3	1	2	2	96
1C	**O**	16	1	3	68	4		4		96
2A	**O**	10		1	34			3		48
2B	**D**		43	1			2	1	1	48
2C	**D**		44			1	1	2		48
2D	**D**		42	1			3	1	1	48
3A	**O**	8		2	31	2	2	2	1	48
3B	**O**	6	1		24	1	4	6	6	48
3C	**O**	6	6	1	17	1	3	13	1	48
3D	**O**	7	1	1	29	1	4	4	1	48
5A1	**O**	9			29	2	1	5	2	48
5A2	**O**	16	7		7	6	1	6	5	48
5B1	**O**	9	1		35	1		2		48
5B2	**O**	13	5	1	17	3	1	5	3	48
5C	**O**	12	2	1	31	1		1		48
5D	**T**			1	1	1	40	5		48
5E	**T**		1		6	1	38	2		48
5F	**T**	1	1	1	4	1	36	4		48
5G	**S**	3		2	1	23		4	15	48
5H1	**S**	2		1	3	25		2	15	48
5H2	**S**	3			3	25	1	7	9	48
5I	**S**	6		1	6	22		4	9	48
5J	**D**		43	1		1	2		1	48
5K	**D**		42			2	2	2		48
5L	**D**		43	1			3	1		48
5M	**V**			4		4		2	38	48
5N	**V**	1		1		6		3	37	48
5O	**V**	1		1		5		2	39	48
5P	**H**		1	37		3	2	1	4	48
5Q	**H**	1		37		6	2		2	48
6B	**C**	13	1		30		1	2	1	48
6C	**C**	12		2	27	1	3	3		48

*C = circle, D = diamond, H = horizontal, O = octagon, S = square, T = triangle, U = unknown or did not answer, and V = vertical.

Blank cell = 0 responses.
Shaded cell = correct response.

Table 43. Percentage Response to Sign Shape Question when Viewing Peripherally.

ID	Correct Shape*	Percent (%) Response to Sign Shape*								
		C	D	H	O	S	T	U	V	Frequency Total
1A	O	22	0	1	69	3	1	2	2	96
1C	O	17	1	3	71	4	0	4	0	96
2A	O	21	0	2	71	0	0	6	0	48
2B	D	0	90	2	0	0	4	2	2	48
2C	D	0	92	0	0	2	2	4	0	48
2D	D	0	88	2	0	0	6	2	2	48
3A	O	17	0	4	65	4	4	4	2	48
3B	O	13	2	0	50	2	8	13	13	48
3C	O	13	13	2	35	2	6	27	2	48
3D	O	15	2	2	60	2	8	8	2	48
5A1	O	19	0	0	60	4	2	10	4	48
5A2	O	33	15	0	15	13	2	13	10	48
5B1	O	19	2	0	73	2	0	4	0	48
5B2	O	27	10	2	35	6	2	10	6	48
5C	O	25	4	2	65	2	0	2	0	48
5D	T	0	0	2	2	2	83	10	0	48
5E	T	0	2	0	13	2	79	4	0	48
5F	T	2	2	2	8	2	75	8	0	48
5G	S	6	0	4	2	48	0	8	31	48
5H1	S	4	0	2	6	52	0	4	31	48
5H2	S	6	0	0	6	52	2	15	19	48
5I	S	13	0	2	13	46	0	8	19	48
5J	D	0	90	2	0	2	4	0	2	48
5K	D	0	88	0	0	4	4	4	0	48
5L	D	0	90	2	0	0	6	2	0	48
5M	V	0	0	8	0	8	0	4	79	48
5N	V	2	0	2	0	13	0	6	77	48
5O	V	2	0	2	0	10	0	4	81	48
5P	H	0	2	77	0	6	4	2	8	48
5Q	H	2	0	77	0	13	4	0	4	48
6B	C	27	2	0	63	0	2	4	2	48
6C	C	25	0	4	56	2	6	6	0	48

*C = circle, D = diamond, H = horizontal, O = octagon, S = square, T = triangle, U = unknown or did not answer, and V = vertical.

Shaded cell = correct response.

Table 44. Frequency Response to Sign Shape Question when Viewing Straight.

ID	Correct Shape*	Frequency Response to Sign Shape*								
		C	D	H	O	S	T	U	V	Total
1A	O	2			46					48
1C	O	2		1	44			1		48
5A1	O	1			46			1		48
5A2	O	15	2		24	3	1	2		47
5B1	O	1			45			2		48
5B2	O	16	5		22	2	1	2		48
5C	O	1	1		46	1				49
5D	T		1		1		45	1		48
5E	T		3				45			48
5F	T		3				44	1		48
5G	S	2	1			39		1	4	47
5H1	S	1				42		1	3	47
5H2	S	2				41		3	3	49
5I	S	3				40		2	3	48
5J	D		46					1	1	48
5K	D		43		1		2	2		48
5L	D		46					1	1	48
5M	V			1	1	1		1	44	48
5N	V			2		2		1	43	48
5O	V			1	1	2		2	42	48
5P	H	1		45					2	48
5Q	H			46		1	1			48
6B	C	14			34					48
6C	C	17			31					48

*C = circle, D = diamond, H = horizontal, O = octagon, S = square, T = triangle, U = unknown or did not answer, and V = vertical.

Blank cell = 0 responses.
Shaded cell = correct response.

Table 45. Percentage Response to Sign Shape Question when Viewing Straight.

ID	Correct Shape*	Percent (%) Response to Sign Shape*								
		C	D	H	O	S	T	U	V	Total
1A	O	4	0	0	96	0	0	0	0	48
1C	O	4	0	2	92	0	0	2	0	48
5A1	O	2	0	0	96	0	0	2	0	48
5A2	O	32	4	0	51	6	2	4	0	47
5B1	O	2	0	0	94	0	0	4	0	48
5B2	O	33	10	0	46	4	2	4	0	48
5C	O	2	2	0	94	2	0	0	0	49
5D	T	0	2	0	2	0	94	2	0	48
5E	T	0	6	0	0	0	94	0	0	48
5F	T	0	6	0	0	0	92	2	0	48
5G	S	4	2	0	0	83	0	2	9	47
5H1	S	2	0	0	0	89	0	2	6	47
5H2	S	4	0	0	0	84	0	6	6	49
5I	S	6	0	0	0	83	0	4	6	48
5J	D	0	96	0	0	0	0	2	2	48
5K	D	0	90	0	2	0	4	4	0	48
5L	D	0	96	0	0	0	0	2	2	48
5M	V	0	0	2	2	2	0	2	92	48
5N	V	0	0	4	0	4	0	2	90	48
5O	V	0	0	2	2	4	0	4	88	48
5P	H	2	0	94	0	0	0	0	4	48
5Q	H	0	0	96	0	2	2	0	0	48
6B	C	29	0	0	71	0	0	0	0	48
6C	C	35	0	0	65	0	0	0	0	48

*C = circle, D = diamond, H = horizontal, O = octagon, S = square, T = triangle, U = unknown or did not answer, and V = vertical.
Shaded cell = correct response.

RESULTS

The signs are illustrated in this chapter as they were seen by the participant during the study: with a black background and without any illumination. Since the flashing pattern cannot be adequately illustrated on paper, the signs are described in more detail later in this document.

Stop Sign Same/Different Size Comparisons (Sections 1 and 4)

Section 1 evaluated pairs of the three signs shown in Figure 30 and asked participants if they were the same size or not. The signs shown in Figure 30 were all the same size of 36 in. Although not distinguishable from the figure, the left and center sign, 1A and 1B, respectively, used different flashing rates. 1C is the typical Stop sign referenced as R1-1 in the MUTCD.

Section 4 evaluated the pair of signs shown in Figure 31. The two signs in Section 4 actually were different sizes. The typical sign in 4A was 48 in. and the flashing Stop sign 1A was 36 in.

The results for the question "Are the two signs the same or different size?" can be found in Table 46. The statistical evaluation found the type of sign pairing significantly affected the participant's opinion of whether the signs were perceived as the same size. Correct responses are shown in the shaded cells.

1A (Stop w/8 red dots flash 1:9)	**1B (Stop w/8 red dots flash 2:8)**	**1C (Stop 36 in.)**
8 red lights placed at corners of the octagonal Stop sign (36 in.), flashing at a rate of 1:9 on:off per sec.	8 red lights placed at corners of the octagonal Stop sign (36 in.), flashing at a rate of 2:8 on:off per sec.	Typical octagonal Stop sign (36 in.) with no lights.

Figure 30. Stop Signs Used in Comparison of Size.

4A (Stop 48 in.)	**1A (Stop w/8 red dots flash 1:9)**
Typical octagonal Stop sign (48 in.) with no lights.	8 red lights placed at corners of the octagonal Stop sign, flashing at a rate of 1:9 on:off per sec.

Figure 31. Additional Comparisons between Stop Signs.

Table 46. Results for “Are the Signs the Same or Different Size?”.

Stimulus Pair ID’s	Description	Percent Who Answered Signs Were Same Sizes	Percent Who Answered Signs Were Different Sizes
1A – 1A	Stop w/8 red dots flash 1:9 – Stop w/8 red dots flash 1:9	93	7
1A – 1B	Stop w/8 red dots flash 1:9 – Stop w/8 red dots flash 2:8	83	17
1A – 1C	Stop w/8 red dots flash 1:9 – Stop 36 in.	81	19
1A – 4A	Stop w/8 red dots flash 1:9 – Stop 48 in.	6	94
1B – 1A	Stop w/8 red dots flash 2:8 – Stop w/8 red dots flash 1:9	83	17
1B – 1B	Stop w/8 red dots flash 2:8 – Stop w/8 red dots flash 2:8	87	13
1B –1C	Stop w/8 red dots flash 2:8 – Stop 36 in.	79	21
1C –1A	Stop 36 in. – Stop w/8 red dots flash 1:9	65	35
1C –1B	Stop 36 in. – Stop w/8 red dots flash 2:8	67	33
1C –1C	Stop 36 in. – Stop 36 in.	98	2
4A –1A	Stop 48 in. – Stop w/8 red dots flash 1:9	2	98
4A – 4A	Stop 48 in. – Stop 48 in.	94	6
Shaded cell = correct response			
A Pearson’s Chi-Square test showed there was a significant association between the same/different judgments and the type of sign pairing, $\chi^2 (8) = 29.77$, $p < 0.001$.			

The results for the question, “Which sign was bigger?” are found in Table 47. The combination with the fewest correct answers was when the unlighted Stop sign was shown first and the lighted Stop sign (with either a flash rate of 1:9 or 2:8) was shown second (1C-1A or 1C-1B). Only 65 to 67 percent of the participants correctly identified that the signs were of the same size. For other combinations, the percent answering correctly was over 79 percent. The initial statistical evaluation considered whether there was an effect due to order of presentation. Overall, in 10 percent of the cases, the participant felt the initial sign was smaller, while in 7 percent of the cases did the participant answer that the second sign was smaller. The statistical evaluation did find that presentation order was significant.

Table 47. Results for "Which Sign Is Bigger?"

Stimulus ID (a – b)	Description (a – b)	Percent Who Answered First Sign was Smaller than Second Sign (a < b)	Percent Who Answered First Sign was Larger than Second Sign (a > b)	Percent Who Answered First Sign was Same Size as Second Sign (a = b)	Percent Who Did Not Reply
1A – 1A	Stop w/8 red dots flash 1:9 – Stop w/8 red dots flash 1:9	5	2	93	0
1A – 1B	Stop w/8 red dots flash 1:9 – Stop w/8 red dots flash 2:8	10	6	83	0
1A – 1C	Stop w/8 red dots flash 1:9 – Stop 36 in.	19	0	81	0
1A – 4A	Stop w/8 red dots flash 1:9 – Stop 48 in.	92	0	6	2
1B – 1A	Stop w/8 red dots flash 2:8 – Stop w/8 red dots flash 1:9	4	10	83	2
1B – 1B	Stop w/8 red dots flash 2:8 – Stop w/8 red dots flash 2:8	8	4	88	0
1B – 1C	Stop w/8 red dots flash 2:8 – Stop 36 in.	21	0	79	0
1C – 1A	Stop 36 in. – Stop w/8 red dots flash 1:9	8	27	65	0
1C – 1B	Stop 36 in. – Stop w/8 red dots flash 2:8	17	17	67	0
1C – 1C	Stop 36 in. – Stop 36 in.	2	0	98	0
4A – 1A	Stop 48 in. – Stop w/8 red dots flash 1:9	0	98	2	0
4A – 4A	Stop 48 in. – Stop 48 in.	2	4	94	0
Shaded cell = correct response.					
A Pearson's Chi-Square test was performed. Excluding the cases where no reply was given, Pearson Chi-Square analysis indicated that the pattern of responses to perceived sign size was associated with sign pairing, $\chi^2(22) = 617.35$, $p < 0.001$.					

A follow-up evaluation compared those cases in which both signs were the same size and a flashing light was presented in the first but not the second sign versus those cases in which a flashing light was shown in the second but not the first (see Table 48 for the subset of data of interest). When the non-lighted sign was shown first, 27 percent (comparing 1C to 1A) or 17 percent (comparing 1C to 1B) of the participants incorrectly indicated that the lighted sign was smaller. When the non-lighted signs were shown second, 19 percent (1A to 1C) or 21 percent (1B to 1C) incorrectly thought the lighted sign was smaller. In general, the lighted sign was perceived to be smaller in about 20 percent of the cases. The statistical evaluation indicated that the presence of flashing lights was associated with a statistically significant perception that the sign with the flashing lights is smaller.

Table 48. Results for "Which Sign Is Bigger?" when Comparing Same Size Signs with and without Lights.

Stimulus ID (a – b)	Description (a – b)	Percent who Answered Lighted Sign was Smaller	Percent who Answered Non-Lighted Sign was Smaller	Percent who Answered that the Signs were the Same Size	Percent Who Did Not Reply
1A – 1C	Stop w/8 red dots flash 1:9 – Stop 36 in.	19	0	81	0
1B – 1C	Stop w/8 red dots flash 2:8 – Stop 36 in.	21	0	79	0
1C – 1A	Stop 36 in. – Stop w/8 red dots flash 1:9	27	8	65	0
1C – 1B	Stop 36 in. – Stop w/8 red dots flash 2:8	17	17	67	0
Shaded cell = correct response.					
A follow-up analysis comparing the cases where a flashing light was presented in the first but not second signs versus those cases where a flashing light was shown in the second but not first, indicated that the presence of flashing lights was associated with a significant reduction in perceived sign size, $\chi^2(1) = 20.28$, $p < 0.001$.					

White versus Sign-Colored Light Comparisons (Section 2)

Figure 32 and Figure 33 display the signs tested in Section 2. Section 2 included a response time to and the recognition of the color, shape, and type of the sign. The intention of this section was to evaluate different colored lights for the same typical 36 in. sign and same flash pattern. Both red and white lights using the same flashing pattern were tested for the Stop sign. For the pedestrian warning sign as seen in Figure 33, yellow and white lights were both evaluated with the same flashing pattern, as well as the typical sign with no lights. All three signs were 36 in.

Table 49 shows the average response time for each sign measured in milliseconds (ms). The values represent the averages after outliers were removed. As described earlier, outliers were flagged using Tukey's interquartile range method. Details on the statistical evaluation are included in Table 49. Note that the statistical evaluation used the log transformed data. Table 49 shows the untransformed data to facilitate understanding of the results. The results indicated that the response time to signs without lights was significantly faster than to signs with either white or colored lights (red for Stop and yellow for Pedestrian Crossing).

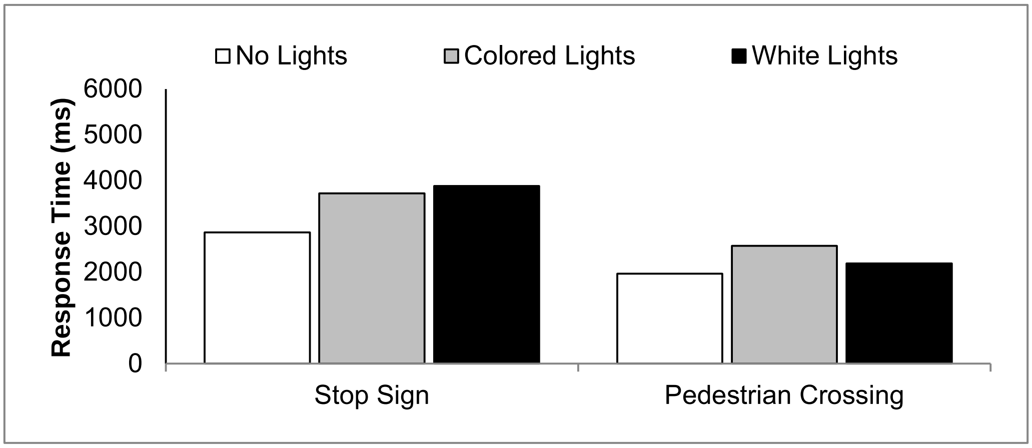
		
1C (Stop 36 in.)	**1A (Stop w/8 red dots flash 1:9)**	**2A (Stop w/8 white dots flash 1:9)**
Typical octagonal Stop sign (36 in.) with no lights.	8 red lights placed at corners of the octagonal Stop sign (36 in.), simultaneous flashing at a rate of 1:9 on:off per sec.	8 white lights placed at corners of the octagonal Stop sign (36 in.), simultaneous flashing at a rate of 1:9 on:off per sec.

Figure 32. Stop Signs for Section 2.

		
2B (36 in. Ped)	**2C (Ped w/8 yellow dots flash 1:9)**	**2D (Ped w/8 white dots flash 1:9)**
Typical diamond Pedestrian Crossing sign (36 in.) with no lights.	8 yellow lights placed along edge and at corners of the diamond Pedestrian Crossing sign (36 in.), simultaneous flashing at a rate of 1:9 on:off per sec.	8 white lights placed along edge and at corners of the diamond Pedestrian Crossing sign (36 in.), simultaneous flashing at a rate of 1:9 on:off per sec.

Figure 33. Pedestrian Crossing Signs.

Table 49. Mean Response Time Results for Stop and Pedestrian Crossing Signs.



Code	Sign Description	Number of Participants	Average Response Time (ms)
1C	Stop 36 in.	44	2866
1A	Stop w/8 red dots flash 1:9	48	3724
2A	Stop w/8 white dots flash 1:9	47	3880
2B	Ped 36 in.	42	1964
2C	Ped w/8 yellow dots flash 1:9	45	2574
2D	Ped w/8 white dots flash 1:9	42	2191

A 2 (sign type) × 3 (light type) Factorial Repeated Measures ANOVA on log transformed reaction times indicated a main effects of sign, $F(1,34) = 34.81$, $p < 0.001$, but not lights, $F(2,68) = 2.00$, $p > 0.05$. The interaction between sign and lights was also not significant, $F < 1$.

Stimuli viewed from participant's peripheral.
SD = standard deviation.

Table 50 provides the percentages of the participant responses regarding sign type. Over 73 percent of the participants correctly identified the Stop sign. The results for the Pedestrian Crossing sign initially look poor, if only the exact name of the sign is counted as correct; however, when similar but not exact names are included, about 70 percent of the participants correctly identified the sign. A greater number of the participants did not offer a guess for the lighted Pedestrian Crossing signs (23 to 25 percent as compared to 19 percent for the non-lighted Pedestrian Crossing sign). A similar finding was present for Stop signs—more participants did not provide a guess when the Stop signs were lighted (18 to 21 percent for either red or white dot lights) compared to only 15 percent for the unlighted Stop sign.

Table 50. Percentage Response to Sign Type Question when Viewing Peripheral for Stop and Pedestrian Crossing Signs.

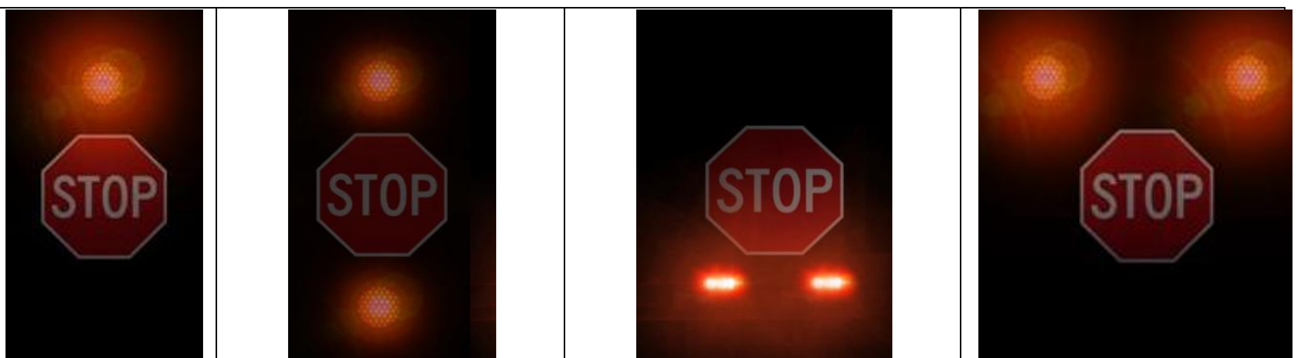
ID	Correct Sign Type	Percent (%) Response to Sign Type Question*										
		A	D	I	O	P	RR	SL	Stop	U	Y	Frequency Total
1A	Stop	0	0	0	7	0	1	1	73	18	0	96
1C	Stop	0	1	1	5	0	0	0	78	15	0	96
2A	Stop	0	0	0	2	0	4	0	73	21	0	48
2B	Ped	0	0	2	42	27	0	0	4	19	6	48
2C	Ped	0	0	2	40	33	0	0	0	23	2	48
2D	Ped	0	0	2	42	21	2	0	0	25	8	48

*A = Arrow, D = Do Not Enter sign (without words on sign face), I = Intersection Ahead, O = other, P or Ped = Pedestrian Crossing, RR = Railroad, SL = Speed Limit, Stop = Stop, U = did not know or offer a guess, and Y = Yield.

Shaded cell = correct response.

Stop Signs with and without Beacon(s) (Section 3)

Section 3 evaluated four different red beacon configurations used with a 36 in. Stop sign (see Figure 34). The test included a response time to and the recognition of the color, shape, and type of sign.

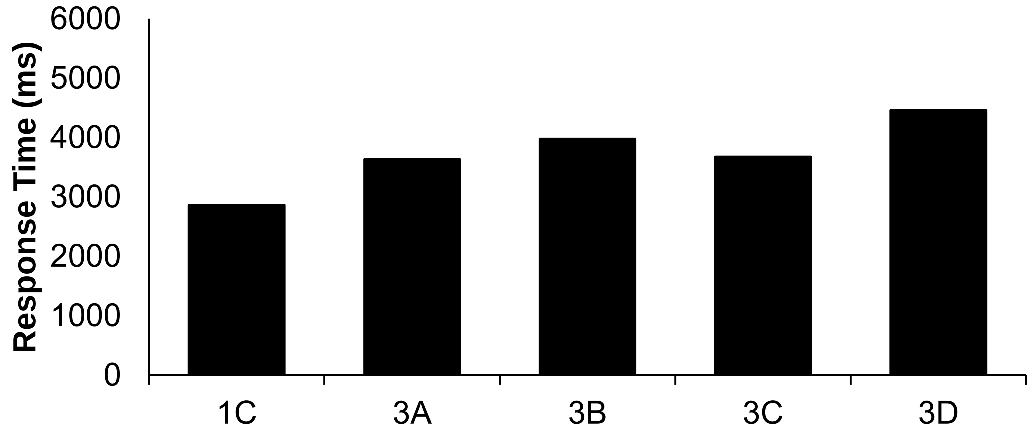


3A (stop w/one top beacon)	3B (stop w/top & bottom beacons)	3C (stop w/rapid flash bottom beacons)	3D (stop w/two top beacons)
Typical Stop sign (36 in.) with single beacon on top of sign.	Typical Stop sign (36 in.) with beacons on top and on bottom of sign with alternating flash rate of 5:5 on:off per sec (note figure shows both beacons on for illustration purposes).	Typical Stop sign (36 in.) with two rectangular beacons below sign with a rapid flash (the flashing cycle is 800 ms, the left rectangular beacon flashes two times and the right flashes three times in each cycle).	Typical Stop sign (36 in.) with two beacons on top of sign with simultaneous flash rate of 5:5 on:off per sec.

Figure 34. Stop Signs with and without Beacon(s).

The response time results for the signs with beacons compared to the typical Stop sign without a beacon can be found in Table 51 along with the results to the statistical evaluation. The pairwise comparisons revealed no significant difference in response time between any of the signs with beacons. However, response times to the sign without a beacon were faster than to any of the signs with beacons.

Table 51. Mean Response Time Results for Stop Signs with and without Beacon(s).



Code	Sign Description	Num	Average Response Time (ms)
1C	Stop 36 in.	44	2866
3A	Stop w/one top beacon	42	3636
3B	Stop w/top & bottom beacons	45	3982
3C	Stop w/rapid flash bottom beacons	40	3677
3D	Stop w/two top beacons	45	4458

Analysis included a one-way, repeated measures ANOVA with 5 groups (1C, 3A, 3B, 3C, 3D) on log transformed reaction times. Overall results indicated that at least one of the groups was different from the rest, $F(4,128) = 3.76$, $p < 0.01$. Pairwise comparisons, adjusted using the Bonferroni technique for multiple comparisons, revealed no significant difference in response time between any of the signs with beacons (all p's > 0.05). However, response times to the sign with 2 top beacons were significantly slower than to the unlighted sign, $p < 0.01$.

Stimuli viewed from participant's peripheral.
Num=Number of participants.

Table 52 lists the responses to the question regarding sign type. Only 46 percent of participants correctly identified the Stop sign with top and bottom beacons (3B). Approximately 23 percent did not provide any guesses. This is surprising since the use of top and bottom beacons with Stop signs is one of the most common treatments to enhance a Stop sign in Texas, just following the use of oversized Stop signs. Participants provided the following guesses for the type of the sign: information, school zone, speed limit, warning/caution, and railroad.

The Stop sign with rapid-flash bottom beacons (3C) was also correctly identified by only 46 percent of participants. A large percentage (35 percent) of the participants did not offer a guess for this option; this does not seem surprising, as this sign and beacon configuration is not currently in use on roadways.

The responses to the 3B and 3C signs also indicated a low percentage of correct shape recognition. Only 50 percent of the participants recognized 3B as being octagonal, and 35 percent recognized 3C as octagonal (see Table 43).

Table 52. Percentage Response to Sign Type Question when Viewing Peripheral for Stop Signs with and without Beacons.

ID	Correct Sign Type	Percent (%) Response to Sign Type Question*										
		A	D	I	O	P	RR	SL	Stop	U	Y	Frequency Total
1C	Stop	0	1	1	5	0	0	0	78	15	0	96
3A	Stop	0	2	0	4	0	2	2	73	17	0	48
3B	Stop	0	0	0	13	0	15	2	46	23	2	48
3C	Stop	0	0	0	10	0	4	0	46	35	4	48
3D	Stop	0	0	4	13	0	4	0	67	13	0	48

*A = Arrow, D = Do Not Enter sign (without words on sign face), I = Intersection Ahead, O = other, P = Pedestrian Crossing, RR = Railroad, SL = Speed Limit, Stop = Stop, U = did not know or offer a guess, Y = Yield.

Shaded cell = correct response.

Different LED Arrangements for Several Signs (Section 5 and 5.1)

The sign stimuli in Sections 5 and 5.1 were identical, with only the participants' view changing from peripheral to straight. The results from both sections are presented here together by sign type. Table 34 and Table 35 show the response time average and standard deviation for each sign using the response time (measured in ms) along with the log transformation of the response time. The values represent the averages after outliers were removed. Table 34 provides the results when the participants were looking off-angle from the screen while Table 35 represents the data when the participants were looking straight at the screen.

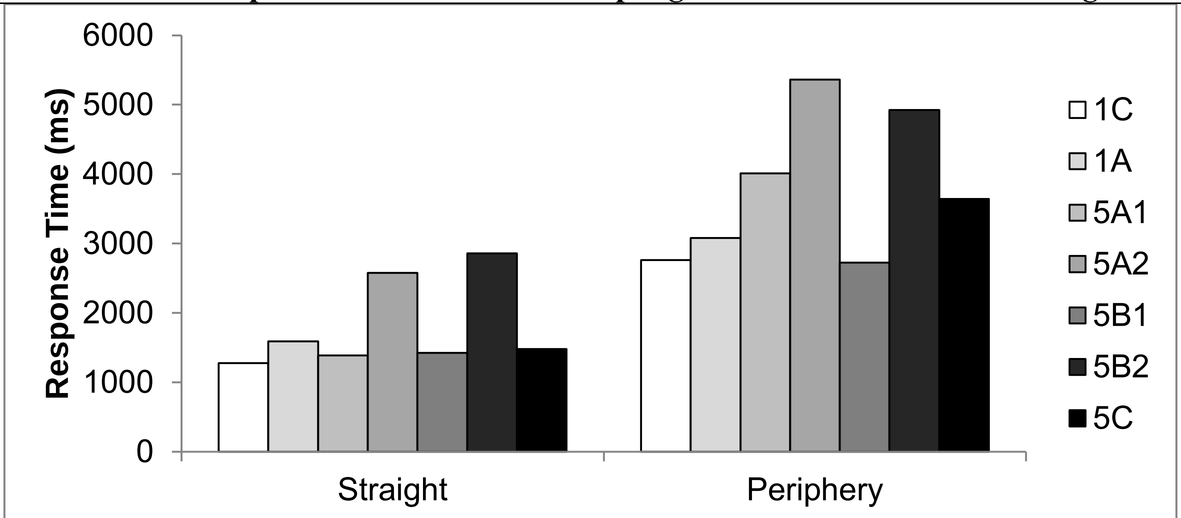
Stop Signs with Different LED Arrangements

Figure 35 shows the seven Stop sign variations tested in these sections. All signs were the same size of 36 in. Variations included point lights (called dots for this study) and bars of lights, as well as simultaneous and alternating flashing patterns. Both gaze point (straight or off angle/periphery) response time data results for the Stop signs are found in Table 53. The statistical evaluation indicated that the response times could be clumped into two distinct groups. One group includes the signs with the four bars with alternating flash (5A2, 5B2). The other group contains the unlighted sign (1C), the two signs with red dots (1A, 5C), and the two signs with simultaneous flashing for the white and red bars (5A1, 5B1).

			
1C (Stop 36 in.)	**1A (Stop w/8 red dots flash 1:9)**	**5A1 (Stop w/8 white bars simultaneous flash 1:9)**	**5A2 (Stop w/4 white bars alternating flash 1:9)**
Typical octagonal Stop sign (36 in.) with no lights.	8 red dots placed at corners of the octagonal Stop sign (36 in.), simultaneous flashing at a rate of 1:9 on:off per sec.	8 white bars placed along the edges of the octagonal Stop sign (36 in.), simultaneous flashing at a rate of 1:9 on:off per sec.	8 white bars placed along the edges of the octagonal Stop sign (36 in.) with opposing 4 bars alternating flash at a rate of 5:5 on:off per sec.
			
5B1 (Stop w/8 red bars simultaneous flash 1:9)	**5B2 (Stop w/4 red bars alternating flash 1:9)**	**5C (Stop w/4 red dots flash 1:9)**	
8 red bars placed along the edges of the octagonal Stop sign (36 in.), simultaneous flashing at a rate of 1:9 on:off per sec.	8 red bars placed along the edges of the octagonal Stop sign (36 in.) with opposing 4 bars alternating flash at a rate of 5:5 on:off per sec.	4 large red dots placed within the sign face of the octagonal Stop sign (36 in.) simultaneous flashing at a rate of 1:9 on:off per sec.	

Figure 35. Stop Signs for Examining Different LED Arrangements.

Table 53. Mean Response Time Results for Stop Signs with Different LED Arrangements.



Code	Sign Description	Viewing Peripheral		Viewing Straight	
		Num	Average Response Time (ms)	Num	Average Response Time (ms)
1C	Stop 36 in.	43	2763	44	1276
1A	Stop w/8 red dots flash 1:9	43	3080	45	1589
5A1	Stop w/8 white bars simultaneous flash 1:9	45	4010	44	1388
5A2	Stop w/4 white bars alternating flash 1:9	44	5362	43	2577
5B1	Stop w/8 red bars simultaneous flash 1:9	43	2725	46	1425
5B2	Stop w/4 red bars alternating flash 1:9	44	4924	42	2859
5C	Stop w/4 red dots simultaneous flash 1:9	44	3642	44	1477

Main effects of lights, $F(6,138) = 60.90$, $p < .001$, fixation, $F(1, 23) = 25.53$, $p < 0.001$, and the interaction between lights and fixation $F(6, 138) = 3.65$, $p < 0.01$, were all significant. Pairwise comparisons, using the Bonferroni adjustment for multiple comparisons, indicated that the response times could be clumped into two distinct groups. The first group included the unlighted sign (1C), the two signs with red dots (1A, 5C), the two 8 bar signs (5A1, 5B1). The second group included the two signs with 4 bars.

Num = Number of participants.

The percent of participant responses by sign ID and viewing angle is listed in Table 54 for sign color, Table 55 for sign shape, and Table 56 for sign type. When viewing straight, most of the responses to the sign type question (see Table 56) were very similar with two exceptions. The Stop sign with four white bars with alternating flash (5A2) had 13 percent of the participants not offering a guess and the Stop sign with four red bars with alternating flash (5B2) had 6 percent not offering a guess compared to at most 2 percent for the other LED arrangements. The signs with the alternating flashing bars also resulted in a high percentage of participants thinking they were associated with a railroad (11 to 15 percent) or were providing either a warning or information (6 to 9 percent).

Surprisingly, the red bars (5B2) resulted in the highest percentage of participants providing incorrect answers to the color question (see Table 54). When viewing straight, 8 percent of the participants said the sign color was orange, and 19 percent said the sign color was orange when viewed at an angle. The alternating flashing white bars (5A2) resulted in the fewest participants indicating that the Stop sign was red or red and white when viewed peripherally. Half of the participants said the sign color was white when the alternating flashing white bars were present. When the white bars were simultaneously flashing, only 8 percent said the sign was white. The simultaneous red flashing bars resulted in the highest number of participants correctly identifying the color of the sign.

For the conditions present within this lab study, a larger percentage of the participants correctly identified the Stop sign when the LED arrangement simultaneously flashed as compared to the alternating flash pattern (see Table 57). Red bars were associated with more correct answers than the white bars for either flash pattern.

Table 54. Response to Sign Color Question for Stop Sign with Different LED Arrangements.

ID	Response (%) to Sign Color Question*										Frequency Total
	Straight					Peripheral					
	O	RWR	U	W	Y	O	RWR	U	W	Y	
1A	0	100	0	0	0	3	83	2	1	10	96
1C	0	98	2	0	0	3	90	3	0	4	96
5A1	0	98	2	0	0	4	77	6	8	4	48
5A2	0	91	2	4	2	2	42	4	50	2	48
5B1	0	96	4	0	0	4	92	2	2	0	48
5B2	8	88	2	0	2	19	67	2	8	4	48
5C	0	100	0	0	0	4	83	2	8	2	48

*O = orange, RWR = red and white or red, U = did not know or did not answer, W = white, Y = yellow.

Shaded cell = correct response.

Table 55. Response to Sign Shape Question for Stop Sign with Different LED Arrangements.

ID	View	Response (%) to Sign Shape Question*								Frequency Total
		C	D	H	O	S	T	U	V	
1A	**Per**	22	0	1	69	3	1	2	2	96
1C	**Per**	17	1	3	71	4	0	4	0	96
5A1	**Per**	19	0	0	60	4	2	10	4	48
5A2	**Per**	33	15	0	15	13	2	13	10	48
5B1	**Per**	19	2	0	73	2	0	4	0	48
5B2	**Per**	27	10	2	35	6	2	10	6	48
5C	**Per**	25	4	2	65	2	0	2	0	48
1A	**Str**	4	0	0	96	0	0	0	0	48
1C	**Str**	4	0	2	92	0	0	2	0	48
5A1	**Str**	2	0	0	96	0	0	2	0	48
5A2	**Str**	32	4	0	51	6	2	4	0	47
5B1	**Str**	2	0	0	94	0	0	4	0	48
5B2	**Str**	33	10	0	46	4	2	4	0	48
5C	**Str**	2	2	0	94	2	0	0	0	49

*C = circle, D = diamond, H = horizontal, O = octagon, S = square, T = triangle, U = unknown or did not answer, and V = vertical.
Per = peripheral view, Str = straight view.

Shaded cell = correct response.

Table 56. Response to Sign Type Question for Stop Sign with Different LED Arrangements.

ID	View	Response (%) to Sign Type Question*										Frequency Total
		A	D	I	O	P	RR	SL	Stop	U	Y	
1A	**Per**	0	0	0	7	0	1	1	73	18	0	96
1C	**Per**	0	1	1	5	0	0	0	78	15	0	96
5A1	**Per**	0	0	0	10	0	2	0	67	21	0	48
5A2	**Per**	0	6	0	19	0	15	2	17	42	0	48
5B1	**Per**	0	0	0	6	0	2	0	81	8	2	48
5B2	**Per**	0	0	0	8	0	6	0	44	42	0	48
5C	**Per**	0	0	0	4	0	4	0	69	23	0	48
1A	**Str**	0	0	0	0	0	0	0	98	2	0	48
1C	**Str**	0	0	0	0	0	0	0	98	2	0	48
5A1	**Str**	0	0	0	0	0	0	0	98	2	0	48
5A2	**Str**	0	0	0	9	0	11	0	68	13	0	47
5B1	**Str**	0	0	0	0	0	0	0	100	0	0	48
5B2	**Str**	0	0	0	6	0	15	0	73	6	0	48
5C	**Str**	0	2	0	2	0	0	0	94	2	0	49

*A = Arrow, D = Do Not Enter sign (without words on sign face), I = Intersection Ahead, O = other, P or Ped = Pedestrian Crossing, RR = Railroad, SL = Speed Limit, Stop = Stop, U = did not know or offer a guess, Y = Yield.
Per = peripheral view, Str = straight view.

Shaded cell = correct response.

Table 57. Type Results (Percent of Participants) for Stop Signs with Different LED Arrangements while Viewing Peripherally.

Code	Simultaneous or Alternating Flash	No Lights	Red Dots (on Edges or Interior)	White Bars	Red Bars
1C	No lights	78			
1A	Simultaneous (on Edge)		73		
5A1	Simultaneous			67	
5B1	Simultaneous				81
5C	Simultaneous (Interior)		69		
5A2	Alternating			17	
5B2	Alternating				44

Table 58. Shape Results (Percent of Participants) for Stop Signs with Different LED Arrangements while Viewing Peripherally.

Code	Simultaneous or Alternating Flash	No Lights	Red Dots (on Edges or Interior)	White Bars	Red Bars
1C	No lights	92			
1A	Simultaneous (on Edge)		96		
5A1	Simultaneous			96	
5B1	Simultaneous				94
5C	Simultaneous (Interior)		94		
5A2	Alternating			51	
5B2	Alternating				46

Table 59. Color Results (Percent of Participants) for Stop Signs with Different LED Arrangements while Viewing Peripherally.

Code	Simultaneous or Alternating Flash	No Lights	Red Dots (on Edges or Interior)	White Bars	Red Bars
1C	No lights	90			
1A	Simultaneous (on Edge)		83		
5A1	Simultaneous			77	
5B1	Simultaneous				92
5C	Simultaneous (Interior)		83		
5A2	Alternating			42	
5B2	Alternating				67

Yield Signs

Two flashing versions of the Yield sign were tested as well as the typical non-flashing sign (see Figure 36). All signs were the same size of 36 in. The response time results for the Yield signs along with the statistical evaluation results are provided in Table 60. Pairwise comparisons indicated that the two lighted conditions differed from the unlighted condition and the two lighted signs did not differ from each other.

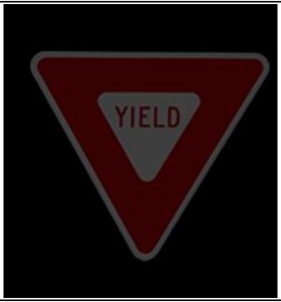
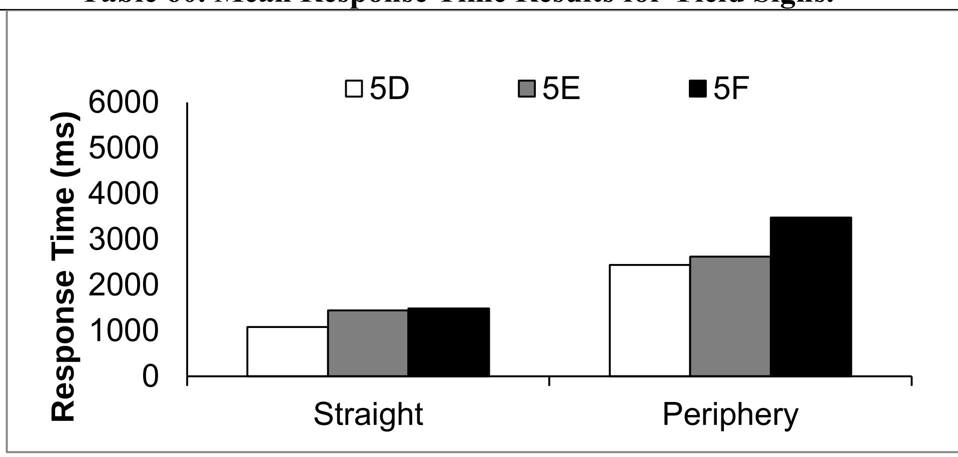
5D (Yield 36 in.)	5E (Yield w/3 red dots flash 1:9)	5F (Yield w/3 red bars flash 1:9)
		
Typical triangular Yield sign (36 in.) with no lights.	3 red lights placed at corners of the triangular Yield sign, flashing at a rate of 1:9 on:off per sec.	3 red bars placed along edge of the triangular Yield sign, flashing at a rate of 1:9 on:off per sec.

Figure 36. Yield Signs.

Table 60. Mean Response Time Results for Yield Signs.



Code	Sign Description	Viewing Peripherally		Viewing Straight	
		Num	Average Response Time (ms)	Num	Average Response Time (ms)
5D	Yield 36 in.	41	2440	44	1077
5E	Yield w/3 red dots flash 1:9	43	2619	45	1448
5F	Yield w/3 red bars flash 1:9	46	3477	45	1487

The test performed was a 2 (fixation) × 3 (lights) Factorial Repeated Measures ANOVA on log transformed reaction times. Main effects of fixation, $F(1, 34) = 61.33$, $p < 0.001$, and lights, $F(2,68) = 12.78$, $p < 0.001$, were observed, however, the interaction between lights and fixation, $F < 1$, was not significant. Pairwise comparisons indicated that the two lighting conditions differed from the unlighted condition (p's < 0.001) but that the two lighted signs did not differ from each other ($p > 0.05$).

Num = Number of participants.

The percent of participant responses by sign identification and viewing angle is listed in Table 61 for sign color, Table 62 for sign shape, and Table 63 for sign type. Participants appear to be not as familiar with the Yield sign as with the Stop sign. Between 8 and 13 percent of the participants did not offer a guess as to the sign type for any of the three Yield sign options when viewing directly (see Table 63) as compared to 2 percent for the Stop sign (1C, see Table 56). When viewing peripherally, between 10 and 21 percent did not offer a guess for the Yield sign type as compared to 15 percent for the Stop sign (1C). The version of the Yield sign without lights (5D) resulted in similar accuracy at 69 percent compared to 67 percent for three dots flashing (5E) and 60 percent for three bars flashing (5F).

Table 61. Response to Sign Color Question for Yield Signs.

ID	Response (%) to Sign Color Question*										Frequency Total
	Straight					Peripheral					
	O	RWR	U	W	Y	O	RWR	U	W	Y	
5D	0	98	2	0	0	2	77	4	4	13	48
5E	0	100	0	0	0	4	67	6	4	19	48
5F	0	98	2	0	0	4	77	6	4	8	48
*O = orange, RWR = red and white or red, U = did not know or did not answer, W = white, Y = yellow.											
Shaded cell = correct response.											

Table 62. Response to Sign Shape Question for Yield Signs.

ID	View	Response (%) to Sign Shape Question*								Frequency Total
		C	D	H	O	S	T	U	V	
5D	Per	0	0	2	2	2	83	10	0	48
5E	Per	0	2	0	13	2	79	4	0	48
5F	Per	2	2	2	8	2	75	8	0	48
5D	Str	0	2	0	2	0	94	2	0	48
5E	Str	0	6	0	0	0	94	0	0	48
5F	Str	0	6	0	0	0	92	2	0	48
*C = circle, D = diamond, H = horizontal, O = octagon, S = square, T = triangle, U = unknown or did not answer, and V = vertical. Per = peripheral view, Str = straight view.										
Shaded cell = correct response.										

Table 63. Response to Sign Type Question for Yield Signs.

ID	View	Response (%) to Sign Type Question*										Frequency Total
		A	D	I	O	P	RR	SL	Stop	U	Y	
5D	Per	0	0	0	8	0	0	0	2	21	69	48
5E	Per	0	0	0	13	0	0	0	10	10	67	48
5F	Per	0	0	0	13	0	0	0	8	19	60	48
5D	Str	0	0	0	6	0	0	0	0	10	83	48
5E	Str	0	0	0	2	0	0	0	0	13	85	48
5F	Str	0	0	0	6	0	0	0	0	8	85	48

*A = Arrow, D = Do Not Enter sign (without words on sign face), I = Intersection Ahead, O = other, P or Ped = Pedestrian Crossing, RR = Railroad, SL = Speed Limit, Stop = Stop, U = did not know or offer a guess, Y = Yield.
Per = peripheral view, Str = straight view.

Shaded cell = correct response.

Do Not Enter Signs (without Words)

Three flashing versions of a Do Not Enter sign were tested as well as a non-flashing sign (see Figure 37). All signs were the same size of 36 in. As seen in Figure 37, the legend "DO NOT ENTER" was mistakenly not included on all four signs. Section 5 and 5.1 response time results for the Do Not Enter signs are found in Table 64 along with the statistical evaluation results. Pairwise comparisons indicated that response times to the sign with the rotating light (5H2) and the sign with white flashing bars (5I) differed from the no light condition (5G) and the 8 red dots (5H1).

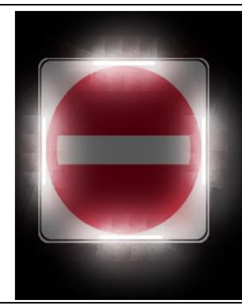
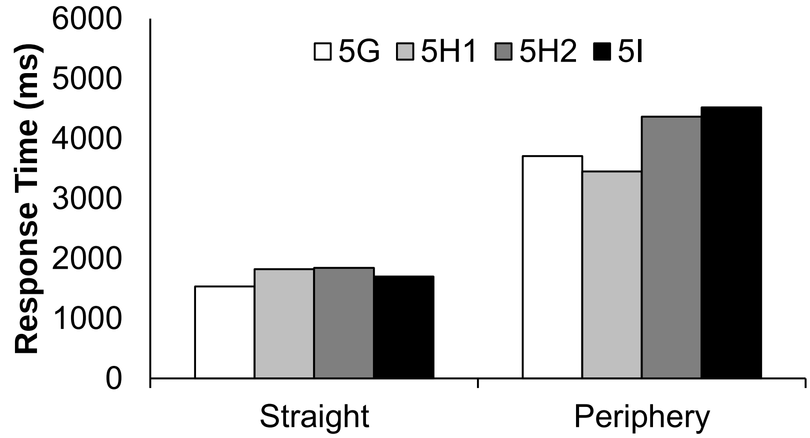
			
5G (Do Not Enter 36 in.)	**5H1 (Do Not Enter w/8 red dots flash 1:9)**	**5H2 (Do Not Enter w/8 red dots flash rotating)**	**5I (Do Not Enter w/4 white bars flash 1:9)**
Do Not Enter sign (36 in.) with no lights.	8 red dots placed in a circle on the interior red circle, flashing at a rate of 1:9 on:off per sec.	8 red dots placed in a circle, flashing in a continuous pattern with each red dot flashing alternately at a rate of 1:7 on:off per sec.	4 white bars placed along the outer edge, flashing at a rate of 1:9 on:off per sec.

Figure 37. Do Not Enter Signs.

Table 64. Mean Response Time Results for Do Not Enter Signs.



Code	Sign Description	Viewing Peripherally		Viewing Straight	
		Num	Average Response Time (ms)	Num	Average Response Time (ms)
5G	Do Not Enter 36 in.	43	3709	43	1535
5H1	Do Not Enter w/8 red dots flash 1:9	45	3450	46	1824
5H2	Do Not Enter w/8 red dots flash rotating	45	4367	45	1846
5I	Do Not Enter w/4 white bars flash 1:9	42	4523	45	1700

A 2 (fixation) × 4 (lights) Factorial Repeated Measures ANOVA on log transformed reaction times test was performed. Main effects of fixation, $F(1,29) = 67.84$, $p < 0.001$, and lights, $F(3,87) = 6.20$, $p < 0.001$, were observed. Additionally, the interaction between lights and fixation was significant, $F(3,87) = 5.44$, $p < 0.01$. Pairwise comparisons indicated that the unlighted (5g) and flashing dot (5H1) signs were responded to more quickly than the flashing/rotating dot (5H2) or the flashing white bar (5I) signs, $P < 0.05$.

Num = Number of participants.

The percent of participant responses by sign ID and viewing angle is listed in Table 65 for sign color, Table 66 for sign shape, and Table 67 for sign type. The results may have been affected by the missing "Do Not Enter" words. About 9 to 14 percent of the participants did not offer a guess as to the sign type when viewing straight (see Table 66). When viewing peripherally, the percentage ranged between 38 and 48 percent of the participants not offering a guess.

Table 65. Response to Sign Color Question for Do Not Enter Signs (without Words).

ID	Response (%) to Sign Color Question*										Frequency Total
	Straight					Peripheral					
	O	RWR	U	W	Y	O	RWR	U	W	Y	
5G	0	85	2	13	0	2	33	4	60	0	48
5H1	0	85	2	13	0	4	46	2	48	0	48
5H2	0	84	4	12	0	6	48	6	29	10	48
5I	0	77	4	19	0	0	44	2	52	2	48

*O = orange, RWR = red and white or red, U = did not know or did not answer, W = white, Y = yellow.

Shaded cell = correct response.

Table 66. Response to Sign Shape Question for Do Not Enter Signs (without Words).

ID	View	Response (%) to Sign Shape Question*								Frequency Total
		C	D	H	O	S	T	U	V	
5G	**Per**	6	0	4	2	48	0	8	31	48
5H1	**Per**	4	0	2	6	52	0	4	31	48
5H2	**Per**	6	0	0	6	52	2	15	19	48
5I	**Per**	13	0	2	13	46	0	8	19	48
5G	**Str**	4	2	0	0	83	0	2	9	47
5H1	**Str**	2	0	0	0	89	0	2	6	47
5H2	**Str**	4	0	0	0	84	0	6	6	49
5I	**Str**	6	0	0	0	83	0	4	6	48

*C = circle, D = diamond, H = horizontal, O = octagon, S = square, T = triangle, U = unknown or did not answer, and V = vertical.
Per = peripheral view, Str = straight view.

Shaded cell = correct response.

Table 67. Response to Sign Type Question for Do Not Enter Signs (without Words).

ID	View	Response (%) to Sign Type Question*										Frequency Total
		A	D	I	O	P	RR	SL	Stop	U	Y	
5G	Per	0	23	0	23	0	0	6	6	42	0	48
5H1	Per	0	13	0	25	2	0	13	10	38	0	48
5H2	Per	0	25	0	10	0	0	2	8	48	6	48
5I	Per	0	19	0	21	0	0	4	15	42	0	48
5G	Str	0	68	0	13	0	0	0	9	9	2	47
5H1	Str	0	70	0	4	0	0	0	15	9	2	47
5H2	Str	0	69	0	6	0	2	0	6	14	2	49
5I	Str	0	65	0	8	0	4	0	10	10	2	48
*A = Arrow, D = Do Not Enter sign (without words on sign face), I = Intersection Ahead, O = other, P or Ped = Pedestrian Crossing, RR = Railroad, SL = Speed Limit, Stop = Stop, U = did not know or offer a guess, Y = Yield. Per = peripheral view, Str = straight view.												
Shaded cell = correct response.												

Intersection Ahead Sign

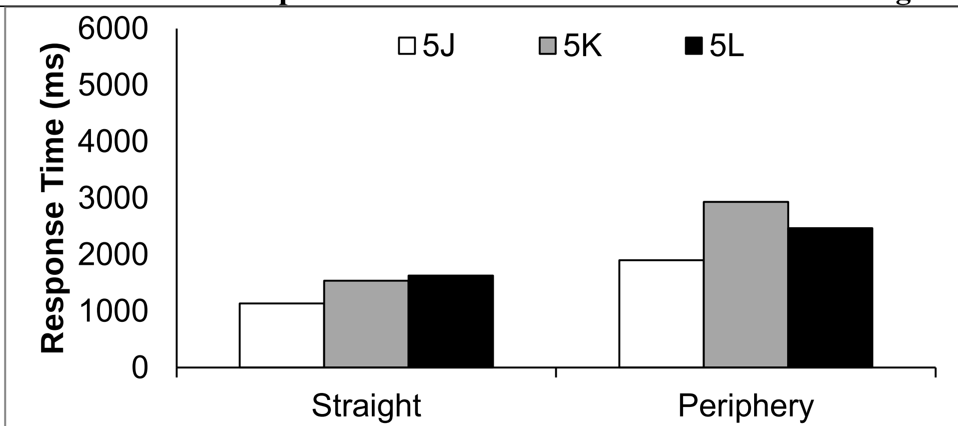
Shown in Figure 38 are the three Intersection Ahead signs that were tested. All signs were the same size of 36 in. Table 68 displays the response time results when the participants viewed the sign both peripherally and straight along with the statistical evaluation results. Pairwise comparisons indicated that participants responded to the unlighted sign significantly faster than to either of the lighted signs and that the lighted signs did not differ from each other.

		
5J (Intersection Ahead 36 in.)	**5K (Intersection Ahead w/4 yellow dots flash 1:9)**	**5L (Intersection Ahead w/8 yellow dots flash 1:9)**
Typical diamond Intersection Ahead sign (36 in.) with no lights.	4 yellow lights placed at corners of the diamond Intersection Ahead sign, flashing at a rate of 1:9 on:off per sec.	8 yellow lights placed at corners and along the sides of the diamond Intersection Ahead sign, flashing at a rate of 1:9 on:off per sec.

Figure 38. Intersection Ahead Signs.

The percent of participant responses by sign identification and viewing angle is listed in Table 69 for sign color, Table 70 for sign shape, and Table 71 for sign type. Similar results were identified for all sign options when viewing straight—over 90 percent of the participants could correctly identify the color, shape, and type of the Intersection Ahead sign. When viewing peripherally, about 25 percent of the participants did not offer a guess as to the sign type for any of the three Intersection Ahead sign options. When viewing peripherally, the signs with LEDs (5K and 5L) resulted in slightly higher numbers of correct identifications (29 or 31 percent) as compared to the unlighted sign (19 percent) (see Table 71).

Table 68. Mean Response Time Results for Intersection Ahead Signs.



Code	Sign Description	Viewing Peripherally		Viewing Straight	
		Num	Average Response Time (ms)	Num	Average Response Time (ms)
5J	Intersection Ahead 36 in.	45	1900	46	1139
5K	Intersection Ahead w/4 yellow dots flash 1:9	46	2935	45	1540
5L	Intersection Ahead w/8 yellow dots flash 1:9	44	2466	46	1631

The test preformed was a 2 (fixation) × 3 (lights) Factorial Repeated Measures ANOVA on log transformed reaction times. Results showed the main effects of fixation, $F(1, 35) = 33.00$, $p < 0.001$, and lights, $F(2,70) = 10.16$, $p < 0.001$, were observed; however, the interaction between lights and fixation was not significant, $F < 1$. Pairwise comparisons using the Bonferroni adjustment indicated that participants responded to the unlighted sign significantly faster than to either of the lighted signs ($p < 0.01$), but that the lighted signs did not differ from each other.

Num = Number of participants.

Table 69. Response to Sign Color Question for Intersection Ahead Signs.

ID	Response (%) to Sign Color Question*										Frequency Total
	Straight					Peripheral					
	O	RWR	U	W	Y	O	RWR	U	W	Y	
5J	4	0	0	0	96	6	0	0	0	94	48
5K	6	0	2	0	92	6	0	2	0	92	48
5L	4	0	0	0	96	4	0	0	0	96	48

* O = orange, RWR = red and white or red, U = did not know or did not answer, W = white, Y = yellow.

Shaded cell = correct response.

Table 70. Response to Sign Shape Question for Intersection Ahead Signs.

ID	View	Response (%) to Sign Shape Question*								Frequency Total
		C	D	H	O	S	T	U	V	
5J	Per	0	90	2	0	2	4	0	2	48
5K	Per	0	88	0	0	4	4	4	0	48
5L	Per	0	90	2	0	0	6	2	0	48
5J	Str	0	96	0	0	0	0	2	2	48
5K	Str	0	90	0	2	0	4	4	0	48
5L	Str	0	96	0	0	0	0	2	2	48

*C = circle, D = diamond, H = horizontal, O = octagon, S = square, T = triangle, U = unknown or did not answer, and V = vertical.
Per = peripheral view, Str = straight view.

Shaded cell = correct response.

Table 71. Response to Sign Type Question for Intersection Ahead Signs.

ID	View	Response (%) to Sign Type Question*										Frequency Total
		A	D	I	O	P	RR	SL	Stop	U	Y	
5J	Per	4	0	19	42	4	2	0	0	25	4	48
5K	Per	4	0	31	31	8	0	0	0	25	0	48
5L	Per	2	0	29	35	2	2	0	0	25	4	48
5J	Str	0	0	90	6	0	0	0	0	4	0	48
5K	Str	0	0	90	6	0	0	0	0	4	0	48
5L	Str	0	0	92	6	0	0	0	0	2	0	48

*A = Arrow, D = Do Not Enter sign (without words on sign face), I = Intersection Ahead, O = other, P or Ped = Pedestrian Crossing, RR = Railroad, SL = Speed Limit, Stop = Stop, U = did not know or offer a guess, Y = Yield.
Per = peripheral view, Str = straight view.

Shaded cell = correct response.

Speed Limit Signs

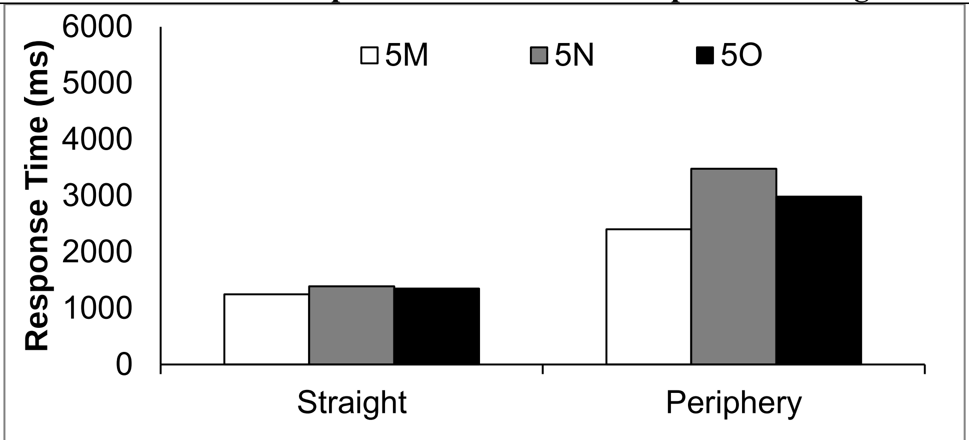
Figure 39 displays the three Speed Limit signs tested. All three signs were sized at 36 × 48 in. Section 5 and 5.1 response time results for Speed Limit signs are found in Table 72. Pairwise comparisons indicated that participants responded to the unlighted sign significantly faster than to either of the lighted signs and that the lighted signs did not differ from each other.

The percent of participant responses by sign ID and viewing angle is listed in Table 73 for sign color, Table 74 for sign shape, and Table 75 for sign type. Similar results were identified for all sign options when viewing straight; almost all of the participants could correctly identify the color, shape, and type of the Speed Limit signs. When viewing peripherally, the accuracy was reduced and a difference between the sign options can be observed (see Table 75). The sign with four white dots (5N) resulted in the highest number of participants not offering a guess (38 percent) compared to only 19 percent not guessing for the unlighted sign (5M) and 27 percent not guessing for the sign lighted with LED bars (5O).

		
5M (Speed Limit 36 × 48)	**5N (Speed Limit w/4 white dots flash 1:9)**	**5O (Speed Limit w/4 white bars flash 1:9)**
Typical Speed Limit sign (36 in. × 48 in.) with no lights.	4 white lights placed at corners of the Speed Limit sign, flashing at a rate of 1:9 on:off per sec.	4 white bars placed along edge of the Speed Limit sign, flashing at a rate of 1:9 on:off per sec.

Figure 39. Speed Limit Signs.

Table 72. Mean Response Time Results for Speed Limit Signs.



Code	Sign Description	Viewing Peripherally		Viewing Straight	
		Num	Average Response Time (ms)	Num	Average Response Time (ms)
5M	Speed Limit 36 × 48 in.	44	2400	47	1244
5N	Speed Limit w/ 4 white dots flash 1:9	44	3475	46	1387
5O	Speed Limit w/ 4 white bars flash 1:9	43	2982	42	1347

A 2 (fixation) × 3 (lights) Factorial Repeated Measures ANOVA on log transformed reaction times test was performed. Main effects of fixation, $F(1, 33) = 112.98$, $p < 0.001$, and lights, $F(2,66) = 5.95$, $p < 0.001$, were observed; however, the interaction between lights and fixation, $F < 1$, was not significant. Pairwise comparisons using the Bonferroni adjustment indicated that participants responded to the unlighted sign significantly faster than to either of the lighted signs ($p < 0.05$), but that the lighted signs did not differ from each other.

Num = Number of participants.

Table 73. Response to Sign Color Question for Speed Limit Signs.

ID	Response (%) to Sign Color Question*										Frequency Total
	Straight					Peripheral					
	O	RWR	U	W	Y	O	RWR	U	W	Y	
5M	2	0	2	96	0	10	0	4	85	0	48
5N	6	0	2	92	0	6	0	4	90	0	48
5O	4	0	4	92	0	4	0	2	94	0	48

*O = orange, RWR = red and white or red, U = did not know or did not answer, W = white, Y = yellow.

Shaded cell = correct response.

Table 74. Response to Sign Shape Question for Speed Limit Signs.

ID	View	Response (%) to Sign Shape Question*								Frequency Total
		C	D	H	O	S	T	U	V	
5M	**Per**	0	0	8	0	8	0	4	79	48
5N	**Per**	2	0	2	0	13	0	6	77	48
5O	**Per**	2	0	2	0	10	0	4	81	48
5M	**Str**	0	0	2	2	2	0	2	92	48
5N	**Str**	0	0	4	0	4	0	2	90	48
5O	**Str**	0	0	2	2	4	0	4	88	48

*C = circle, D = diamond, H = horizontal, O = octagon, S = square, T = triangle, U = unknown or did not answer, and V = vertical.
Per = peripheral view, Str = straight view.
Shaded cell = correct response.

Table 75. Response to Sign Type Question for Speed Limit Signs.

ID	View	Response (%) to Sign Type Question*										Frequency Total
		A	D	I	O	P	RR	SL	Stop	U	Y	
5M	**Per**	0	0	0	33	0	0	48	0	19	0	48
5N	**Per**	0	0	0	25	0	0	38	0	38	0	48
5O	**Per**	0	0	0	27	0	0	46	0	27	0	48
5M	**Str**	0	0	0	2	0	0	94	0	4	0	48
5N	**Str**	0	0	0	2	0	0	98	0	0	0	48
5O	**Str**	0	0	0	2	0	0	98	0	0	0	48

*A = Arrow, D or Do Not = Do Not Enter sign (without words on sign face),
I or Int = Intersection Ahead, O = other, P or Ped = Pedestrian Crossing, RR = Railroad,
SL = Speed Limit, Stop = Stop, U = did not know or offer a guess, Y = Yield.
Per = peripheral view, Str = straight view.
Shaded cell = correct response.

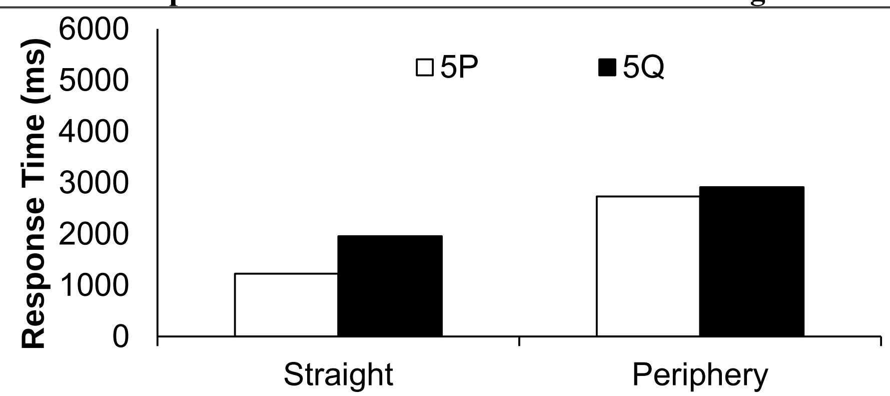
Two-Direction Large Arrow Signs

Two versions of the two directional LARGE arrow warning sign were tested as seen in Figure 40. Both signs were sized at 36 × 18 in. Table 76 shows the response time results for the arrow signs along with the statistical evaluation results. A statistical significant difference was identified for the effects of viewing angle (peripheral versus straight) and for the effects of lights (with and without lights).

	
5P (Two-Direction Large Arrow 36 × 18)	**5Q (Two-Direction Large Arrow w/4 yellow dots flash 1:9)**
Typical Two-Direction Large Arrow sign (36 in. × 18 in.) with no lights.	4 yellow lights placed at corners of the Two-Direction Large Arrow sign, flashing at a rate of 1:9 on:off per sec.

Figure 40. Two-Direction Large Arrow Signs.

Table 76. Mean Response Time Results for Two-Direction Large Arrow Sign.



Code	Sign Description	Viewing Peripherally		Viewing Straight	
		Num	Average Response Time (ms)	Num	Average Response Time (ms)
5P	Two-Direction Large Arrow 36 × 18	43	2736	45	1230
5Q	Two-Direction Large Arrow w/4 yellow dots flash 1:9	45	2914	46	1959

The test performed was a 2 (fixation) × 2 (lights) Factorial Repeated Measures ANOVA on log transformed reaction times. The results showed a main effects of fixation, $F(1, 37) = 41.80$, $p < 0.001$, Lights, $F(1, 37) = 10.82$, $p < 0.01$, and a significant interaction between lights and fixation, $F(1, 37) = 4.19$, $p < 0.05$.

Num = Number of participants.

The percent of participant responses by sign ID and viewing angle is listed in Table 77 for sign color, Table 78 for sign shape, and Table 79 for sign type. The results illustrate the unfamiliarity of drivers with this sign. Only about half of the participants correctly identified the sign when viewing straight (see Table 79). A large percentage of the participants did not offer a guess as to the type of the signs when viewing peripherally—33 percent for the unlighted sign and

44 percent for the lighted sign. When viewed straight, most participants correctly identified the color and shape of the sign regardless of the presence of the LEDs.

Table 77. Response to Sign Color Question for Two-Direction Large Arrow Signs.

ID	Response (%) to Sign Color Question*										Frequency Total
	Straight					Peripheral					
	O	RWR	U	W	Y	O	RWR	U	W	Y	
5P	10	0	0	0	90	17	2	0	0	81	48
5Q	13	0	0	0	88	13	2	0	0	85	48

*O = orange, RWR = red and white or red, U = did not know or did not answer, W = white, Y = yellow.
Shaded cell = correct response.

Table 78. Response to Sign Shape Question for Two-Direction Large Arrow Signs.

ID	View	Response (%) to Sign Shape Question*								Frequency Total
		C	D	H	O	S	T	U	V	
5P	**Per**	0	2	77	0	6	4	2	8	48
5Q	**Per**	2	0	77	0	13	4	0	4	48
5P	**Str**	2	0	94	0	0	0	0	4	48
5Q	**Str**	0	0	96	0	2	2	0	0	48

*C = circle, D = diamond, H = horizontal, O = octagon, S = square, T = triangle, U = unknown or did not answer, and V = vertical.
Per = peripheral view, Str = straight view.
Shaded cell = correct response.

Table 79. Response to Sign Type Question for Two-Direction Large Arrow Signs.

ID	View	Response (%) to Sign Type Question*										Frequency Total
		A	D	I	O	P	RR	SL	Stop	U	Y	
5P	**Per**	17	0	0	48	0	0	0	0	33	2	48
5Q	**Per**	10	0	2	40	0	0	0	2	44	2	48
5P	**Str**	56	0	0	40	0	0	0	2	2	0	48
5Q	**Str**	52	0	0	46	0	0	0	0	2	0	48

*A = Arrow, D = Do Not Enter sign (without words on sign face), I = Intersection Ahead, O = other, P or Ped = Pedestrian Crossing, RR = Railroad, SL = Speed Limit, Stop = Stop, U = did not know or offer a guess, Y = Yield.
Per = peripheral view, Str = straight view.
Shaded cell = correct response.

Circular Stop Sign

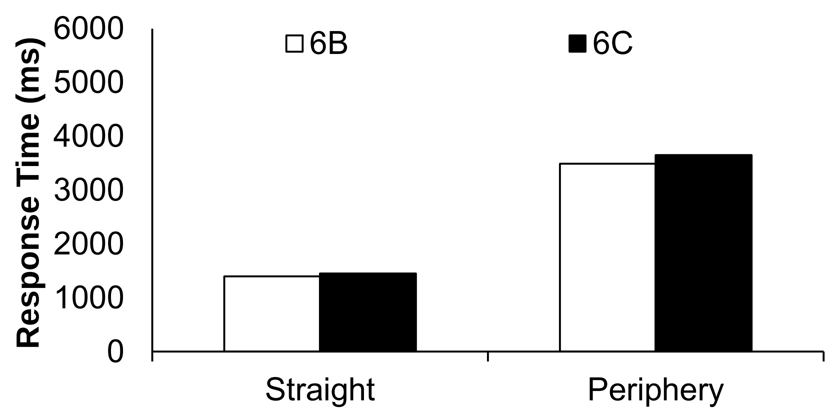
Finally, a circular version of the Stop sign was created and tested to evaluate whether drivers were assuming that the Stop signs were octagonal, or if they could really distinguish the shape of the sign (see Figure 41). The two signs tested were 36 in. in diameter. Response time results along with the results from the statistical evaluation for the circular Stop sign can be found in

Table 80. A significant difference was found between the viewing angles (peripheral versus straight); however, a significant difference was not found between the response time for the circular sign with and without lights.

 	
6C (circular Stop 36 in.)	**6B (circular Stop w/8 red dots flash 1:9)**
Circular Stop sign created for this study (36 in.).	8 red dots placed in a circle on the circular Stop sign (36 in.), flashing simultaneously at a rate of 1:9 on:off per sec.

Figure 41. Circular Stop Signs.

Table 80. Mean Response Time Results for Circular Stop Signs.



Code	Sign Description	Viewing Peripherally		Viewing Straight	
		Num	SD Response Time (ms)	Num	Average Response Time (ms)
6B	Circular Stop w/8 red dots flash 1:9	40	1600	46	1401
6C	Circular Stop 36 in.	45	1622	44	1455

The test performed was a 2 (fixation) × 2 (lights) Factorial Repeated Measures ANOVA on log transformed reaction times. The results showed the main effects of fixation, $F(1, 37) = 41.80$, $p < 0.001$. However, the effect of lights was not significant, $F(1,36) = 1.62$, $p > 0.05$ and neither was the interaction between lights and fixation, $F < 1$.

Num = Number of participants.

The percent of participant by sign ID and viewing angle is listed in Table 81 for sign color, Table 82 for sign shape, and Table 83 for sign type. Similar results were identified for both sign options. Almost all of the participants could correctly identify the type when viewing straight (see Table 83). When viewing peripherally, the accuracy was less, however, still similar between the two options. About three-fourths of the participants correctly identified the type for these signs. The participants correctly identified the color of the sign (see Table 81). The answers to shape of the sign are interesting. Even when viewing straight, less than a third realized the sign was circular (see Table 82).

Table 81. Response to Sign Color Question for Circular Stop Signs.

ID	Response (%) to Sign Color Question*										Frequency Total
	Straight					Peripheral					
	O	RWR	U	W	Y	O	RWR	U	W	Y	
6B	0	100	0	0	0	6	90	0	4	0	48
6C	0	96	4	0	0	4	79	4	10	2	48

*O = orange, RWR = red and white or red, U = did not know or did not answer, W = white, Y = yellow.

Shaded cell = correct response.

Table 82. Response to Sign Shape Question for Circular Stop Signs.

ID	View	Response (%) to Sign Shape Question*								Frequency Total
		C	D	H	O	S	T	U	V	
6B	Per	27	2	0	63	0	2	4	2	48
6C	Per	25	0	4	56	2	6	6	0	48
6B	Str	29	0	0	71	0	0	0	0	48
6C	Str	35	0	0	65	0	0	0	0	48

*C = circle, D = diamond, H = horizontal, O = octagon, S = square, T = triangle, U = unknown or did not answer, and V = vertical.
Per = peripheral view, Str = straight view.

Shaded cell = correct response.

Table 83. Response to Sign Type Question for Circular Stop Signs.

ID	View	Response (%) to Sign Type Question*										Frequency Total
		A	D	I	O	P	RR	SL	Stop	U	Y	
6B	Per	0	0	0	2	0	2	2	75	17	2	48
6C	Per	0	0	0	2	0	0	0	73	21	4	48
6B	Str	0	0	2	0	0	0	0	96	0	2	48
6C	Str	0	0	0	0	0	0	0	100	0	0	48

*A = Arrow, D = Do Not Enter sign (without words on sign face), I = Intersection Ahead, O = other, P or Ped = Pedestrian Crossing, RR = Railroad, SL = Speed Limit, Stop = Stop, U = did not know or offer a guess, Y = Yield.
Per = peripheral view, Str = straight view.

Shaded cell = correct response.

Final Questions (Section 6)

The first question in Section 6 asked participants if they thought these types of flashing signs were on all the time or were activated by an approaching vehicle. As seen in Table 84, 85 percent of participants assumed that the flashing lights on this type of sign would be on/flashing all the time; 15 percent thought the light would be activated by an approaching vehicle.

The next question showed the three Stop signs displayed in Figure 42. Participants were asked for their preference. The results are also shown in the figure. The participants overwhelmingly preferred the top and bottom beacon arrangement (69 percent) over the other choices available.

Finally, the last question of the survey asked how TxDOT should decide where to put flashing signs like these. The majority of the participants favored placing the signs in areas where there are a high number of crashes. Many participants recommended utilizing the signs in areas where either the sign or the intersection is difficult to see, and also using them in rural areas. Finally, a small number of participants mentioned using the signs where there is a high volume of traffic.

Table 84. Response to "Do You Think the Flashing Lights Are on all the Time, or Are Activated by an Approaching Vehicle?"

1 = All the time	85
2 = Turned on by the vehicle	15

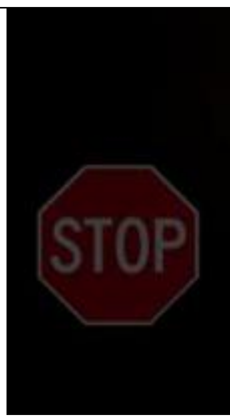
			
	1C (Stop 36 in.)	**3B (Stop w/top & bottom beacons)**	**1A (Stop w/8 red dots flash 1:9)**
	Typical octagonal Stop sign (36 in.) with no lights.	Typical Stop sign (36 in.) with beacons on top and on bottom of sign with alternating flash rate of 5:5 on:off per sec (Note that figure shows both beacons on for illustration purposes).	8 red dots placed at corners of the octagonal Stop sign (36 in.), simultaneous flashing at a rate of 1:9 on:off per sec.
Response:	21	69	10

Figure 42. Results from Question Asking for Participant's Preference of Stop Sign.

DISCUSSION

The laboratory method used here was the first use of TTI's new Visibility Research Laboratory for human factors testing. The method proved successful for detecting differences in participant responses to sign lighting factors. The laboratory study provided a cost-effective way to test many variations of sign design variables in order to narrow which signs were actually fabricated for the closed-course test track study.

The first question asked in this study was whether flashing lights affected sign size perception. In general, participants perceived the lighted signs to be smaller than unlighted signs in 20 percent of cases. For static unlighted signs, previous studies have shown a direct correlation between size of sign and detection distance. This is why many agencies consider upsizing a sign as a means to increase conspicuity. It may be that in the field the added visibility distance provided by the lights compensates for a reduction in perceived size. This question was carried over to the closed-course study described in the next chapter, which provided direct comparisons of lighted and unlighted signs in terms of sign detection and recognition.

The second question asked in this study was whether the color of the embedded lights affected sign perception. The results indicated that the response times to signs without lights was significantly faster than those to signs with either white or colored lights (red for Stop and yellow for Pedestrian Crossing). Since there was not a significant effect for light color, this variable was not carried forward to the closed-course study.

The third section of the lab study addressed different flashing beacon placements. The results showed no significant difference in response time between any of the signs with beacons. However, response times to the signs without beacons were faster than those to any of the signs with beacons. Both this result and the previous one suggest that the flashing lights caused participants to hesitate before responding. This may be an artifact of the lighting conditions in the lab study with the bright lights generating a slight startle response in the participants, causing them to hesitate before pressing the response button.

The fourth section of the study examined various arrangements of embedded LEDs on sign faces of several types. Some of the designs tested were based on actual products and some were variations envisioned by the research team. The results showed that regardless of whether the signs were viewed directly or in peripheral vision, the use of alternating flashing bars along the edge of the sign increased response time. When the bars flashed along all edges simultaneously, the signs performed equally to those with single-point LEDs. The white bars caused poorer performance than the red bars for Stop signs, most likely due to the brightness of the lights obscuring the sign shape. Because no product currently uses light bars, this variation was deemed lower priority and was excluded from the closed-course study. Other variations of sequential flashing lights ("marquee lights") along the edge of the signs performed poorly and were also excluded from the closed-course study. Across other sign types, the presence of lights consistently slowed sign recognition times.

The last part of the laboratory study asked participants' opinions regarding application and operation of lighted signs. When asked whether lighted signs would operate all the time or be actuated by approaching vehicles, 85 percent indicated they believed they would operate continuously. When asked about potential applications, the majority of the responses recommended placing the signs in areas where there is a high number of crashes. Many participant responses included utilizing the signs in areas where either the sign or the intersection is difficult to see and also using them in rural areas. Finally, a small number of participants mentioned using the signs where there was a high volume of traffic.

CHAPTER 6

CLOSED-COURSE STUDY TO IDENTIFY DRIVER DETECTION OF TRAFFIC CONTROL DEVICES

INTRODUCTION

This chapter describes the methodology and results from the closed-course study that examined driver detection of traffic control devices, primarily Stop signs with beacons, LEDs, or no supplemental flashing device. In addition to the Stop signs, "distractor" warning signs and Speed Limit signs were selected for inclusion along the test route.

Study Objective

The objective of this research project is to evaluate different traffic control device alternatives for use at a rural stop-controlled intersection. The objective within this task was to evaluate the impact of beacons or LEDs on the detection of signs and on the ability to read the words or symbol on a sign.

Study Approach

Participants drove a TTI vehicle accompanied by a TTI employee on a closed course at the Riverside campus while viewing different types of traffic control device.

SIGN SELECTION

Stop Signs Selected for This Study

Researchers selected a total of nine different Stop and "stop decoy" sign types for testing on the Riverside driving course. Table 85 describes the signs used and the numbers assigned to their locations on the test track.

- A 36-in. Stop sign, tested alone and in conjunction with an overhead flashing beacon.
- A 36-in. Stop sign with red alternating vertical beacons (see Figure 43a).
- A 48-in. Stop sign, tested alone and in conjunction with an overhead flashing beacon.
- A 36-in. internally illuminated Stop sign (see Figure 43b).
- A 36-in. Stop sign with a cluster of LEDs at each corner (see Figure 43c).
- 36-in. Stop sign with a single LED at each corner, set at a daytime/ "high" brightness level (see Figure 44a).
- The same with LEDs set at a nighttime/"low" brightness level.
- A 36-in. sign reading "SPOT" (see Figure 44b).
- A 36-in. blank red sign (see Figure 44c).

Table 85. Stop Signs Used in Closed-Course Riverside Track Study.

Sign Position Number on Test Track	Size	Description/Lighting	Vendor
1	48 in.	0.2 in. Alum high-intensity prismatic	Centerline Supply
4	36 in.	0.125 in. Alum high-intensity prismatic; paired with overhead red beacon	Centerline Supply
7	36 in.	8 Perimeter LED clusters	K&K
8	36 in.	8 Perimeter LEDs set at low light level	Tapco, Inc.
9	36 in.	0.125 in. Alum high-intensity prismatic; no sign legend	Centerline Supply
11	36 in.	Internally illuminated	Sun Inno Tech
13	36 in.	8 Perimeter LEDs set at high light level	Tapco, Inc.
14	36 in.	0.125 in. Alum high-intensity prismatic	Centerline Supply
17	36 in.	0.125 in. Alum high-intensity prismatic; with alternating vertical beacons	Centerline Supply
19	36 in.	0.125 in. Alum high-intensity prismatic; legend “SPOT”	Centerline Supply
101	36 in.	0.125 in. Alum high-intensity prismatic; legend “SPOT”	Centerline Supply
104	48 in.	0.2 in. Alum high-intensity prismatic; paired with overhead red beacon	Centerline Supply
107	36 in.	0.125 in. Alum high-Intensity prismatic	Centerline Supply
108	36 in.	8 Perimeter LEDs set at high light level	Tapco, Inc.
109	36 in.	0.125 in. Alum high-intensity prismatic; legend “SPOT”	Centerline Supply
111	36 in.	0.125 in. Alum high-intensity prismatic; legend “SPOT”	Centerline Supply
113	36 in.	8 Perimeter LEDs set at low light level	Tapco, Inc.
114	36 in.	8 Perimeter LED clusters	K&K
117	36 in.	0.125 in. Alum high-intensity prismatic; with alternating vertical beacons	Centerline Supply
119	36 in.	0.125 in. Alum high-intensity prismatic; no sign legend	Centerline Supply

(a) Stop with beacons (b) Internally illuminated Stop (c) Stop with clustered LEDs at corners

Figure 43. Stop Signs Tested in Riverside Study: 36-in. Stop with Beacons, Sun Inno Tech, K&K.

(a) Stop with single LEDs at corners (b) "SPOT" sign (c) Blank sign

Figure 44. Some of the Stop Signs Tested in Riverside Study.

Other Signs Selected for This Study

In addition to the Stop signs, "distractor" warning signs and Speed Limit signs were included along the test route. These signs served several purposes: to help hold participants' attention on the course, to distract participants (to some extent) from the fact that the Stop signs were the focus of the research, and to provide some additional data points to observe detection and legibility distances.

Two of the warning signs were "Stop Ahead" symbols, each placed 750 ft ahead of a Stop sign location. Another warning sign position was equipped with amber flashing beacons to test the effects of the beacons on the detection and legibility distances for the signs (one for Lap A, another for Lap B) in both daytime and nighttime conditions.

The distractor signs included along the test route are listed below and illustrated in Figure 45 and Figure 46. Most of these signs were also used to answer other research questions as indicated below.

(a) Stop Ahead

(b) ROUGH ROAD (shown with beacons)

(c) LOOSE GRAVEL

(d) CHURCH

(e) SOFT SHOULDER

Figure 45. Warning Signs Used on Riverside Test Course.

Distractor only:

- Warning sign "Stop Ahead" (symbol sign).

Effect of beacons on accuracy of reading message:

- Warning sign LOOSE GRAVEL (with and without amber alternating vertical beacons).
- Warning sign ROUGH ROAD (with and without amber alternating vertical beacons).

Accuracy of reading message (legibility distance):

- Warning sign CHURCH.
- Warning sign SOFT SHOULDER.
- Speed Limit sign 35 mph.

- Speed Limit sign 42 mph.
- Speed Limit sign 45 mph.
- Speed Limit sign 48 mph.

(a) 35 mph (b) 42 mph (c) 45 mph (d) 48 mph

Figure 46. Speed Limit Signs Used on Riverside Test Course.

DATA COLLECTION

Riverside Campus and Site Selection for Signs

The runway system on Texas A&M Riverside campus served as the test roadway for data collection. The runways offer a mixture of long straightaways, short intersecting segments, and curves. Researchers designed a route to permit nearly every Stop sign to be seen by each participant at two different locations on the track, at different viewing distances. Viewing distances for the sign locations ranged from 961 ft to 5238 ft. An overhead red flashing beacon was installed at one intersection to accompany the Stop signs tested at that position; the same overhead assembly included amber flashing beacons that were visible to drivers on the intersecting runway. Table 86 lists the Stop sign types and the viewing conditions under which each was tested.

Two Stop sign types could be tested at only one location on the track and therefore at one viewing distance. The 36-in. Stop sign with alternating vertical beacons (Sign 17 and 117), because of its weight and power requirements, had to be professionally installed next to one of the runways; a second installation of this type at a different location on the course was impractical. Only one internally illuminated sign (Sign 11) was available for the test and so was used at a single location on the course (switched out with a different sign at the same location between laps).

Stop Ahead signs were included along two approaches, 750 ft in advance of the respective Stop sign positions:

- The approach to the Stop sign position at the overhead flashing beacon.
- The approach to the Stop sign with alternating vertical beacons.

Table 86. Stop Sign Types Tested in Riverside Study.

Stop Sign Numbers	Shorter Viewing Distance (ft)	Longer Viewing Distance (ft)
36-in. Stop	2859	4702
48-in. Stop	1887	2378
36-in. Stop w/vertical beacons (preceded by Stop Ahead sign)		5163
36-in. Stop w/overhead beacon (preceded by Stop Ahead sign)		5238
48-in. Stop w/overhead beacon (preceded by Stop Ahead sign)		5238
36-in. Stop with single LEDs (high light level)	961	3758
36-in. Stop with single LEDs (low light level)	961	3758
36-in. Stop with clustered LEDs	2859	4702
36-in. internal illuminated stop		2378
36-in. SPOT	1898	2378
36-in. Blank	1898	2378

Besides the Stop and Stop Ahead signs, warning signs and Speed Limit signs were placed throughout the course as “distractor” signs. These additional signs helped to maintain participants’ attention and interest between Stop signs, distracted participants from the study’s focus on the Stop signs, and also provided additional information regarding legibility distance (since drivers could not as easily guess at the words/numbers appearing on the distractor signs). One distractor sign position included amber beacons to determine how both daytime and nighttime detection and legibility distances were affected by the beacons.

Because of the large number of Stop sign types and distractor signs used on the course, the route was laid out so that participants drove each runway section in both directions during a single lap, maximizing the total roadway distance. Two laps were designed, using two different sets of signs at the designated sign positions. Figure 47 shows the signs that participants saw on Lap A of the course along with photograph of the signs. Figure 48 shows the Lap B signs. Sign types listed in the table include “stop” (red octagonal sign), “warning” (yellow diamond-shaped sign), and “regulatory” (white rectangular sign).

Figure 49 shows the route and the sign placements for Lap A, and Figure 50 shows the route and sign placements for Lap B. Numbers on the graphic indicate the sign positions, in the order in which they appeared on the route. Sign position number 2, originally designated as a location for a distractor sign, was eliminated from the route prior to the beginning of data collection. Figure 51 shows the distance between the signs, while Figure 52 presents the viewing distance for a sign.

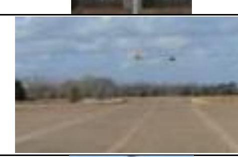
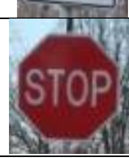
Position	Type	Sign	Position	Type	Sign
1	48-in. Stop		11.5	Yellow overhead beacon	
3	Stop ahead		12	LOOSE GRAVEL	
4	36-in. Stop w/overhead beacon		13	36-in. Stop w/single LEDs (high light level)	
5	CHURCH		14	36-in. Stop	
6	48 mph		15	ROUGH ROAD w/beacons	
7	36-in. Stop w/cluster LEDs		16	Stop ahead	
8	36-in. Stop w/single LEDs (low light level)		17	36-in. Stop w/vertical beacons	
9	36-in. blank		17.5	Yellow overhead beacon	
10	35 mph		18	45 mph	
11	36-in. Stop w/ internal illumination		19	36-in. SPOT	

Figure 47. Signs in Order of Appearance – Lap A.

Position	Type	Sign
101	48-in. Stop	
103	Stop ahead	
104	48-in. Stop w/overhead beacon	
105	SOFT SHOULDER	
106	45 mph	
107	36-in. Stop	
108	36-in. Stop w/single LEDs (high light level)	
109	36-in. SPOT	
110	35 mph	
111	48-in. Stop	

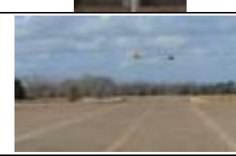
Position	Type	Sign
111.5	Yellow overhead beacon	
112	ROUGH ROAD	
113	36-in. Stop w/single LEDs (low light level)	
114	36-in. Stop w/cluster LEDs	
115	LOOSE GRAVEL w/beacons	
116	Stop ahead	
117	36-in. Stop w/vertical beacons	
117.5	Yellow overhead beacon	
118	42 mph	
119	36-in. blank	

Figure 48. Signs in Order of Appearance – Lap B.

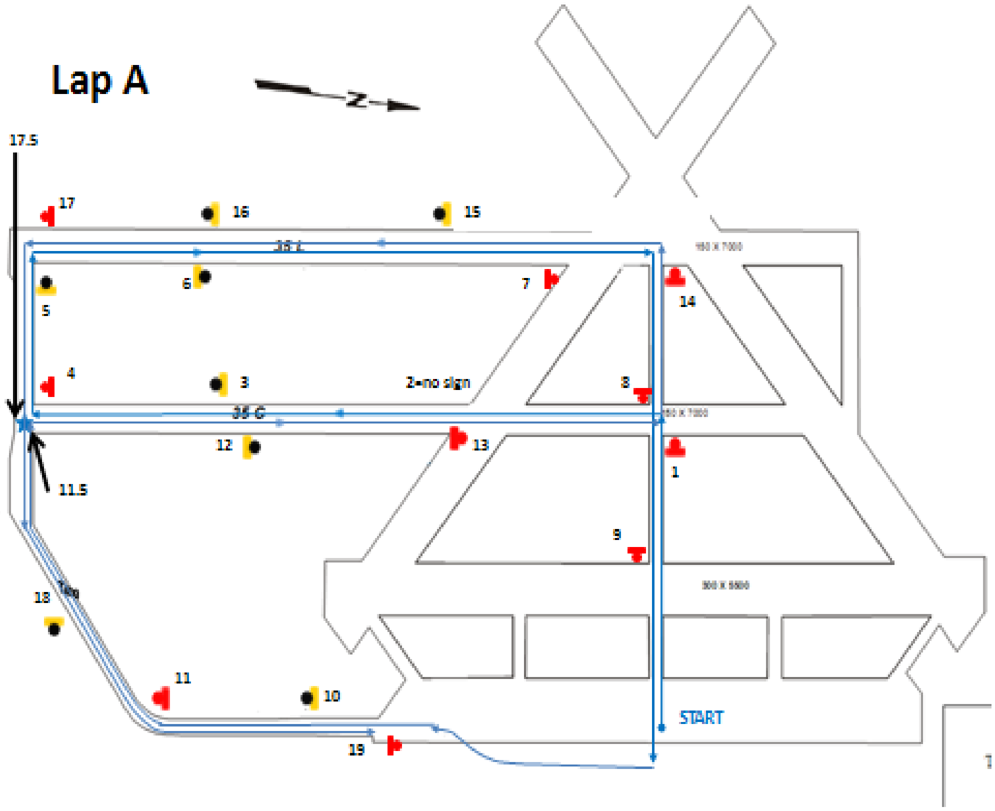


Figure 49. Test Route for Riverside Study – Lap A.

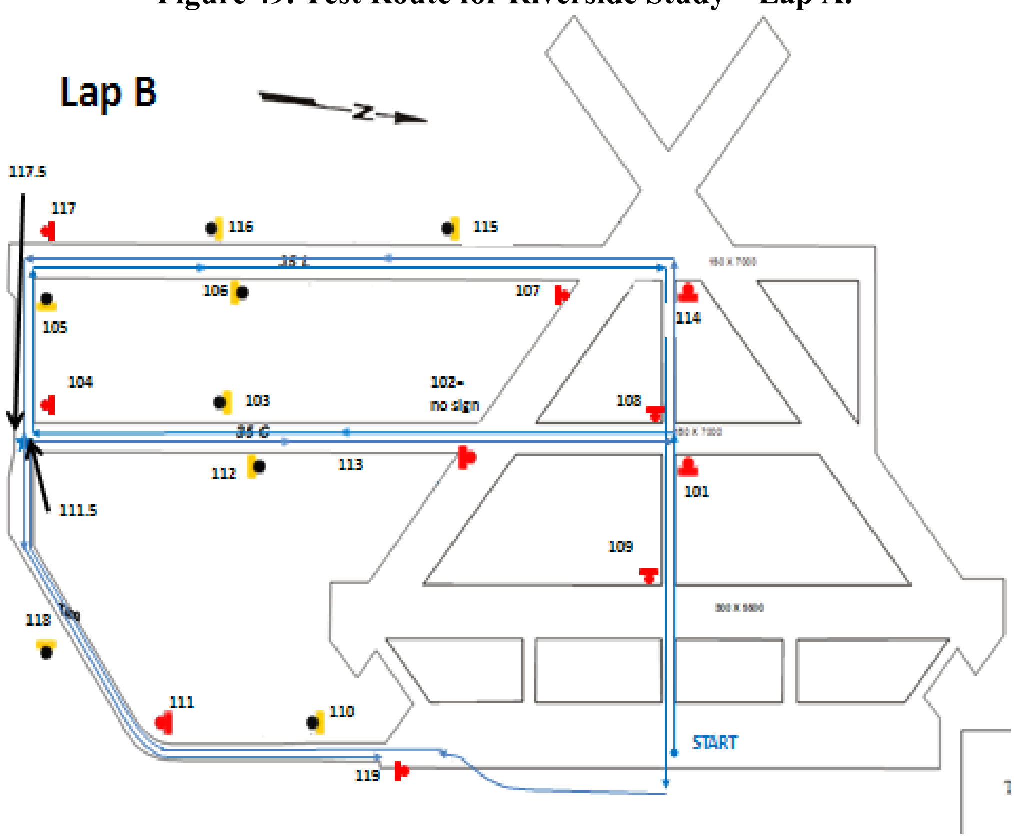


Figure 50. Test Route for Riverside Study – Lap B.

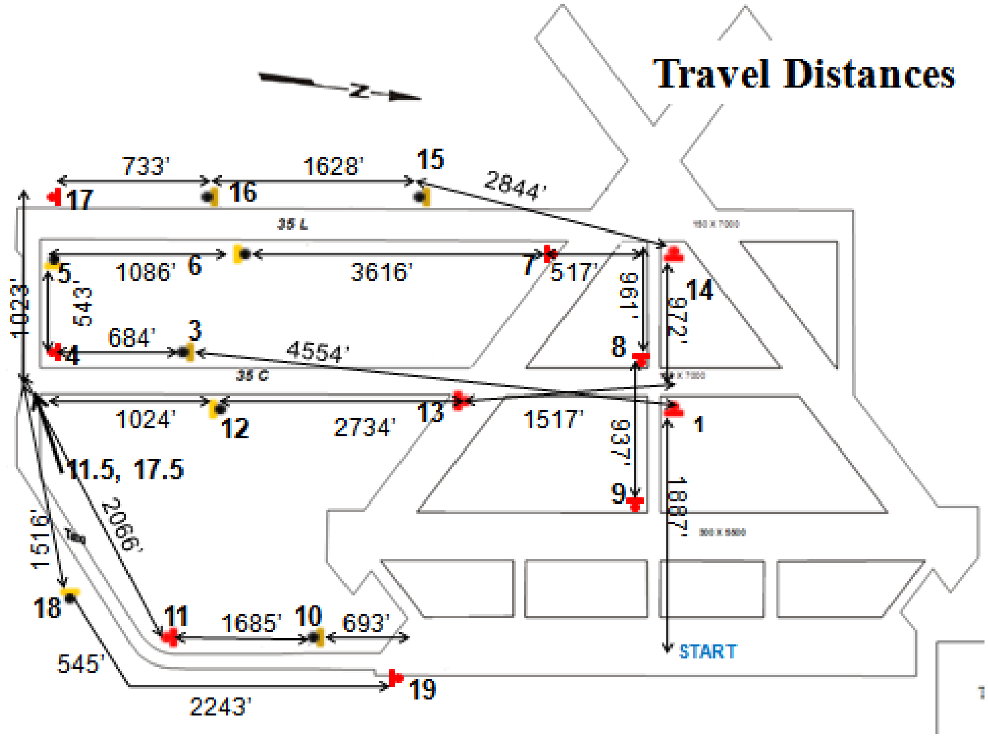


Figure 51. Travel Distances between Sign Locations.

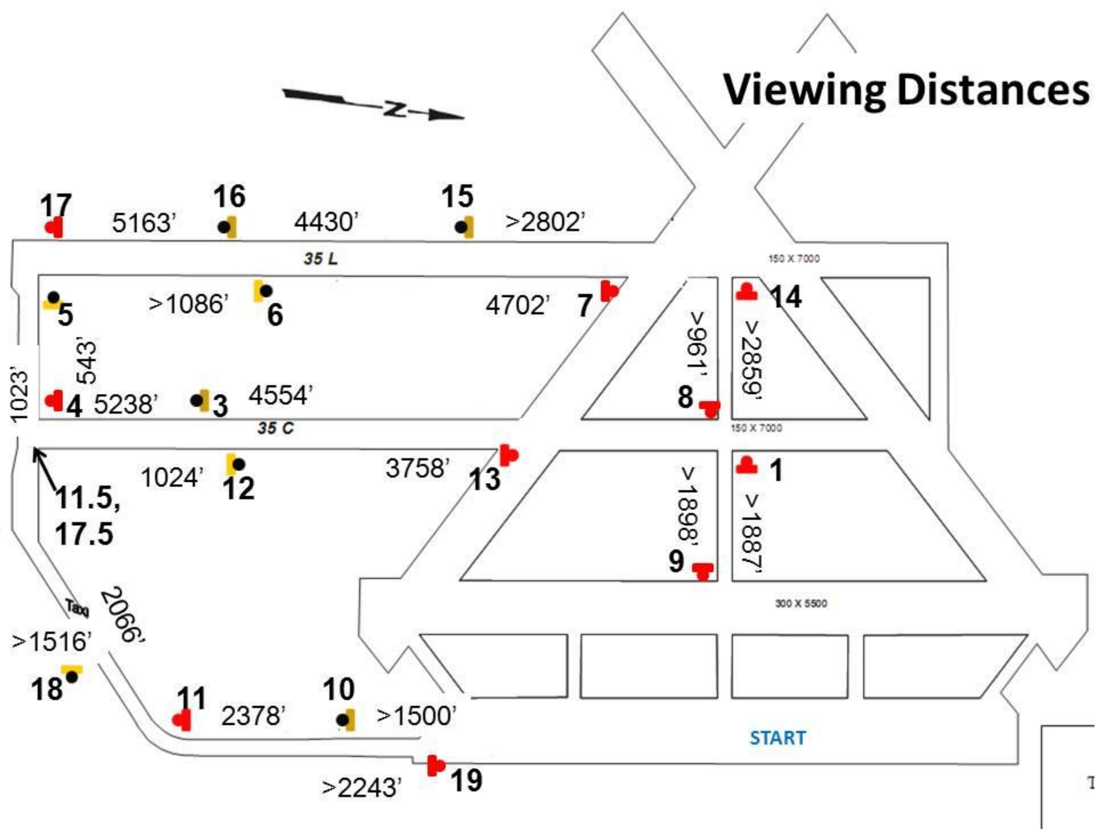


Figure 52. Viewing Distances between Sign Locations.

Route Preparation

Several of the Riverside campus runways were already marked with yellow centerline striping and white edgeline striping to simulate rural roadways. Where striping was not present, the research team installed temporary reflective pavement markings (RPMs) to act as a roadway centerline. Stop bars were installed at each Stop sign position on the course (see Figure 53).

Figure 53. Stop Bar Installation.

An overhead flashing beacon was installed at the intersection of Runway 35C and Taxiway 7 (see Figure 54 and Figure 55). TxDOT's Bryan District installed two signs with attached flashing-beacon assemblies next to the pavement edge on Runway 35L at sign positions 15 and 17 (see Figure 49 and Figure 56). The rest of the Stop and distractor signs were placed on or near the runway using existing installed sign posts or moveable signposts mounted in concrete-filled tires (see Figure 57).

Figure 54. Overhead Beacon (Red Beacons) Viewed from Runway 35C, Facing South.

Figure 55. Overhead Beacon (Amber Beacons) Viewed from Taxiway 7 (Facing West).

Figure 56. Installation of Stop and Warning Signs with Flashing Beacon Assemblies.

Figure 57. Concrete Tire Signpost Bases.

Sign changes between laps were accomplished in a variety of ways, depending on the sign types, sizes, and locations:

- LED illumination levels on the two Stop signs with single LEDs at the corners were reset between the laps; on each lap, one sign was set at the high (brighter/daytime) level and the other was set at the low (dimmer/nighttime) level. Field crew changed the illumination settings on these signs using a laptop computer carried in their vehicle. The unit's brightness can be changed on a scale from 0 (lowest) to 20 (highest). The low setting used in this study was 5. The high setting was 12.5.
- For warning signs and non-illuminated Stop signs with counterparts of the same size and shape (e.g., a 36-in. "SPOT" sign and a 36-in. red blank sign, or two different warning signs), the sign for Lap A was mounted on a signpost. The field crew then attached the corresponding sign for Lap B over the Lap A sign using metal spring clips. (See Figure 58).
- For signs of different sizes (e.g., the 36-in. Stop sign and the 48-in. Stop sign at position 4) or illuminated/powered signs paired with other signs (e.g., the Stop sign with clustered LEDs and the 36-in. Stop sign at positions 7 and 14), the field crew hid one sign behind the other, often laying the sign that was not currently being viewed flat on the ground. (See Figure 59).

Figure 58. Sign Change Lap A to Lap B, with Clip-on Sign.

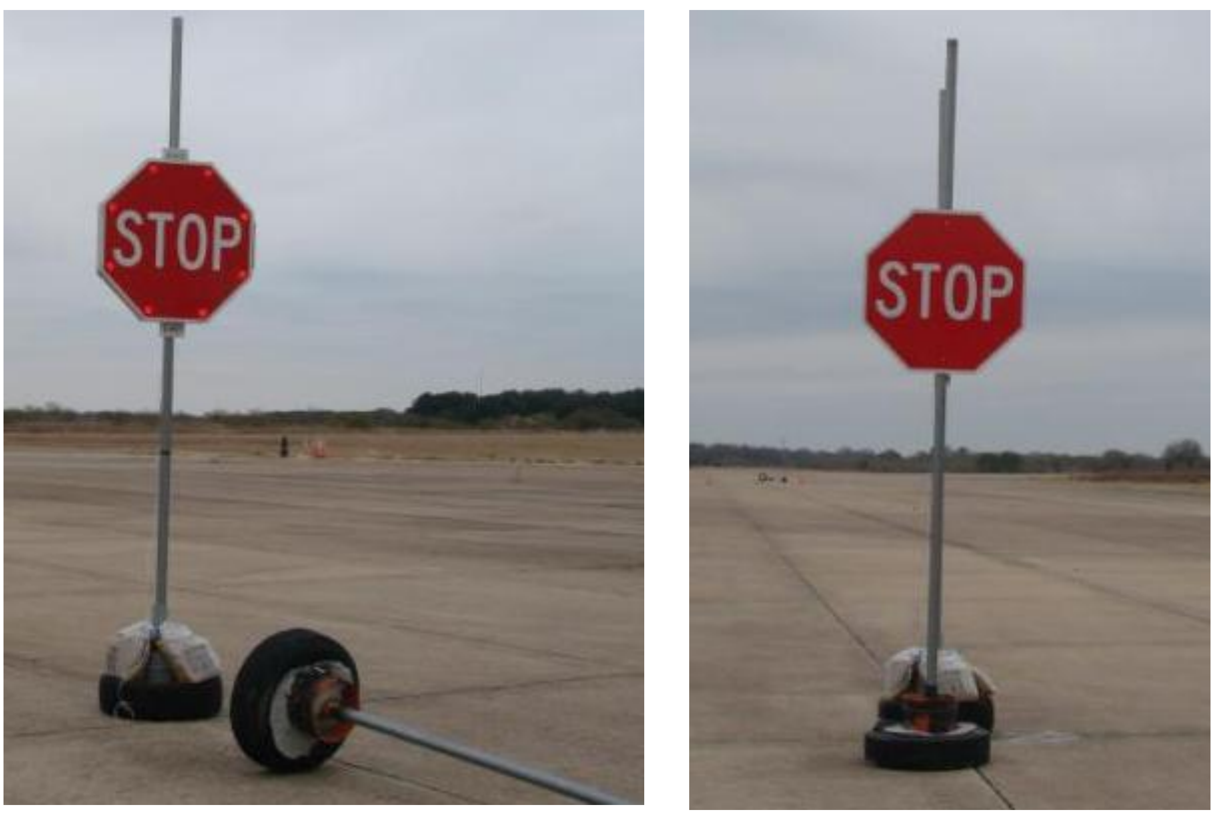


Figure 59. Sign with Clustered LEDs Visible for Lap A; Hidden behind a Standard 36-in. Sign (on Separate Post) for Lap B.

Study Periods

The study was conducted under both daytime and nighttime conditions over two weeks in December 2010. The actual dates for the study were as follows:

- Sunday, December 5–Friday, December 10, 2010.
- Sunday, December 12–Saturday, December 18, 2010.

For December 2010, sunset occurred about 5:25 p.m. The study took slightly over 1 hour from meeting the participant to the close of debriefing (see Table 87); often one participant was completing initial processing with the greeter while the previous participant completed the second lap of the course with the researcher. Half of the participants drove during daylight hours and half during nighttime conditions. The following time blocks were used:

- 8:15–9:15 a.m.
- 9:15–10:15 a.m.
- 10:15–11:15 a.m.
- 11:15 a.m.–12:15 p.m.
- 1:15–2:15 p.m.
- 2:15–3:15 p.m.
- 6:00–7:00 p.m.
- 7:00–8:00 p.m.
- 8:00–9:00 p.m.
- 9:00–10:00 p.m.

The latest daytime slots were scheduled to end by 3:15 in the afternoon because the angle of the setting sun after that time caused glare on many of the signs, interfering with legibility. Testing on Wednesday morning, December 15, ended earlier than scheduled due to high winds and resumed Thursday evening, December 16.

Table 87. Participant Time in Study.

Activity	**Time (min)**
Initial processing and pretest	10
Drive to start, test route (first lap)	20
Wait Time for sign changes	0–5
Route (second lap), drive back to origin	20
Final processing and payment	10
Total	**60–65**

Participants

The initial intent was to recruit a group of participants composed of one-quarter males over 55 years, one-quarter females over 55 years, one-quarter males under 55 years, and one-quarter females under 55 years. Within each of those demographic groups, the goal was to have an even distribution between those who drove at day and those who drove at night and between those who drove Lap A first and those who drove Lap B first. Therefore, the following divisions were used in structuring participant recruitment:

- Light level: day or night.
- Age group: young (younger than 55 years) and old (55 years or older).
- Gender: male or female.
- Lap driven first: A or B.

These divisions resulted in 16 participant categories. The research goal was to have 4 participants in each category for a total of 64 participants. A total of 73 participants were included in the study. Participants were added to (a) replace a handful of participants whose data was not recorded successfully and (b) add additional data to offset missing data points due to signs that had fallen or were temporarily disabled. The final participant pool is shown in Table 88. Participants were at least 18 years old and possessed a valid driver's license with no restrictions.

Participants were recruited by word of mouth, flyer distribution, and communication with people who participated in past studies and indicated an interest in future studies. Flyers with information about the study, location, contact information, dates, and compensation were distributed among friends and acquaintances and were posted in public places. Upon completion of the survey, participants received monetary compensation of $50.

Table 88. Distribution of Participants.

		Day		Night		
Age	**Gender**	**Lap A first**	**Lap B first**	**Lap A first**	**Lap B first**	**Total**
Younger than 55	Female	5	5	4	5	19
	Male	5	5	5	4	19
55 or older	Female	4	4	4	5	17
	Male	4	5	5	4	18
Total		**18**	**19**	**18**	**18**	**73**

Tasks

The tasks for the participants while driving the route were to indicate when they could first see warning lights, when they could first see a road sign, and when they could read the words or identify the symbol on the road sign.

After the driving portion of the study, participants returned to the meeting location and participated in a brief survey in which they were shown six pairs of Stop signs with varying lighting configurations (standard Stop sign, Stop sign with embedded LEDs, or Stop sign with flashing beacons in three different configurations). The participants indicated which sign of each pair was most effective in alerting motorists to stop.

Instrumented Vehicle

An instrumented 2006 Toyota Highlander served as the participant car for this experiment (see Figure 60). The instrumented vehicle has a larger alternator, radiator, and fan coupling than a normal vehicle and has a greater alternator capacity to power instruments in the vehicle. The vehicle also has an eight-way power seat in order to best accommodate test participants. The headlamp is 33 in. high and 28 in. offset from center.

The principal system within the instrumented vehicle is the Dewetron DEWE-5000. Essentially a large portable computer, the DEWE-5000 serves as the data acquisition device for all the peripheral systems in the vehicle. The DEWE-5000 is capable of sampling at 5000 Hz. For this experiment, data were collected at 100 Hz.

A Trimble® DSM 232 global positioning system (GPS) receiver tracked the position of the subject vehicle during a study. It employs a differential GPS antenna, which is mounted on the roof of the vehicle directly over the driver's seat. The GPS samples data at 10 Hz, and the receiver is mounted inside the equipment cabinet. The accuracy of the GPS unit is ±3.28 ft. A black-and-white video camera mounted on the passenger-side sun visor recorded the forward roadway scene.

Figure 60. Instrumented 2006 Toyota Highlander.

PROCEDURE

Participant Intake

Participant intake was headquartered at TTI's Environmental Emissions Research Facility on the Riverside campus. This location was selected because it was near the driving route, had public parking available, included restroom facilities, and was available for both daytime and nighttime use during the data collection period.

After meeting with a member of the research team to review the informed consent documentation and complete the demographic questionnaire, participants were given an overview of the study and how the data were to be collected. They were also given a Snellen visual acuity test and the Dvorine color vision test.

To ensure consistency, the research team used checklists and slide shows to aid in providing instructions to each participant. Participants were given the following instructions, with a slide show picture illustrating each bullet point:

> *While driving the test course you will see a number of road signs. There may be multiple signs on each stretch of road. As you approach each of the road signs, please tell me:*
>
> - *If you can see warning lights.*
> - *When you can see the road sign.*
> - *Then read the word or words on the sign as soon as you can read them. Some signs may not have words, and for these signs just tell me what you think the sign means. It is OK to make mistakes, just tell me when you have made a mistake and the corrected word or words on the sign.*

Response Time Testing

As part of the intake process, a computer measured the participant's and experimenter's response times to develop a correction factor for each driver. In the vehicle, the experimenter pressed a button when the participant indicated he or she saw lights and/or a road sign and when the participant read the words or identified the symbol on a road sign. There is a small lag between the participant speaking a word, e.g., "lights," and the experimenter pressing the button. The lag could vary between the experimenters collecting the data. To address this concern, a pretest was developed to measure the lag time between when the participant sees a symbol on the computer screen and speaks the symbol's name and when the experimenter presses the button. The following four images were used in the exercise: down arrow, up arrow, plus sign, and black circle (or dot). Each symbol was repeated five times for a total of 20 random images. The task required the participant to identify which stimulus was present and say the correct word, a task analogous to the in-vehicle task of saying "lights" or "sign." For the experimenters, the task was a simple reaction time test. They pressed a single button regardless of what the participant said, again analogous to the in-vehicle task.

The participant was instructed to say the name of the shape as quickly as possible once the image appeared on the computer screen. The experimenter pressed a button upon hearing the participant saying the shape name. The software recorded the time difference between the shape appearing on the screen and when the button was pushed. The participant faced the computer screen, and the experimenter's back was to the participant to avoid any anticipation on the part of the experimenter. Actual detection distance was determined from an average of the pretest reaction time for a participant along with the vehicle's speed.

Vehicle Review

The participant was escorted to the instrumented vehicle and given a walk-through of the vehicle's features. The participant was shown the video camera mounted on the passenger-side sun visor and informed that the camera was recording the forward scene. The participant was provided the opportunity to adjust the seat and mirrors and to become accustomed to the controls of the vehicle.

Participants were informed that they would drive the instrumented vehicle on a closed course and were instructed to drive at a speed not exceeding 45 mph on the runways. They were asked to drive the runway system as though it were a regular roadway and were reminded that they had complete control of the vehicle at all times. A researcher accompanied the participant in the back seat, controlling the data collection equipment and providing direction. Participants were told not to wear sunglasses if testing during the day and to keep the vehicle's headlamps on the low setting if testing at night. Conversation between the participant and the experimenter was kept to a minimum to ensure that the participant did not miss identifying any of the signs and lights on the course.

First Lap of Test Course

The participant drove the instrumented vehicle to the start position of the course, marked with an orange construction-zone barrel, waited while the researcher confirmed the lap (A or B) with the field crew and started recording a new data file on the Dewetron computer, and proceeded toward the first sign position.

The participant was to signify detection of the item by saying a preselected word to indicate the presence of warning lights or a road sign and to read the words or identify the symbol on a road sign as soon as the sign was close enough to be legible. The experimenter recorded the response on the DAS computer. The following instructions were given to the participants:

> *When you see warning lights, I'd like you to indicate so by saying "lights." When you see something that you think may be a road sign, I'd like you to indicate so by saying "sign." When you can read the words or numbers on a sign, I'd like you to read those words or numbers out loud to me. If a sign has a symbol on it instead of words or numbers, I'd like you to tell me what you think the sign means as soon as you can read the symbol. Please stop at any Stop sign or any sign that looks like a Stop sign. This will allow me to make notes in the file and to inform the sign crew about where we are on the route.*

As soon as the driver said "lights," "sign," or read the words/numbers/symbol on a road sign, the rear seat experimenter pressed the space bar on the DAS, which placed a mark in the file to indicate detection. Each sign on the course had two to three marks in the data file: one for detection distance of the sign, one for legibility distance, and (if lights were included on the sign or sign assembly) one for detection distance of the lights. The overhead beacon also had marks in the data file for detection distances on each of the three different approaches to the beacon on the route. The researcher made written notes on a data sheet to distinguish the order of marks made in the Dewetron file and to add any comments needed to clarify the participants' statements. At each Stop sign position, the researcher made a note in the Dewetron file, e.g., at Stop position number 1, the researcher typed a "1" into the Dewetron file. Following the last sign position on the first lap, the researcher stopped recording the Dewetron file and notified the sign crew.

Second Lap of Test Course

After completing the initial route, the participant was told to return to the orange construction barrel marking the route's START point. Following notification from the sign crew that the signs had been changed from Lap A to Lap B (or vice versa), the researcher started a new data file and instructed the participant to proceed with the second lap. Following the second lap, the participant was directed to drive back to the building where the initial processing occurred.

Post-Drive Preference Ratings

The participant viewed a slide show on a computer monitor that began with the following instructions:

You will be shown a pair of signs. Please mark on your sheet which one you think would be most effective in alerting motorists to the need to stop at a rural intersection.

Press the space bar to see the next pair of signs.

The instruction slide was followed with six slides each displaying a pair of Stop signs. The signs included:

- A standard Stop sign.
- A sign with alternating vertical beacons.
- A sign with alternating horizontal beacons.
- A sign with embedded flashing LEDs.

The pairings in the six slides allowed the participant to compare each of the four signs against each of the others. Figure 61 shows examples of the four styles included.

	
Standard Stop sign	Sign with embedded flashing LEDs
	
Sign with horizontal beacons	Sign with vertical beacons

Figure 61. Example of Signs Used in Post-Drive Survey.

DATA REDUCTION

Participant Demographics

Table 89 lists the demographic information for the 72 participants. The large number that selected retired for employment (29 percent) is a reflection of the emphasis on having half of the drivers over 55 years of age.

Table 89. Demographic Information for 72 Participants.

Characteristics		Number (Percent)
Age	<24	11 (15)
	24–33	9 (13)
	34–43	5 (7)
	44–53	10 (14)
	54–63	13 (18)
	64–73	15 (21)
	74–83	6 (8)
	Not Reported	3 (4)
Age Groups	<55	35 (49)
	≥55	34 (47)
	Not Reported	3 (4)
Race	African American	1 (1)
	Asian	1 (1)
	Hispanic	6 (8)
	Other	0 (0)
	White	61 (85)
Employment	Full Time	27 (38)
	Part Time	11 (15)
	Student	7 (10)
	Homemaker	1 (1)
	Retired	21 (29)
	Other	5 (7)

Characteristics		Number (Percent)
Gender	Male	37 (51)
	Female	35 (49)
Education	Some High School	1 (1)
	High School Graduate	9 (13)
	Some College/Vocational	33 (46)
	College Graduate	9 (13)
	Some Graduate School	3 (42)
	Graduate Degree	16 (22)
	Not Reported	1 (1)
Miles Driven Per Year	<10,000	13 (18)
	10,000–15,000	34 (47)
	>15,000	25 (35)
Normal Driving Conditions	Rural Roads	20 (28)
	Freeways	9 (13)
	City Streets	32 (44)
	Mixed	11 (15)

Response Time

The response lag times were determined for each participant during the intake procedures. Data were collected by two experimenters. The average response time for each participant in conjunction with the experimenter who was collecting data for that participant was determined. A review of the data revealed several potential errors. Very long response times were deemed to be caused by some distraction on the part of the participant or the experimenter, which happened occasionally in the intake room. Very short response times were eliminated because on occasion the experimenter accidentally pressed the button before the participant spoke. To eliminate these outliers, data points that were outside of two standard deviations of the average response time for that participant were removed. These steps removed 70 responses (about 5 percent). Table 90 lists the average response time by experimenter before and after removing data. In general, the response time was about 1 s for either experimenter.

Table 90. Response Time by Experimenter.

Condition	Experimenter	Number of Responses	Average Response Time (s)	Standard Deviation (s)
All data	L	780	1.012	0.536
	C	560	0.989	0.507
Remove data greater than two standard deviations of participant's average	L	687	0.980	0.510
	C	528	0.969	0.486

A more detailed review of the response time data indicated that adjusting the detection distance for response time should occur uniquely for each participant rather than using a per-experimenter average response time. Figure 62 shows the plot of the responses measured for each participant before eliminating the outliers. Figure 63 shows the plot of the responses measured after eliminating the outliers. As can be seen in the plots, some participants had average response time below 0.8 s, while other participants' response times averaged above 1.2 s. Therefore, the average response time by participant rather than by experimenter was used to adjust the detection distance.

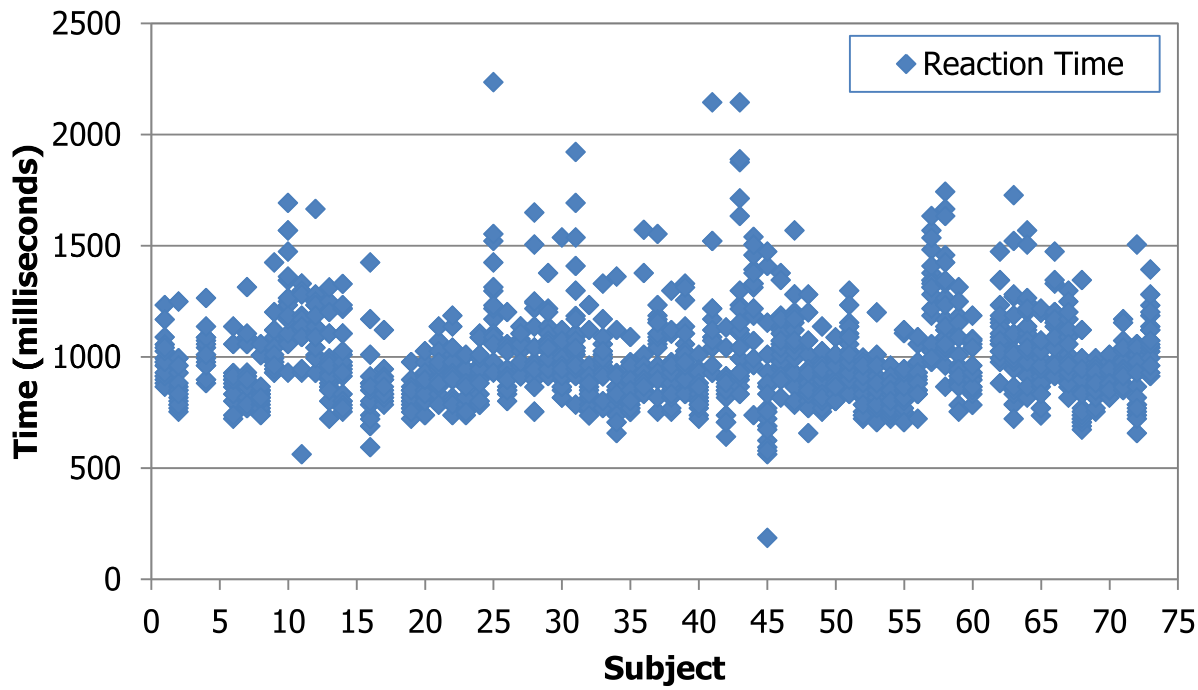


Figure 62. Graph. Measured Response Times by Vehicle/Experimenter and Participant.

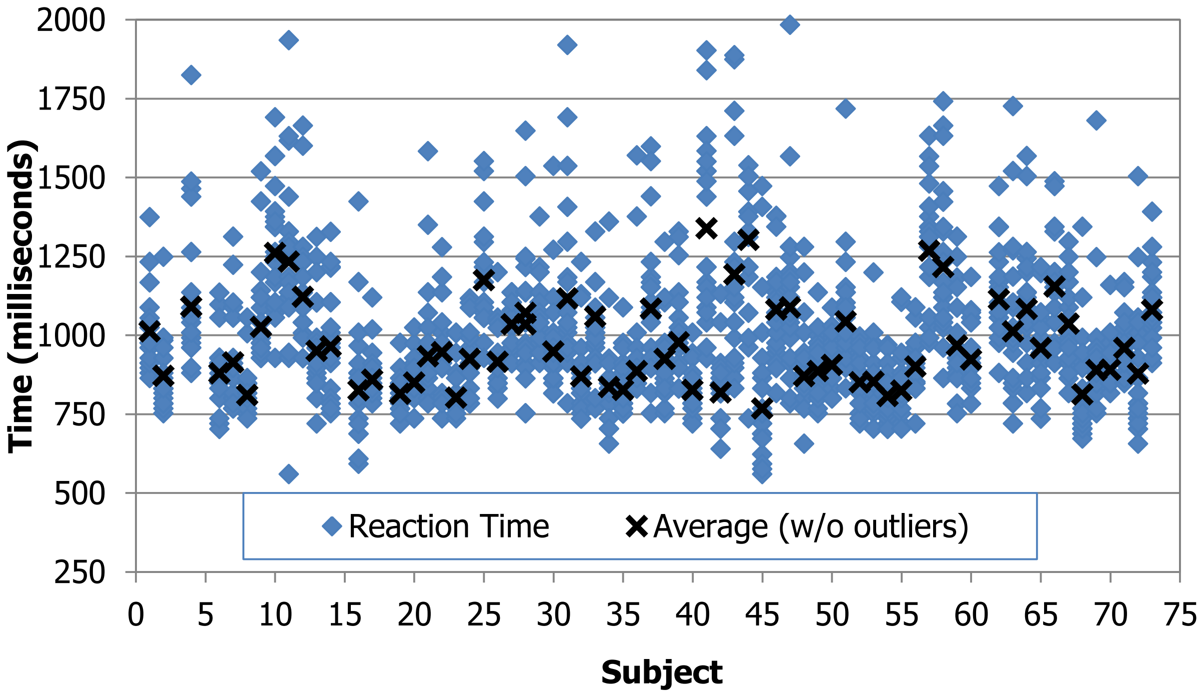


Figure 63. Graph. Response Times by Vehicle/Experimenter and Participant after Removing Outliers.

The measured detection distance was adjusted using the average response time for the participant and the speed of the vehicle at the point when the participant responded to a light or sign. The adjusted detection distance was an average of 1.4 percent higher than the GPS-based detection distance across all participants and sign locations. The maximum response time adjustment distance was 38 ft, while the minimum was 0 ft, a situation which occurs when the vehicle is stationary. The first, second, and third quartiles are 13, 19, and 24 ft, respectively.

Detection Distance

The Dewesoft software package synchronizes the GPS and video data stream records. The synchronized data were used to determine the velocity and GPS coordinates when the driver identified a light or sign. The response time determined for each participant was used along with the DEWE-5000 data to obtain the adjusted detection distances.

The GPS data from the Dewesoft program were exported into spreadsheets. The time and GPS coordinates when the driver said "light" or "sign" or read the words on the sign were identified within the data streams. The GPS locations of each of the signs were recorded before the study began. The detection distance was determined by subtracting this distance from the locations marked by the experimenter in the vehicle. This calculated distance was then adjusted to account for the response time of the experimenter and participant. Average response time of the experimenter for that participant was multiplied by the velocity at the time of identification to obtain the response distance. The response distance was added to the detection distance to obtain the adjusted detection distance.

Data Cleaning

For each analysis, results are presented visually, in the form of box-plots, and quantitatively, in the form of statistical analysis. Box-plots presented in this report were generated using the convention that the central line in the "box" represents the median data point (see Figure 64). The top of the box represents the 75th percentile and the bottom represents the 25th percentile. Thus, the relative position of the median score within the 75th and 25th percentiles can give some indication about the skewness of the data for each dependent measure. The "whiskers" represent the data that lay 1.5 times beyond the interquartile range (IQR). This is the range between the 25th and 75th percentiles. If all data below the 25th percentile and above the 75th percentile are within 1.5 times the IQR, then the end of the whisker represents the greatest or smallest value. Otherwise, all outliers beyond 1.5 times the IQR, added or subtracted from the 25th and 75th percentiles, respectively, are plotted using small black circles.

Before analysis, adjusted detection distance outliers were trimmed using the convention mentioned above (1.5 × IQR ± 25th/75th percentiles) for each sign, at each location. This first pass removed only the most egregious outliers. In order to remove all potential outliers, this procedure could have been repeated multiple times; however, this was not done to help preserve some of the character, and inhomogeneity, of the data.

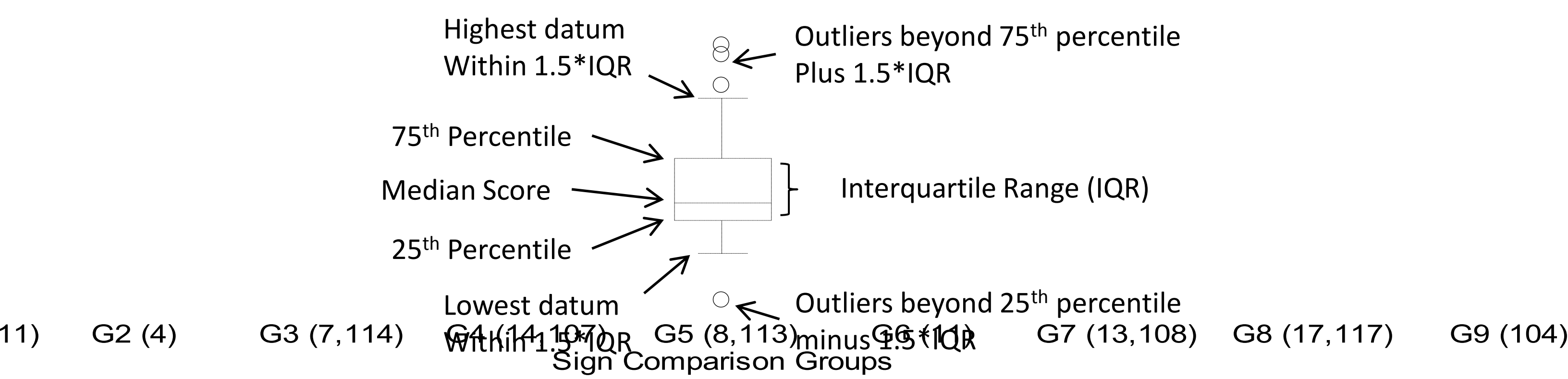


Figure 64. Box Plot Details.

RESULTS

Detection Distance

Detection distance results were analyzed using 1- and n-way repeated measures ANalysis Of VAriance (ANOVA). Violations of sphericity in the ANOVA testing were corrected by adjusting the degrees of freedom following the Greenhouse-Geisser procedure. Violations of the homogeneity of variance assumption did not lead to any adjustments or corrections. Though potentially biasing, the importance of variance homogeneity may be marginalized when larger sample sizes are used and when groups of equal sizes are compared; both of which are present in the current set of analyses. For clarity and readability, the unadjusted degrees of freedom will be reported, regardless of whether an adjustment was made in interpreting the F-statistic, thus preserving the ability of the reader to identify the exact number of samples that were used to compute each statistic.

Following each overall F-test, pairwise comparisons were completed between each of the various conditions. In order to mitigate the potential Type-I error rate (false positives), confidence intervals of all pairwise comparisons were adjusted using the Bonferroni procedure for multiple comparisons; the resulting p-values are then reported.

Following are observations and evaluation findings grouped within key questions investigated within the closed-course study.

Do the Characteristics of the Stop Sign Installation Affect the Distance Needed to Read the Stop Sign?

The intent of this question is to do an initial review of all the Stop signs included in the study. As such, the phrase "Stop sign installation" includes the standard retroreflective signs and the Stop signs at intersections with overhead beacons, with vertically alternating flashing beacons on the same pole, and those with embedded LEDs of various design. To address this question a 9-factor (signs: (1,101,111), (4), (7,114), (14, 107), (8,113), (11), (13,108), (17,117), (104)), 1-way, repeated measures ANOVA was performed, with Age (Young/Old) and Time (Day/Night) as between-subject factors. All Stop sign data and sign positions were included in this analysis, even if there were concerns with the effects of the sign's position (e.g., viewing distance or background clutter). Later analyses will remove those sign positions with viewing distance concerns.

Results (see Figure 65 and Table 91) indicated that the characteristics of the Stop sign installation (or, perhaps, the position of the installation) significantly affected the distance from which the sign could be read. However, the legibility distance for Stop signs was not affected by daytime/nighttime viewing, nor was it affected by Age (Young/Old). Pairwise comparisons of the various sign groups are listed in Table 92.

Added to Figure 65 is the stopping sight distance (SSD) for 75 mph (820 ft). The value for 75 mph was selected as an example because at the time of this study the maximum speed limit for a non-access control roadway (i.e., where a stop-controlled intersection could be present) was 75 mph. While the reading distance to some of the Stop sign installations was significantly longer than to others, the reading distance for all Stop sign installations tested in this study were very long. The average reading distance for all Stop sign installations exceeded the SSD for 75 mph. For several of the Stop sign installations, all of the participants read the words on the Stop sign at a distance greater than the SSD. Remember, these results reflect optimal conditions. Drivers are alert and seeking signs as part of the study.

In reviewing the sign detection data, the researchers discovered that some test positions on the driving course did not provide enough viewing distance or that other features of the approach to the sign caused suspect data. Because of this, data for these affected sign positions were eliminated from further analysis. For sign position 14/114 we observed that some drivers detected the sign before reaching the intersection near sign position 1. Because of a slight change in vertical crest along that approach, the distribution of responses was markedly bimodal with many participants seeing, and in some cases, reading sign position 14 before reaching sign position 1. A similar problem arose for sign position 1 due to a slight downhill approach and heavy foliage along the roadside. For sign position 8/108, the approach distance of 961 ft was not sufficient to provide enough variability in responses; as soon as drivers turned the corner they saw the sign. This produced an artificial maximum of 961 ft for the detection distances. Sign position 111 also had some problems

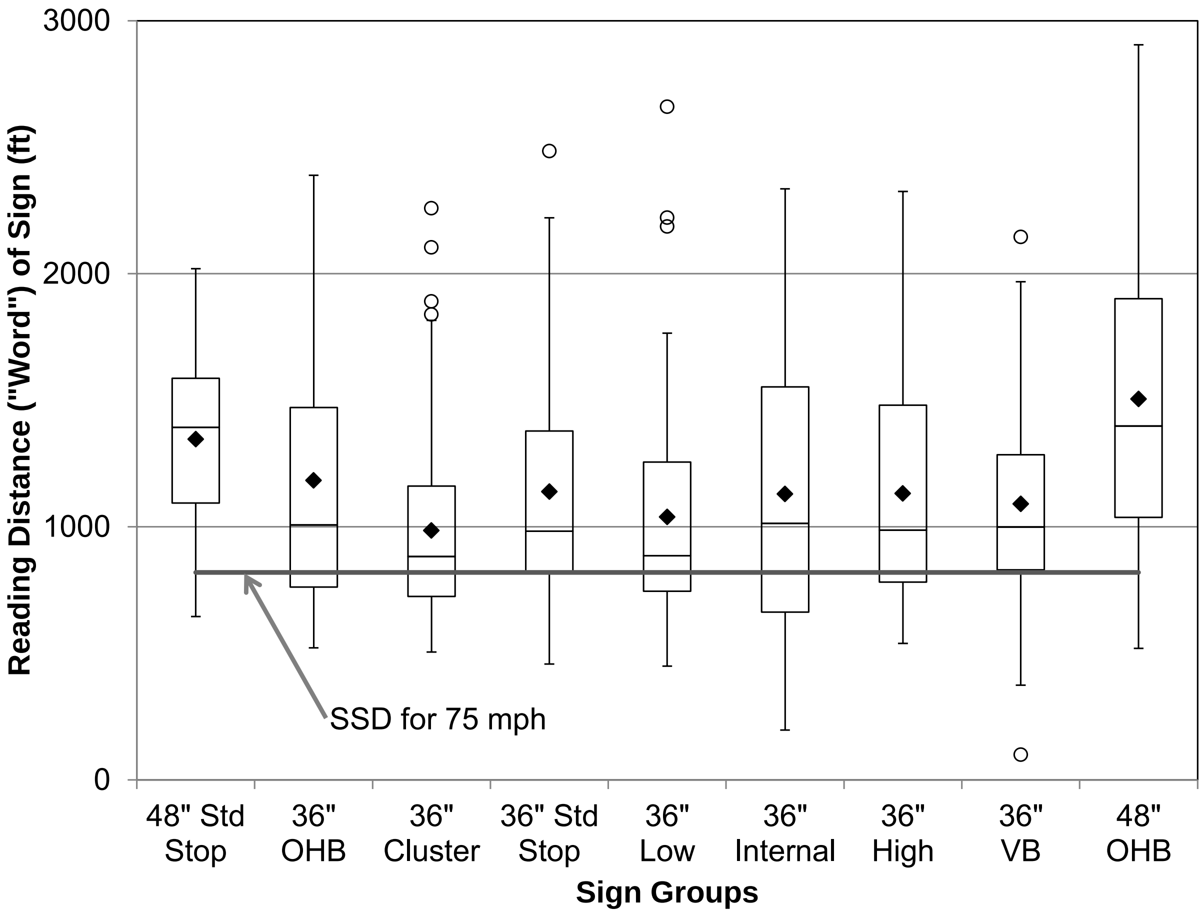


Figure 65. Box Plot for "Do the Characteristics of the Stop Sign Installation Affect the Distance Needed to Read the Stop Sign?" Question (Table 92 Provides the Definitions for the Abbreviations Used in the X-Axis).

Table 91. Statistics for "Do the Characteristics of the Stop Sign Installation Affect the Distance Needed to Read the Stop Sign?" Question.

Comparison	F-statistics	Significant?
Sign Groups	$F(8,368) = 13.2$, $p < 0.001$	Yes
Time (Day/Night)	$F(1,46) = 0.070$, $p > 0.05$	No
Age (Young/Old)	$F(1,46) = 0.374$, $p > 0.05$	No
Sign Groups × Time (Day/Night)	$F(8,368) = 1.97$, $p > 0.05$	No
Sign Groups × Age (Young/Old)	$F(8,368) = 0.628$, $p > 0.05$	No
Time (Day/Night) × Age (Young/Old)	$F(1,46) = 0.149$, $p > 0.05$	No

Table 92. Pairwise Comparisons for "Do the Characteristics of the Stop Sign Installation Affect the Distance Needed to Read the Stop Sign?" Question.

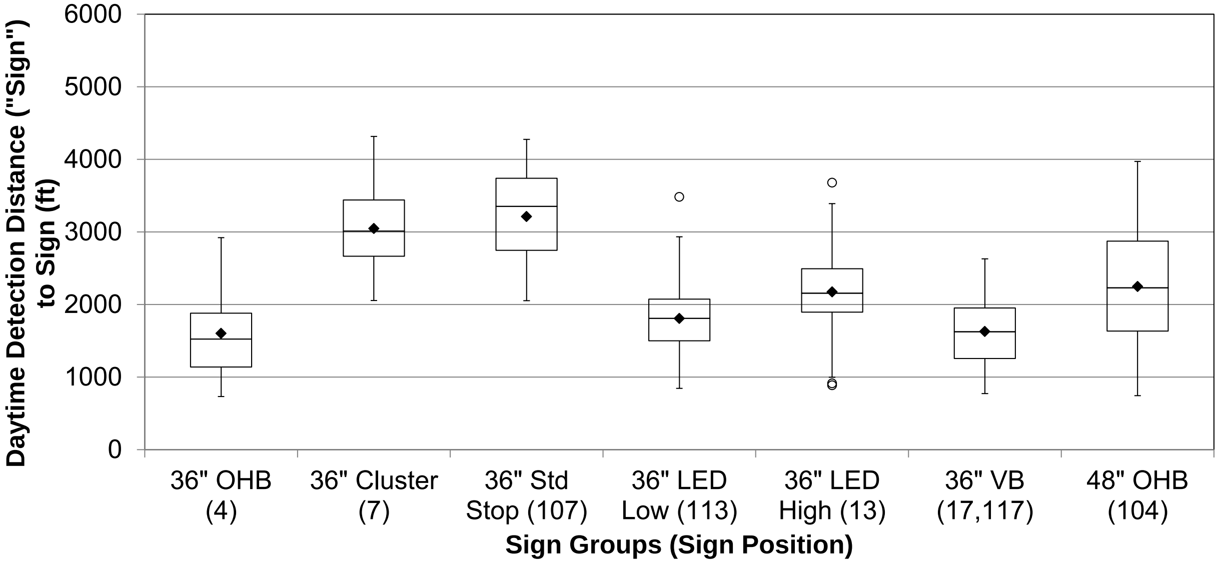
Sign Groups Abbreviation	Sign	Type	G1	G2	G3	G4	G5	G6	G7	G8	G9
G1 48" Std Stop	1, 101, 111	48-in. Stop			*	*	*		*	*	
G2 36" OHB	4	36-in. Stop w/overhead beacon			*						*
G3 36" Cluster	7, 114	36-in. Stop w/cluster LEDs	*	*							*
G4 36" Std Stop	14, 107	36-in. Stop	*								*
G5 36" Low	8, 113	36-in. Stop w/single LEDs (low light level)	*								*
G6 36" Internal	11	36-in. Stop w/ internal illumination									*
G7 36" High	13, 108	36-in. Stop w/single LEDs (high light level)	*								*
G8 36" VB	17, 117	36-in. Stop w/vertical beacons	*								*
G9 48" OHB	104	48-in. Stop w/overhead beacons		*	*	*	*	*	*	*	

*significant, $p < 0.05$.

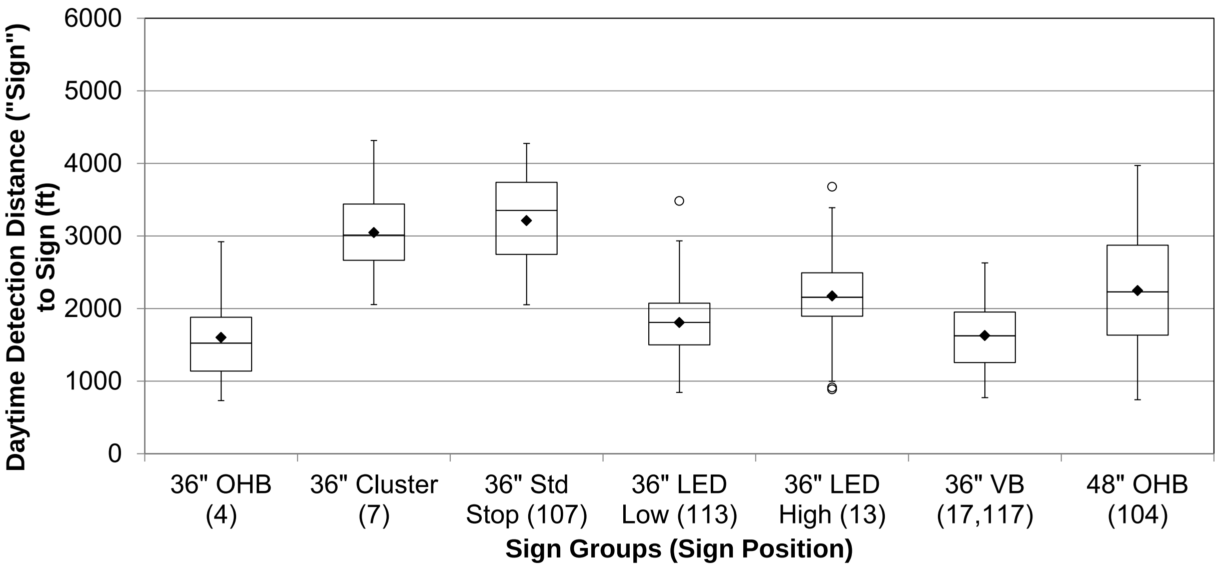
Are Stop Signs with Supplemental Lighting Recognized Earlier (Analysis of "Sign" Distances)?

To address this question a 7-factor (signs: 4, 7, 107, 113, 13, (17,117), 104), 1-way, repeated measures ANOVA was performed, with Age (Young/Old) and Time (Day/Night) as between subjects factors. Results indicated that the type of sign affected the distance at which participants stated that they saw the sign (see Figure 66 and Table 93). However, neither Time (Day/Night) or Age (Young/Old) impacted the distance needed to state that a sign was seen. Nonetheless, a significant interaction between Sign Group and Time was seen), suggesting that participants differed in their responses to some signs depending on whether they were viewed during the day or night. Specifically, the sign detection distance improved during the night for signs 4, 113, 104 (signs with overhead beacons or sign with low light level LEDs) but was worse during the night for signs 7 and 13 (signs with high light level or cluster LEDs). Pairwise comparisons are listed in Table 94.

The Stop sign in the study with the greatest sign detection distance during the day and overall was the 36-in. Stop sign (std stop) at position 107. It was likely recognized as a sign so early due to its conspicuous location with good sight lines.



(a) Day



(b) Night

Figure 66. Box Plot for "Are Signs with Supplemental Lighting Recognized Earlier (Analysis of "Sign" Distances)?" Question.

Table 93. Statistics for "Are Stop Signs with Supplemental Lighting Recognized Earlier (Analysis of "Sign" Distances)?" Question.

Comparison	F-statistics	Significant?
Sign Groups	$F(6,264) = 28.4, p < 0.001$	Yes
Time (Day/Night)	$F(1,44) = 1.06, p > 0.05$	No
Age (Young/Old)	$F(1,44) = 0.722, p > 0.05$	No
Sign Groups × Time (Day/Night)	$F(6,264) = 12.2, p < 0.001$	Yes
Sign Groups × Age (Young/Old)	$F(6,264) = 1.12, p > 0.05$	No
Time (Day/Night) × Age (Young/Old)	$F(1,44) = 4.66, p < 0.05$	Yes

Table 94. Pairwise Comparisons for "Are Stop Signs with Supplemental Lighting Recognized Earlier (Analysis of "Sign" Distances)?" Question.

Sign Group Abbreviation	Sign	Type	G1	G2	G3	G4	G5	G6	G7
G1 36" OHB	4	36-in. Stop w/overhead beacon			*			*	
G2 36" Cluster	7	36-in. Stop w/cluster LEDs			*		*	*	
G3 36" Std Stop	107	36-in. Stop	*	*		*	*	*	
G4 36" LED Low	113	36-in. Stop w/single LEDs (low light level)			*			*	*
G5 36" LED High	13	36-in. Stop w/single LEDs (high light level)		*	*			*	*
G6 36" VB	17,117	36-in. Stop w/vertical beacons	*	*	*	*	*		*
G7 48" OHB	104	48-in. Stop w/overhead beacons				*	*	*	

*significant, $p < 0.05$

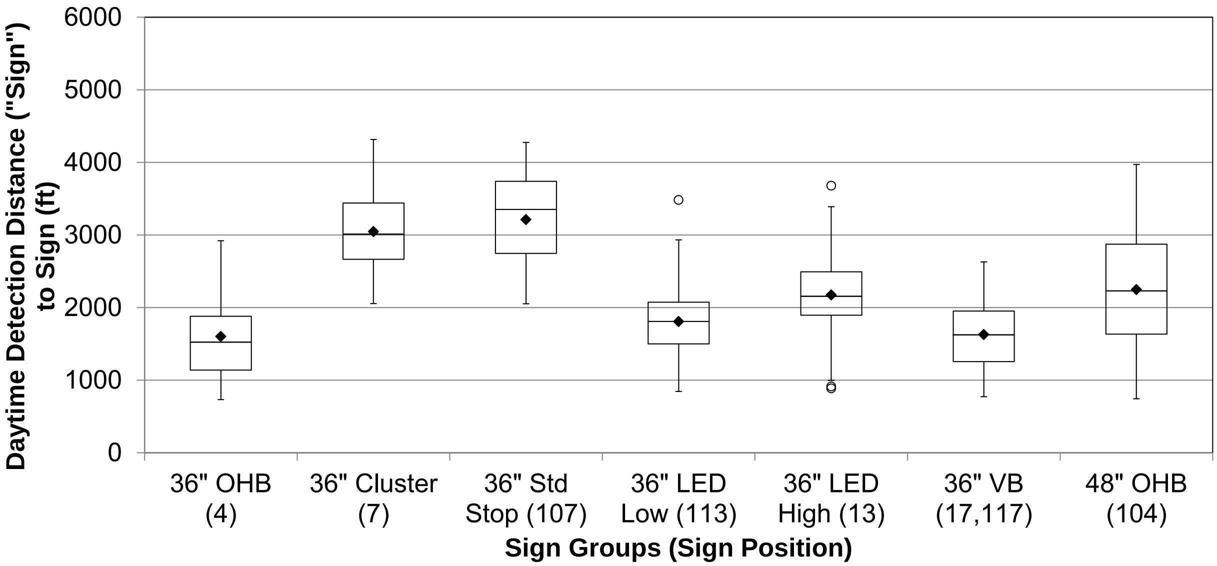
Are Stop Signs with Supplemental Lighting Read Earlier (Analysis of "Word" Distances)?

To address the question about whether Stop signs with beacons are seen earlier a 7-factor (signs: 4, 7, 107, 113, 13, (17,117), 104), 1-way, repeated measures ANOVA was performed, with age (young/old) and time (day/night) as between-subject factors. Results indicated that the type of Stop sign affected the distance at which participants stated that they could read the sign (see Table 95 and Figure 67). However, neither the time (day/night) nor the age (young/old) influenced the distance needed to state that a sign could be read. None of the two-way or three-way interactions among sign group, age, and time was significant. The results for the pairwise comparisons are listed in Table 96.

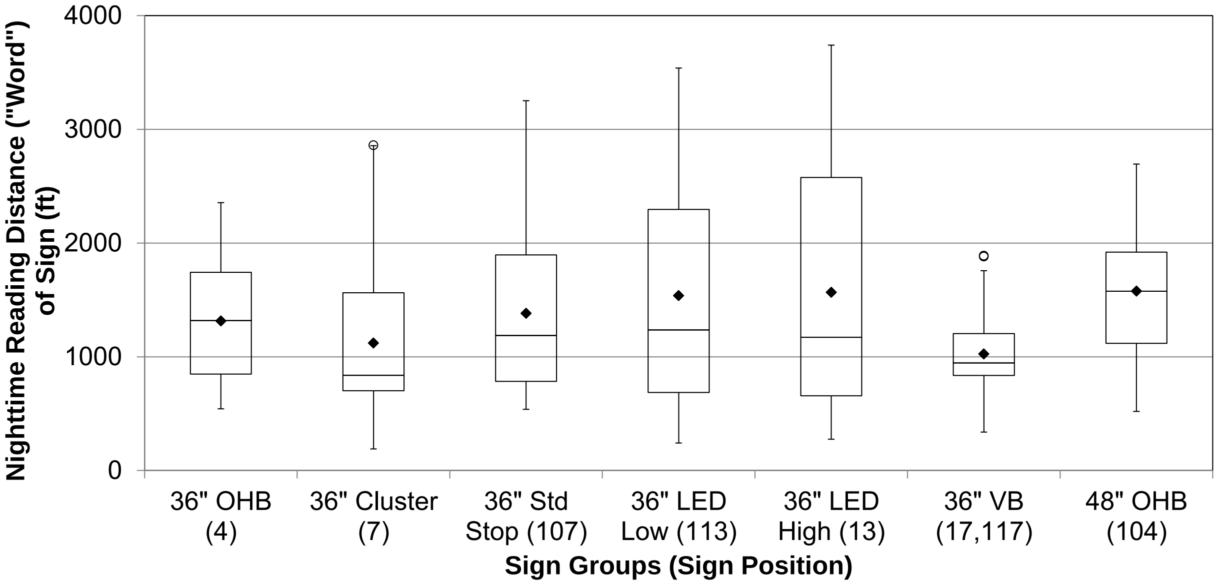
The overall results for both sign detection and word legibility for day and night for all the Stop sign installations retained in the analysis are shown in Figure 68. This graph also plots the 75 mph SSD for comparison. In all cases, the detection distance far exceeds the SSD. In addition, the legibility distance ("word") is also greater than SSD. In some cases, the detection distance is approximately 3000 ft, which is extremely long.

Table 95. Statistics for "Are Stop Signs with Supplemental Lighting Read Earlier (Analysis of "Word" Distances)?" Question.

Comparison	F-statistics	Significant?
Sign Groups	$F(6,246) = 5.40$, $p < 0.001$	Yes
Time (Day/Night)	$F(1,41) = 0.246$, $p > 0.05$	No
Age (Young/Old)	$F(1,41) = 1.38$, $p > 0.05$	No
Sign Groups × Time (Day/Night)	$F(6,246) = 1.17$, $p > 0.05$	No
Sign Groups × Age (Young/Old)	$F(6,246) = 0.304$, $p > 0.05$	No
Time (Day/Night) × Age (Young/Old)	$F(1,41) = 0.156$, $p > 0.05$	No



(a) Day



(b) Night

Figure 67. Box Plot and Statistics for "Are Stop Signs with Supplemental Lighting Read Earlier (Analysis of "Word" Distances)?" Question.

Table 96. Pairwise Comparisons for "Are Stop Signs with Supplemental Lighting Read Earlier (Analysis of "Word" Distances)?" Question.

Sign Group Abbreviation	Sign	Type	G1	G2	G3	G4	G5	G6	G7
G1 36" OHB	4	36-in. Stop w/overhead beacon							*
G2 36" Cluster	7	36-in. Stop w/cluster LEDs							*
G3 36" Std Stop	107	36-in. Stop							
G4 36" Low	113	36-in. Stop w/single LEDs (low light level)							
G5 36" High	13	36-in. Stop w/single LEDs (high light level)							
G6 36" VB	17, 117	36-in. Stop w/vertical beacons							*
G7 48" OHB	104	48-in. Stop w/overhead beacon	*	*				*	
*significant, $p < 0.05$									

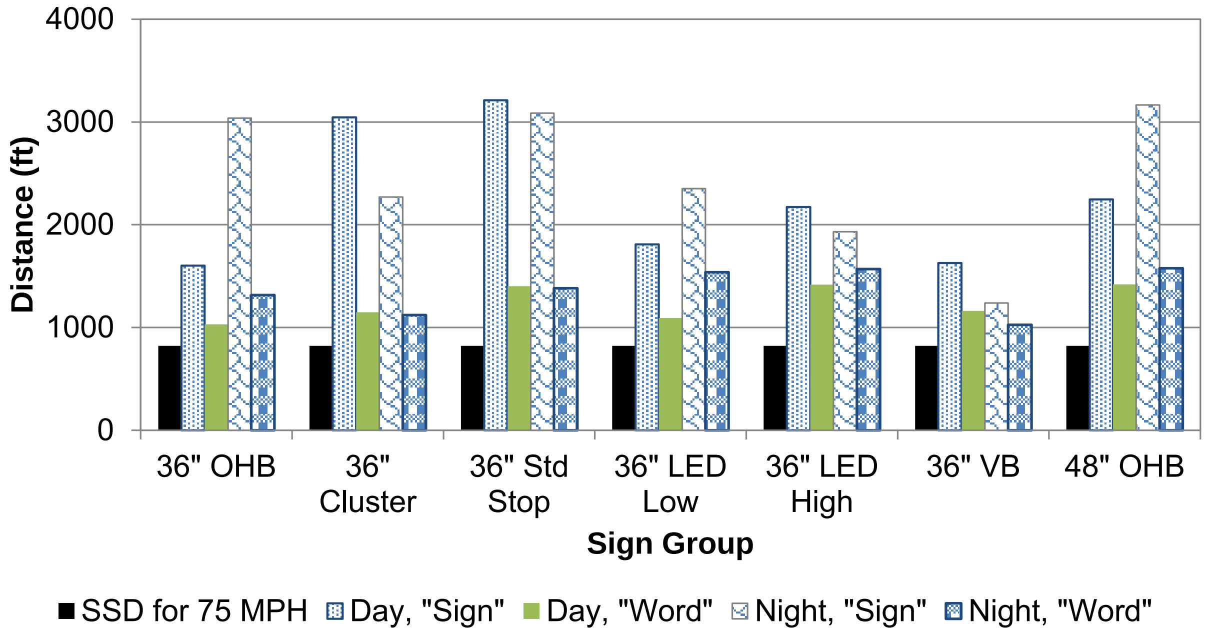


Figure 68. Detection and Legibility Distances by Time of Day for All Stop Sign Installations.

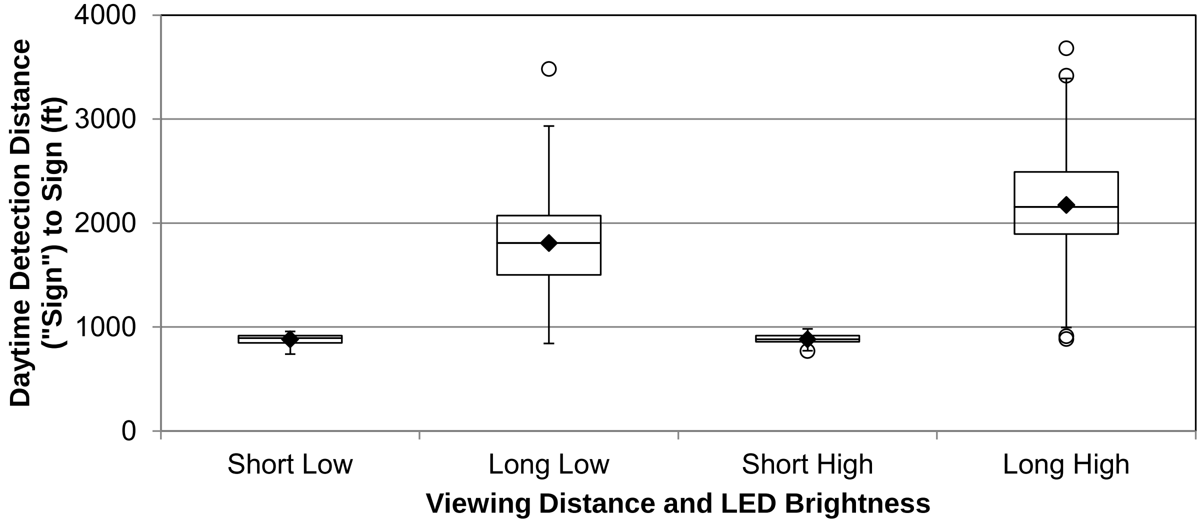
Does the Brightness of LED Lighting, and Sign Location, Affect "Sign" Detection?

A 2 (LED brightness: Low/High) by 2 (viewing distance: short/long) repeated measures ANOVA was performed, with Age (Younger/Older) and Time (Day/Night) as between-subject factors. Results (see Table 97 and Figure 69) failed to indicate a main effect of LED brightness on sign detection. A main effect of viewing distance was observed, suggesting that participants for the short viewing distance generally detected signs as soon as they were available. Additionally, neither Time (Day/Night) nor Age was significant. None of the other 2-way interactions were significant.

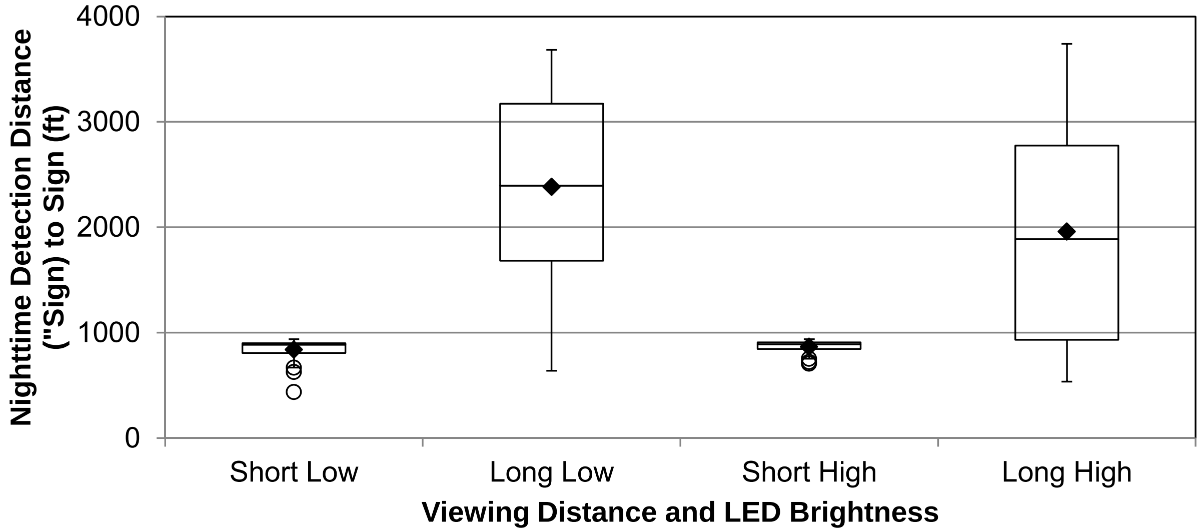
Interestingly, there was a significant interaction between LED brightness and Time (Day/Night) and Viewing Distance (Long/Short), such that participants were aided in sign detection during the day with the bright LED lights but hindered during the night with the same lights, relative to the low LED light setting for the sign position with the long viewing distance. As illustrated in Figure 70, daytime low setting had a mean detection distance of 1808 ft, while the high setting had a detection distance of 2173 ft. During the nighttime, the low setting had the longer mean detection distance (2353 ft) as compared to 1932 ft for the high setting. Thus, adjustments in the light level of LEDs do impact whether or not participants can see past the LEDs to the sign. During the daytime, this was optimally achieved with bright LEDs, during the nighttime; this was optimally achieved with dimmer LEDs.

Table 97. Statistics for "Does the Brightness of LED Lighting, and Sign Location, Affect "Sign" Detection?" Question.

Comparison	F-statistics	Significant?
Viewing Distance (Short/Long)	$F(1,49) = 208, p < 0.001$	Yes
LED Brightness (Low/High)	$F(1,49) = 0.719, p > 0.05$	No
Time (Day/Night)	$F(1,49) = 0.760, p > 0.05$	No
Age (Young/Old)	$F(1,49) = 0.753, p > 0.05$	No
LED Brightness (Low/High) × Time (Day/Night)	$F(1,49) = 12.6, p < 0.001$	Yes
LED Brightness (Low/High) × Age (Young/Old)	$F(1,49) = 0.920, p > 0.05$	No
Viewing Distance (Short/Long) × Time (Day/Night)	$F(1,49) = 1.78, p > 0.05$	No
Viewing Distance (Short/Long) × Age (Young/Old)	$F(1,49) = 0.993, p > 0.05$	No
Time (Day/Night) × Age (Young/Old)	$F(1,49) = 6.46, p < 0.05$	Yes
LED Brightness (Low/High) × Viewing Distance (Short/Long) × Time (Day/Night)	$F(1,49) = 14.9, p < 0.001$	Yes



(a) Day



(b) Night

Figure 69. Box Plot for "Does the Brightness of LED Lighting, and Sign Location, Affect 'Sign' Detection?" Question.

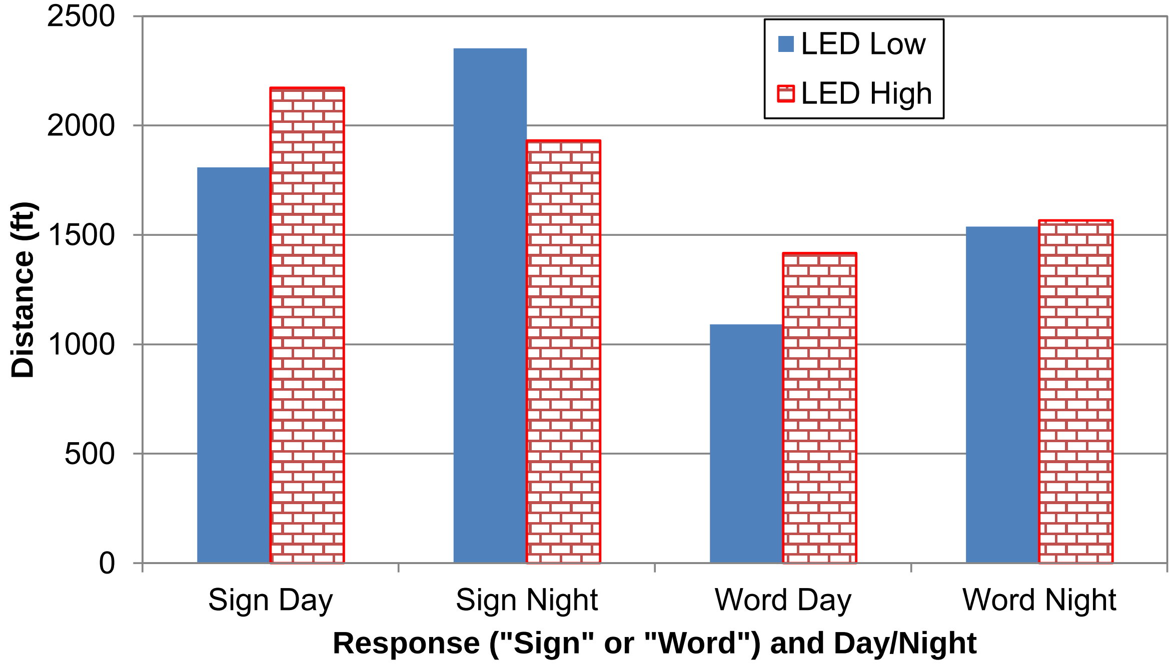


Figure 70. Detection ("Sign") and Legibility ("Word") Distances by Time of Day (Day/Night) and LED Brightness (Low/High) for Signs with Long Viewing Distance.

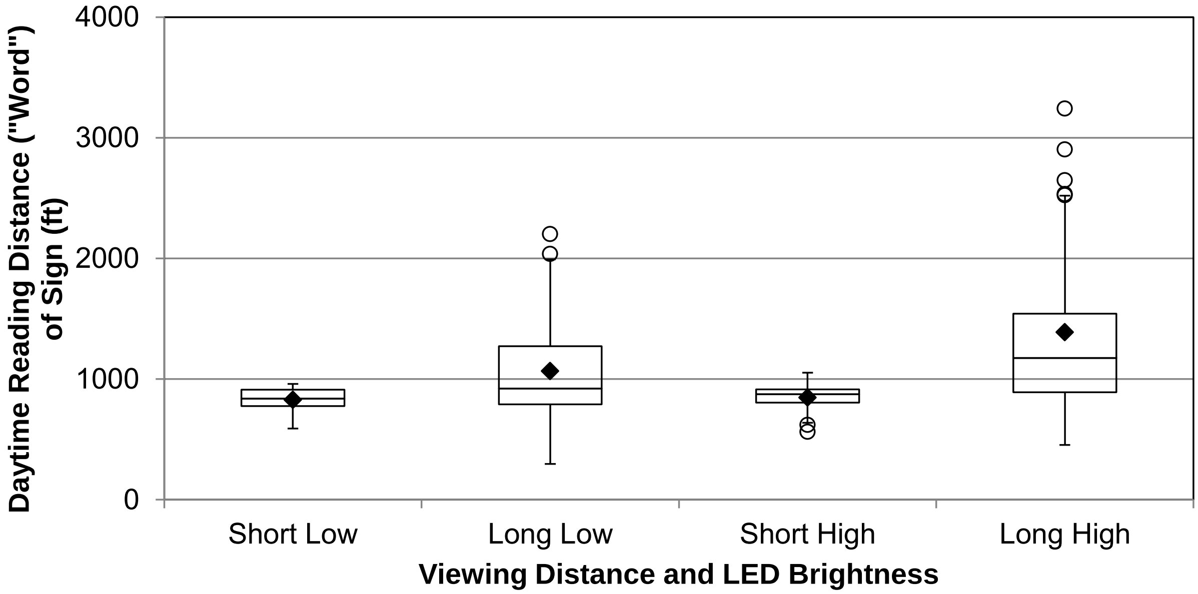
Does the Brightness of LED Lighting, and Sign Location, Affect "Word" Reading?

A 2 (LED brightness: Low/High) by 2 (viewing distance: short/long) repeated measures ANOVA was performed, with Age (Younger/Older) and Time (Day/Night) as between-subject factors. Results (see Table 98 and Figure 71) indicated a main effect of LED brightness on word reading, suggesting that the brighter LEDs aided participants reading of the sign wording. Additionally, a main effect of viewing distance was observed, suggesting that participants for the short viewing distance generally detected signs as soon as they were available. Additionally, neither Time (Day/Night) nor Age was significant. None of the two-way interactions were significant.

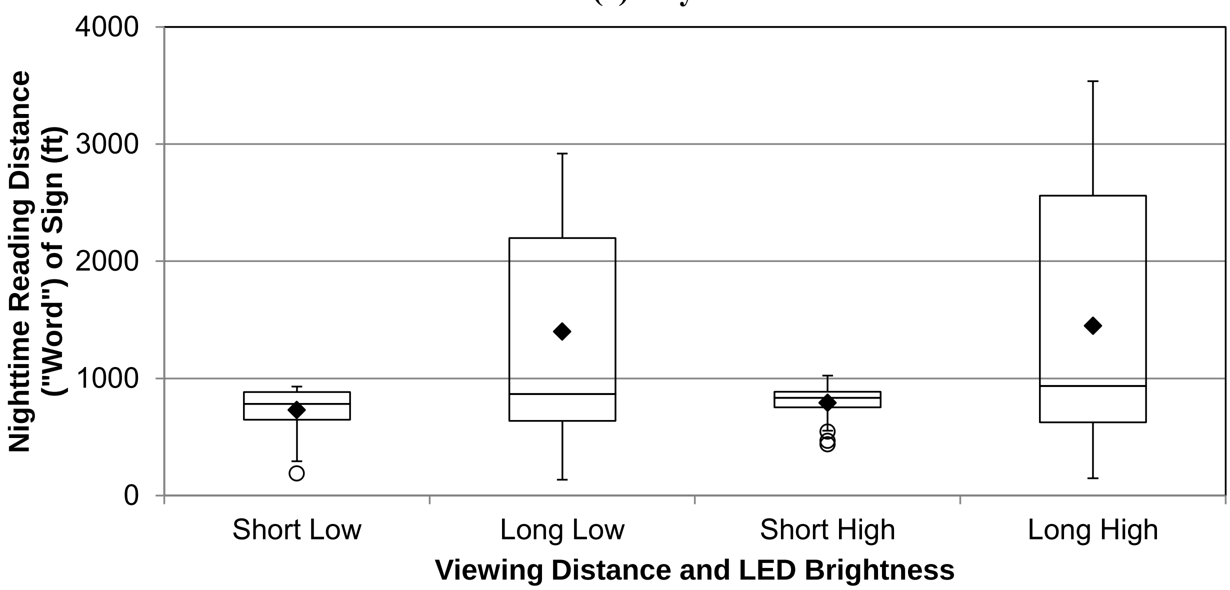
The three-way interaction for brightness was also significant for the "word" response similar to the "sign" response as discussed in the previous paragraphs. Participants were aided in reading the sign during the day with the bright LED lights. During the nighttime, the reading distance was similar. As illustrated in Figure 70, nighttime low setting had a mean reading distance of 1091 ft, while the high setting had a longer reading distance of 1418 ft. During the nighttime, both the low and high setting had mean detection distance of about 1550 ft. Thus, adjustments in the light level of LEDs influenced whether or not participants could read past the LEDs to the words during the day. During the daytime, this was optimally achieved with bright LEDs.

Table 98. Statistics for "Does the Brightness of LED Lighting, and Sign Location, Affect "Word" Reading?" Question.

Comparison	F-statistics	Significant?
Viewing Distance (Short/Long)	$F(1,64) = 38.0$, $p < 0.001$	Yes
LED Brightness (Low/High)	$F(1,64) = 5.23$, $p < 0.05$	Yes
Time (Day/Night)	$F(1,64) = 0.393$, $p > 0.05$	No
Age (Young/Old)	$F(1,64) = 1.54$, $p > 0.05$	No
Viewing Distance (Short/Long) × Time (Day/Night)	$F(1,64) = 2.56$, $p > 0.05$	No
Viewing Distance (Short/Long) × Age (Young/Old)	$F(1,64) = 2.21$, $p > 0.05$	No
LED Brightness (Low/High) × Time (Day/Night)	$F(1,64) = 1.39$, $p > 0.05$	No
LED Brightness (Low/High) × Age (Young/Old)	$F(1,64) = 0.842$, $p > 0.05$	No
Time (Day/Night) × Age (Young/Old)	$F(1,64) = 0.280$, $p > 0.05$	No
LED Brightness (Low/High) × Viewing Distance (Short/Long) × Time (Day/Night)	$F(1,64) = 1.63$, $p < 0.001$	Yes



(a) Day



(b) Night

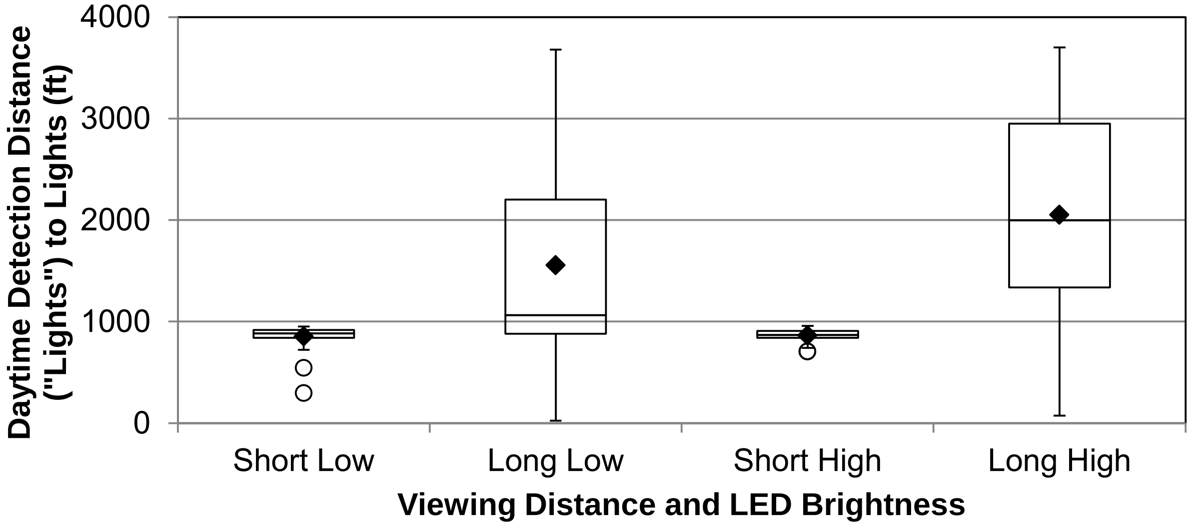
Figure 71. Box Plot for "Does the Brightness of LED Lighting, and Sign Location, Affect "Word" Reading?" Question.

Does the Brightness of LED Lighting, and Sign Location, Affect the Detection of "Lights"?

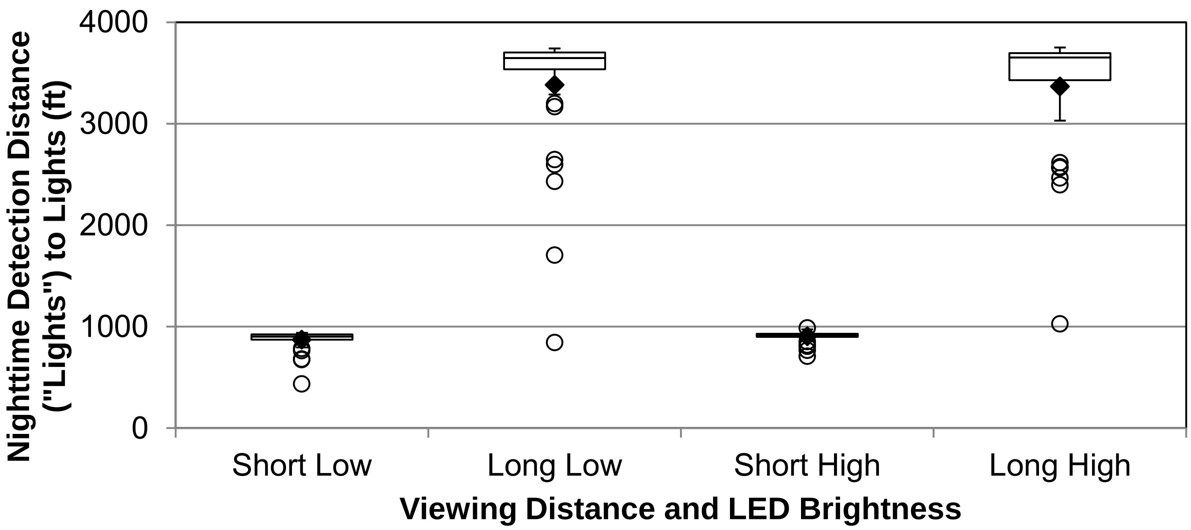
A 2 (LED brightness: Low/High) by 2 (Viewing Distance: Short/Long) repeated measures ANOVA was performed, with Age (Younger/Older) and Time (Day/Night) as between-subject factors. Results (see Table 99 and Figure 72) indicated a main effect of LED brightness on light detection, suggesting that the brighter LEDs aided participants in noticing lights. Additionally, a main effect of viewing distance was observed, suggesting that for short viewing distances, participants generally detected lights as soon as they were available. Additionally, the between-subject factor Time (Day/Night) was significant, but Age (Younger/Older) was not. Not surprisingly, participants were better able to detect the presence of lights during the night. Of note was a significant interaction between LED brightness level (Low/High) and Time (Day/Night) which indicated that participants were better able to see the low lights during the night than the day. Also noteworthy was the interaction between Viewing Distance (Short/Long) and Time (Day/Night), which suggested that in the maximum viewing distance locations, participants were better able to see the lights at night than during the day. All other 2-way interactions were not significant.

Table 99. Statistics for "Does the Brightness of LED Lighting, and Sign Location, Affect the Detection of "Lights"?" Question.

Comparison	F-statistics	Significant?
Viewing Distance (Short/Long)	$F(1,59) = 255$, $p < 0.001$	Yes
LED Brightness (Low/High)	$F(1,59) = 11.5$, $p > 0.001$	Yes
Time (Day/Night)	$F(1,59) = 53.1$, $p < 0.001$	Yes
Age (Young/Old)	$F(1,59) = 1.11$, $p > 0.05$	No
Viewing Distance (Short/Long) × Time (Day/Night)	$F(1,59) = 52.9$, $p < 0.001$	Yes
Viewing Distance (Short/Long) × Age (Young/Old)	$F(1,59) = 1.14$, $p > 0.05$	No
LED Brightness (Low/High) × Time (Day/Night)	$F(1,59) = 10.1$, $p < 0.01$	Yes
LED Brightness (Low/High) ×Age (Young/Old)	$F(1,59) = 2.65$, $p > 0.05$	No
Time (Day/Night) × Age (Young/Old)	$F(1,59) = 0.016$, $p > 0.05$	No



(a) Day

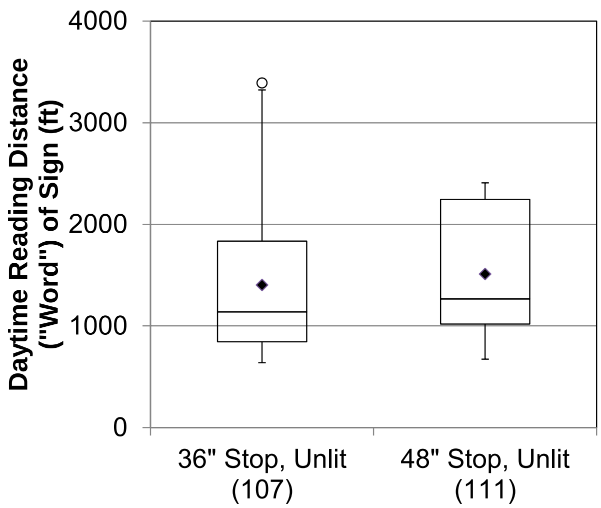


(b) Night

Figure 72. Box Plot for "Does the Brightness of LED Lighting, and Sign Location, Affect the Detection of 'Lights'?" Question.

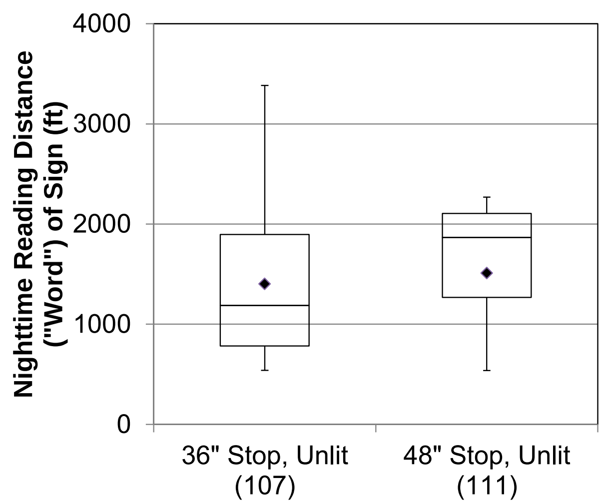
Is the Stop Sign Legibility Distance Affected by Sign Size?

To address the sign size question a 2-factor (signs: 107, 111), 1-way, repeated measures ANOVA was performed, with age (young/old) and time (day/night) as between-subject factors. Not surprisingly, wording on the larger sign was legible earlier than wording on the smaller sign (see Figure 73). However, general sign legibility did not differ as a function of night/day, and neither did it differ as a function of age. None of the 2-way interactions was significant. In summary, while the size of the Stop sign, whether 36-in. or 48-in., had a general effect on legibility, it did not interact with either the age of the participants in this research, or the daytime/nighttime lighting conditions.



36-in. Stop: M = 1396 ft, SE = 775
48-in. Stop: M = 1510 ft, SE = 618

(a) Day



36-in. Stop: M = 1382 ft, SE = 700
48-in. Stop: M = 1691 ft, SE = 543

(b) Night

Figure 73. Box Plot for "Is the Stop Sign Legibility Distance Affected by Sign Size?" Question.

Table 100. Statistics for "Is the Stop Sign Legibility Distance Affected by Sign Size?" Question.

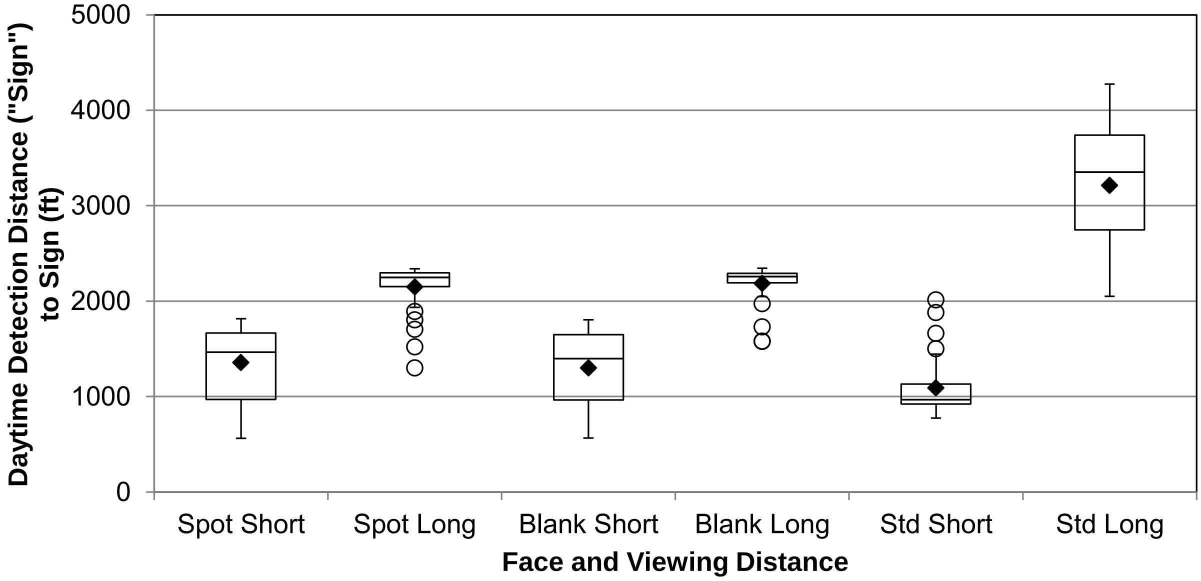
Comparison	F-statistics	Significant?
Sign Groups	$F(1,58) = 6.20, p < 0.05$	Yes
Time (Day/Night)	$F(1,58) = 0.287, p > 0.05$	No
Age (Young/Old)	$F(1,58) = 0.196, p > 0.05$	No
Sign Groups × Time (Day/Night)	$F(1,58) = 1.17, p > 0.05$	No
Sign Groups × Age (Young/Old)	$F(1,58) = 0.023, p > 0.05$	No
Time (Day/Night) × Age (Young/Old)	$F(1,58) = 0.135, p > 0.05$	No

Does the Wording, or Lack of Wording, on a Stop Sign Affect Detection Distance?

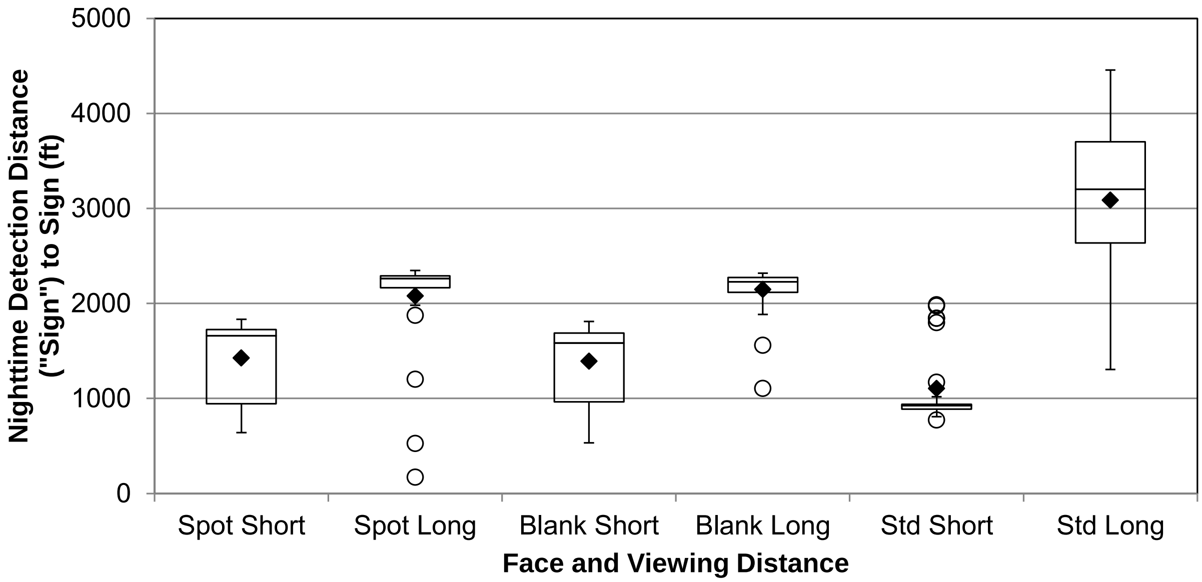
A 2 (Face: Spot/Blank) by 2 (Viewing Distance: Short/Long) repeated measures ANOVA was performed, with Age (Younger/Older) and Time (Day/Night) as between-subject factors. Results (see Table 101 and Figure 74) indicated a non-significant effect of the presence of a word on the sign face (spot/blank) on sign detection distance but a significant effect of viewing distance on detection distance. Given the general differences in available viewing distance of each location, this was not surprising. The between-subject factors of Time (Day/Night) and Age (Young/Old) were also not significant. However, the Viewing Distance of the signs did significantly interact with the age of the participants, but this interaction was weak, somewhat counterintuitive, and not likely reliable. None of the other interaction terms were significant.

Table 101. Statistics for "Does the Wording, or Lack of Wording, on a Stop Sign Affect Detection Distance?" Question.

Comparison	F-statistics	Significant?
Face (Spot/Blank)	$F(1,54) = 0.006$, $p > 0.05$	No
Viewing Distance (Short/Long)	$F(1,54) = 350$, $p < 0.001$	Yes
Time (Day/Night)	$F(1,54) = 0.009$, $p > 0.05$	No
Age (Young/Old)	$F(1,54) = 0.083$, $p > 0.05$	No
Face (Spot/Blank) × Time (Day/Night)	$F(1,54) = 0.119$, $p > 0.05$	No
Face (Spot/Blank) × Age (Young/Old)	$F(1,54) = 0.721$, $p > 0.05$	No
Viewing Distance (Short/Long) × Time (Day/Night)	$F(1,54) = 2.15$, $p > 0.05$	No
Viewing Distance (Short/Long) × Age (Young/Old)	$F(1,54) = 4.42$, $p < 0.05$	Yes
Time (Day/Night) × Age (Young/Old)	$F(1,54) = 1.07$, $p > 0.05$	No



(a) Day



(b) Night

Figure 74. Box Plot for "Does the Wording, or Lack of Wording, on a Stop Sign Affect Detection Distance?" (36-in. Standard Stop Signs Are Included for Comparison) Question.

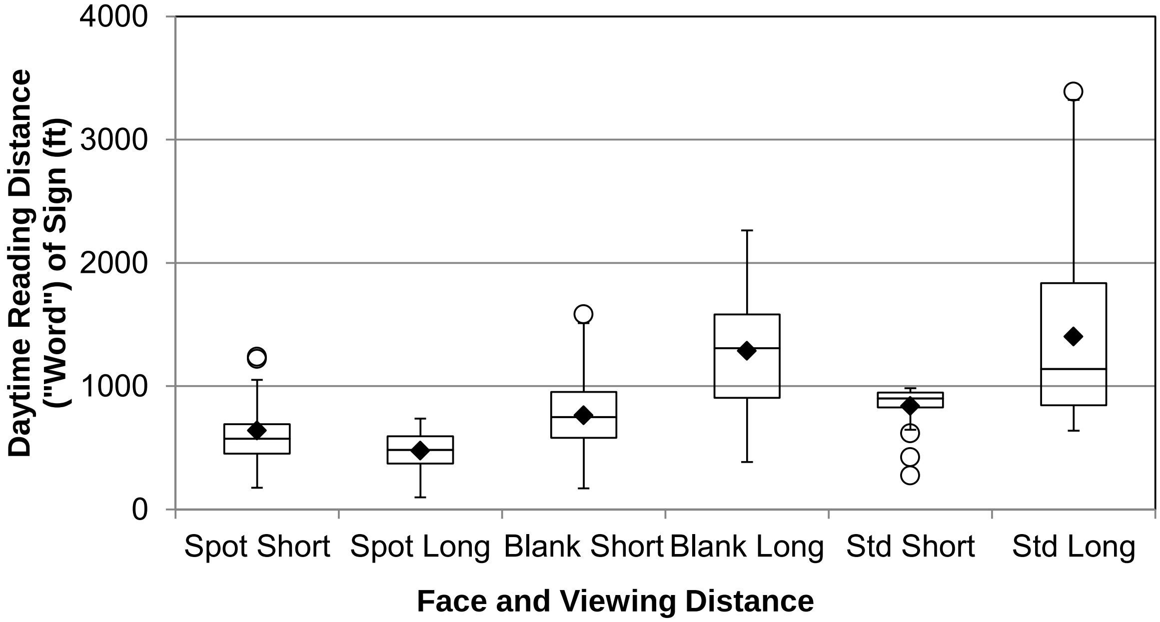
Does the Wording, or Lack of Wording, Affect the Word Reading Distance?

A 2 (Face: Spot/Blank) by 2 (Viewing Distance: Short/Long) repeated measures ANOVA was performed, with Age (Younger/Older) and Time (Day/Night) as between-subject factors. Results (see Table 102 and Figure 75) indicated that lettering on the sign face affected the distance at which participants claimed they could read the words on the sign (Spot/blank). No effect of viewing distance on reading distance was observed. The between-subjects factors of Time (Day/Night) and Age (Young/Old) were significant, suggesting that participants could "read" the signs earlier during the day, and that younger participants could also "read" the signs earlier than older participants. The Face (Spot/Blank) by time of day interaction was also significant; however, none of the other two-way interaction terms was significant.

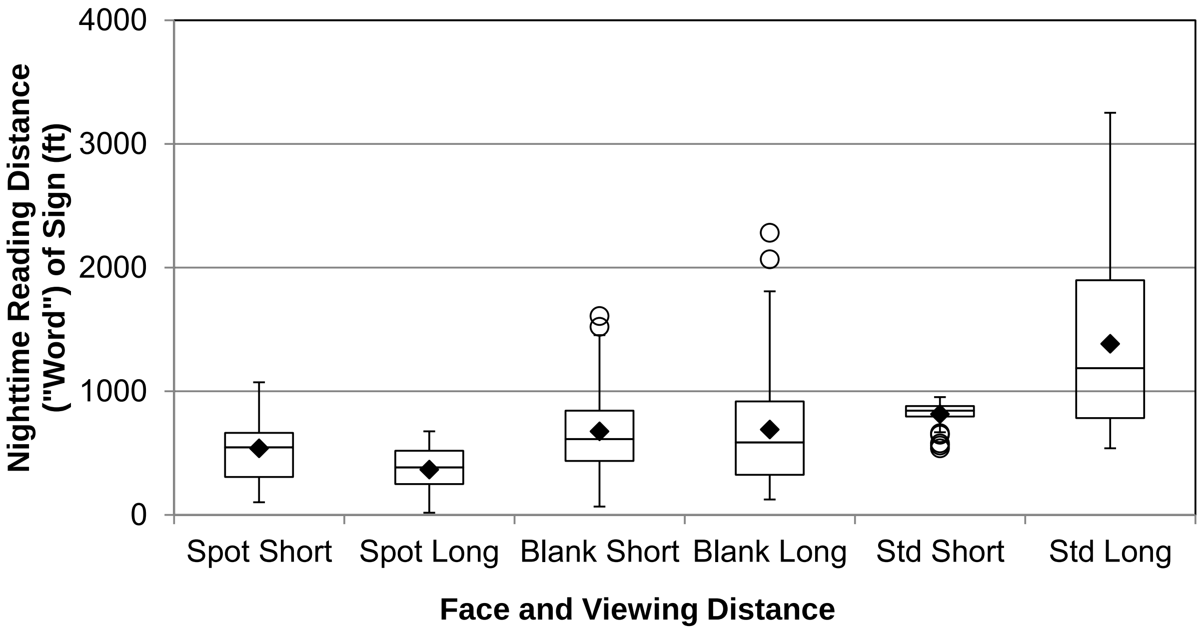
The differences between the sign detection distance and the word identification are shown in Figure 76 for daytime and nighttime performance. These figures highlight the fact that for the "trick" signs the detection distance was still quite long, which confirms that the color, shape, and white border of a Stop sign are key to its detections. These data are only for those participants who correctly identified spot (rather than saying stop).

Table 102. Statistics for "Does the Wording, or Lack of Wording, Affect the Word Reading Distance?" Question.

Comparison	F-statistics	Significant?
Face (Spot/Blank)	$F(1,22) = 28.9, p < 0.001$	Yes
Viewing Distance (Short/Long)	$F(1,22) = 0.536, p > 0.05$	No
Time (Day/Night)	$F(1,22) = 7.27, p < 0.05$	Yes
Age (Young/Old)	$F(1,22) = 5.21, p < 0.05$	Yes
Face (Spot/Blank) × Time (Day/Night)	$F(1,22) = 6.16, p < 0.05$	Yes
Face (Spot/Blank) × Age (Young/Old)	$F(1,22) = 0.212, p > 0.05$	No
Viewing Distance (Short/Long) × Time (Day/Night)	$F(1,22) = 1.44, p > 0.05$	No
Viewing Distance (Short/Long) × Age (Young/Old)	$F(1,22) = 2.27, p > 0.05$	No
Time (Day/Night) × Age (Young/Old)	$F(1,22) = 4.32, p > 0.05$	No

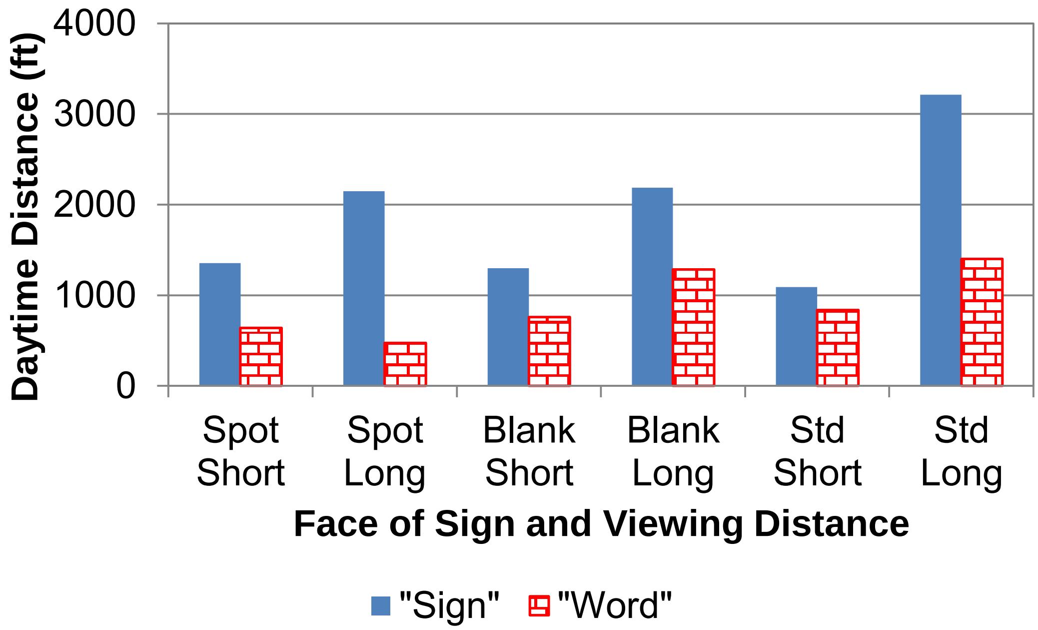


(a) Day

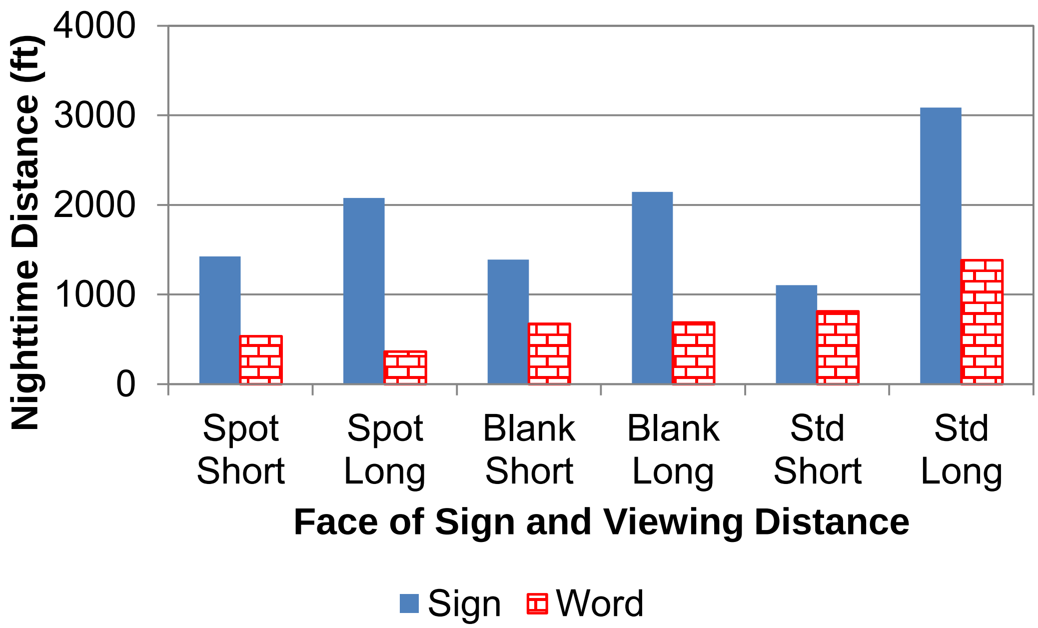


(b) Night

Figure 75. Box Plot for "Does the Wording, or Lack of Wording, Affect the Word Reading Distance?" (36-in. Standard Stop Signs Are Included for Comparison) Question.



(a) Day

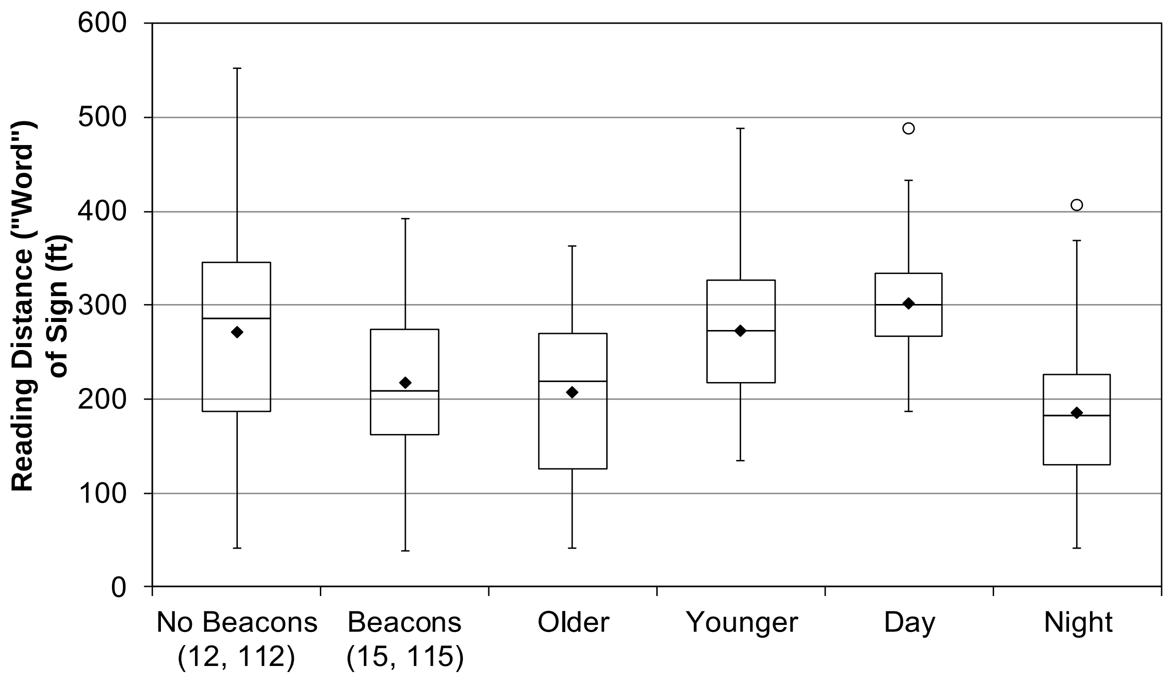


(b) Night

Figure 76. Detection and Legibility Distances by Time of Day for Spot, Blank, and Standard Stop Signs.

Does the Presence of Beacons Affect the Distance Used to Read a Sign (Other than a Stop Sign)?

To address this question a 6-factor (Beacons/No Beacons, Young/Old, Day Night), 3-way, repeated measures ANOVA was performed, with Age (Young/Old) and Time (Day/Night) as between-subject factors. Results showed that when top/bottom beacons were used, the average distance at which the wording of the signs could be read was reduced (see Figure 77 and Table 103), thus indicating that the addition of beacons reduced the ability of participants to read the signs (e.g., mean legibility distance of 288 ft for no beacon compared to 214 ft with beacons). Results also indicated that participants had to be closer to the signs to read them at night than during the day (nighttime mean of 200 ft compared to daytime mean of 299 ft), and that older participants had to be closer than younger participants to read the signs (older mean of 225 ft compared to younger mean of 274 ft). The interaction between Beacons and Time was also significant, suggesting that the detrimental effect of beacons on reading the words on a sign was somewhat lessened during the night than during the day. Other interactions were not significant.



No beacons:
M = 288 ft, SE = 9.1
With beacons:
M = 214 ft, SE = 8.8

Older:
M = 225 ft, SE = 11.5
Younger:
M = 274 ft, SE = 10.2

Day:
M = 299 ft, SE = 10.6
Night:
M = 200 ft, SE = 11.0

Figure 77. Box Plot for "Does the Presence of Beacons Affect the Distance Used to Read a Sign (Other than a Stop Sign)?" Question.

Table 103. Statistics for "Does the Presence of Beacons Affect the Distance Used to Read a Sign (Other than a Stop Sign)?" Question.

Comparison	F-statistics	Significant?
Beacons (No/With)	$F(1,57) = 60.4, p < 0.001$	Yes
Time (Day/Night)	$F(1,57) = 41.5, p < 0.001$	Yes
Age (Young/Old)	$F(1,57) = 10.1, p < 0.01$	Yes
Beacons (No/With) × Time (Day/Night)	$F(1,57) = 6.52, p < 0.05$	Yes
Beacons (No/With) × Age (Young/Old)	$F(1,57) = 0.357, p > 0.05$	No
Age (Young/Old) × Time (Day/Night)	$F(1,57) = 0.186, p > 0.05$	No

Accuracy

Table 104 shows the number of participants who responded "light," "sign," or read the words for a subset of signs. The signs included in this table were incorrectly identified or incorrectly read by at least one participant. Atypical signs, such as "SPOT" and "48 mph" had the highest rates of incorrect identification.

Table 104. Percent of Participants Who Incorrectly Identified Sign or Legend/Words on Sign.

Sign	Number of Participants Saying "Light"	Number of Participants Saying "Sign"	Number of Participants Correctly Saying Words	Number of Participants Incorrectly Saying Words	Percent Incorrect of Those Saying "Sign"
36 in. SPOT	NA	127	93	71	56
48 mph	NA	67	62	29	43
42 mph	NA	68	66	24	35
36 in. Blank	NA	130	120	23	18
ROUGH ROAD w/ Beacon	68	58	56	6	10
SOFT SHOULDER	NA	65	62	3	5
45 mph	NA	133	128	5	4
LOOSE GRAVEL w/beacon	68	61	59	2	3
CHURCH	NA	66	63	2	3
ROUGH ROAD	NA	67	66	2	3
35 mph	NA	135	129	4	3
Stop Ahead	NA	261	258	7	3
LOOSE GRAVEL	NA	68	68	1	1
NA = not applicable.					

Post-Drive Preference Ratings

Table 105 displays the results of the post-drive survey. Subjects were instructed to base their preference on which sign in each pair they believed to be most effective at rural intersections. In this computer survey, participants preferred Stop signs with vertical beacons over Stop signs with horizontal beacons.

Table 105. Subjects' Post-Drive Sign Preference Survey Responses.

Question	Stop Sign Type	Number	Percentage
1	**Alternating Horizontal Beacons**	**69**	**97**
	Standard Stop	2	3
2	Embedded Flashing LEDs	10	14
	Alternating Vertical Beacons	**61**	**86**
3	**Alternating Horizontal Beacons**	**60**	**86**
	Embedded Flashing LEDs	10	14
4	Alternating Horizontal Beacons	19	28
	Alternating Vertical Beacons	**52**	**72**
5	Standard Stop	5	7
	Embedded Flashing LEDs	**66**	**93**
6	Standard Stop	6	9
	Alternating Vertical Beacons	**65**	**91**

DISCUSSION

This closed-course field study demonstrated the trade-off between conspicuity and legibility. Due to sight distance limitations for some of the sign locations, it was not possible to compare performance across all sign types. Lighting, whether provided through flashing beacons or perimeter LEDs, may improve conspicuity and alert drivers to the presence of some object in the roadway they should attend to. Sign recognition and legibility, however, are not always enhanced and in some cases actually hurt by the presence of lights. Policy regarding use should weigh the advantages and disadvantages of conspicuity and legibility.

Key findings from the closed-course study are as follows:

- While the reading distance to some of the Stop sign installations was significantly longer than to others, the reading distance for all Stop sign installations tested in this study were very long. The average reading distance for all Stop sign installations exceeded the SSD for 75 mph. For several of the Stop sign installations, all of the participants read the words on the Stop sign at a distance greater than the SSD.
- Participants were generally better at reading the wording on standard Stop signs than illuminated Stop signs; however, the position of the standard Stop signs may have heavily influenced this result.
- When Stop signs with beacons are compared to Stop signs with LEDs, the only difference in detection distance was identified for the 48-in. stop with overhead beacons when compared to 36-in. stop with overhead beacons, the 36-in. stop with clusters, and

the 36-in. Stop with vertical beacons. In other words, the 36-in. Stop signs with beacons and with LEDs all have similar legibility distances.

- All other things being equal, larger Stop signs were easier to read than smaller Stop signs.
- Participants detected Stop signs with brighter LEDs better during the day but detected Stop signs with dimmer LEDs better during the night. Increased glare from the brighter LEDs during the night may have obscured the sign.
- The addition of beacons made it more difficult for participants to read the lettering on a sign with words ("loose gravel" and "rough road" in this study). This effect did not interact with age.
- The detection for signs with the same shape as a Stop sign but with SPOT rather than STOP on the sign or with no words on the sign, showed average detection distances of greater than 2000 ft. These results demonstrate the importance of the shape, color, and border for sign detection. The majority (56 percent) of drivers did not notice the misspelled Stop message when asked to read the sign, which provides evidence that drivers may not actually read the word on a Stop sign, but rather rely on color and shape for sign identification.

CHAPTER 7

GUIDANCE FOR SELECTING TRAFFIC CONTROL DEVICE TREATMENTS FOR A RURAL STOP-CONTROLLED INTERSECTION

One of the objectives of this study was to identify a procedure or an order of escalation of enhancements to Stop signs. Following is a brief summary of the relevant literature and the TxDOT survey conducted within this research. The final section of this chapter presents principles to consider when selecting a treatment for a rural stop-controlled intersection.

SUMMARY OF PREVIOUS STUDIES

In a study on nighttime crashes (*28*), the authors reported on the progressive approach used by Pierce County, Washington. Pierce County recommends that the least aggressive approach should be considered first in addressing crash problems at rural intersections according to the following ascending order of invasiveness:

- Install Stop Ahead signs.
- Increase the size of Stop and Stop Ahead signs.
- Install transverse rumble strips.
- Install overhead flashing beacon with illumination.

Forbes and Garvey (*41*) examined whether LED-embedded traffic signs are appropriate for use on Canadian roadways. They suggested the following implementation order (additional guidance on these treatments are included in Table 3):

A. Increase the size of the sign.
B. Provide a more reflective sign sheeting.
C. Post an additional (left-side mounted) sign.
D. Post a Stop Ahead warning sign.
E. Add "STOP AHEAD" pavement markings.
F. Add transverse rumble strips.
G. Add a flashing beacon.
H. Embed LEDs in the border of the sign.

Others (*42, 43, 44*) have discussed the need to first determine the type of conditions located at the rural intersection, for example the number of approaches and the crash characteristics. A 2009 paper by Hochstein et al. (*40*) on rural expressway intersections categorized intersection safety treatments into three groups:

- Conflict point management—treatments that remove/reduce, relocate, and/or control the 42 conflict points which occur at a traditional two-way, stop-controlled rural expressway intersection.
- Gap selection aids—countermeasures intended to aid a driver in selecting a safe gap into or through the expressway traffic stream.
- Intersection recognition devices—countermeasures intended to enhance intersection conspicuity for either minor road or expressway drivers.

TXDOT PRACTICES

As part of this research project, a survey of TxDOT personnel was conducted to identify the treatments and the sequence of treatments being used at rural stop-controlled intersections. While one district used as few as three treatments for improving Stop signs, another district used as many as six different treatments. Clearly some districts were willing to try different treatments to improve the effectiveness of the Stop sign and the Intersection Ahead sign. Additional information regarding the survey is available in Chapter 4.

There was clear difference between some districts regarding their selection of enhancements to the Stop sign. For example, one district uses oversized Stop signs in very high proportion, while another uses two vertical beacons as the predominant Stop sign treatment. The predominant treatments for Stop signs in Texas are:

- Oversized signs.
- Two vertical beacons.
- An intersection overhead beacon.

Beacons and LEDs on signs improve their attention value. The beacons are either a single beacon or two beacons either in a horizontal arrangement or a vertical arrangement. Beacons and LEDs can either be steadily on, or they can be flashing either in a simultaneous fashion or an alternating fashion. The districts appear to be fairly consistent in the application and operations of these beacons and LEDs. None of the districts were operating the beacon in a steady On manner. The beacon operation by TxDOT districts is summarized below.

- In single beacon installation, the beacon flashes continuously.
- When two beacons are arranged horizontally, the beacons flash simultaneously.
- When two beacons are arranged vertically, the beacons flash alternately.
- When LEDs are embedded in the sign, LEDs flash simultaneously.

PRINCIPLES TO CONSIDER WHEN TRANSITIONING BETWEEN TREATMENTS

Traffic engineers enhance treatments at a rural intersection usually in response to either accidents or observations of undesirable conditions. Engineers need to weigh various factors in order to select the treatment to install. Primary among them is the expected effectiveness of the TCD to be installed and the cost of the TCD both for installation (capital cost) and maintenance.

Several factors need to be considered in the selection of the appropriate traffic control devices to enhance safety at rural intersections. Following are suggested principles for consideration in determining the order of selection for a treatment:

- **Select treatment to address conditions at the site.** Consider any geometric design issues (e.g., sight distance to crossing roadway or sign) as well as crash patterns associated with the intersection. For example, if the crash data show that many crashes are due to failure to stop, then improvements to the Stop sign may be needed to improve conspicuity and/or attention conspicuity (i.e., to alert a driver who may not be actively looking for a sign). If the problem is related to merging or crossing (e.g., a large percentage of angle crashes that occur after the minor road driver had come to a complete stop), then changes to the Stop sign may not improve safety.

- **Select treatment that is best suited to the visual environment.** Consider a treatment's visual performance characteristics in relation to the approach distance to the intersection; for an intersection with a short sight distance, for instance, a treatment that is intended to provide long-distance visibility would be a waste of resources. Also consider the Stop sign's visual background; if the sign is obscured because of terrain or other visual clutter, moving the sign's mounting position may improve conspicuity better than other improvements.
- **Review the available evidence on treatment effectiveness.** The state-of-knowledge on any particular device or treatment is constantly evolving, and the practitioner should become familiar with the most up-to-date information to make informed decisions. The *Highway Safety Manual* (*51*) or the Texas *Roadway Safety Design Workbook* (*50*) can be consulted for information on crash evaluation. Because the HSM is a static document, FHWA sponsors the CMF Clearinghouse website (*54*) to provide the most current information available. The CMF clearinghouse is continuously updating crash modification factors as new research is available.
- **Conform to local policies and practices.** If an established policy or practice is used within a jurisdiction, then conformance to that practice is an important step in meeting driver expectations.
- **Use traffic control devices with beacons or LEDs sparingly.** Stop signs with beacons or LEDs offer increased conspicuity over static signs; however, due to the potential for distraction and decreasing the effectiveness of similar static signs, use of signs with beacons or LEDs should be limited. One of the reasons that they are effective in capturing driver attention is that they are used sparingly. Widespread use within a jurisdiction will diminish the ability of Stop signs with beacons or LEDs to capture driver attention. It is essential that their use be strictly managed through sound engineering and rational decision making. Stop signs with beacons or LEDs could be considered where:
    - Stop sign is not expected or where driver attention is not directed toward a critical sign.
    - Locations with sign visibility limitations (e.g., horizontal curves, dusk/dawn glare, etc.).
    - Locations with documented problems of drivers failing to recognize an intersection.
    - Crashes resulting from failure to observe a traffic control device.

The closed-course field study found that Stop signs with beacons or LEDs were detected at long distances. Note however, that just because the beacons and LEDs enhanced signs were detected at a greater distance, they may not be advantageous if the detection draws the attention of the driver away from other critical elements, such as driveways located prior to the cross street. In all cases within the closed-course field study, a Stop sign with any type of supplemental illumination had detection distances of more than 820 ft (SSD for 75 mph). Another consideration is whether there is the possibility that a driver may misinterpret whether the cross street has yellow or red beacons. Minnesota DOT (*28*) is replacing overhead flashing beacons with red flashing beacons mounted on the minor road Stop sign and a yellow flashing beacon mounted on the major road warning sign to address this concern.

- **Choose lower cost option**. Both capital and operating costs of the selected option should be a factor in selecting the treatment. The cost of system installation varies from place to place. For treatments that require either beacons or LEDs, availability of a power source is a critical factor. Some TxDOT districts have electricity available in close proximity to the treatments. However, at some remote locations, solar power is the only solution, adding to the capital cost of the treatment. Some districts are very widespread compared to others. Any treatment that requires regular maintenance visits increases maintenance costs. Reasons for visiting the site can range from typical cleaning and maintenance visits to response to vandalism. Vandalism increases costs due to replacement of signs or support equipment.

Once a concern with a rural intersection is identified, traffic engineers install the treatment that best satisfies the above principles and assess the performance to determine whether the issue has been resolved. If the issue is unresolved, then another solution is employed and the assessment is conducted again. This iterative approach is repeated until the concern is resolved.

CHAPTER 8

SUMMARY AND CONCLUSIONS

SUMMARY OF RESEARCH

The goal of this project is to obtain a better understanding of the effectiveness of modern traffic control devices for rural intersections. TTI researchers conducted a literature review of the effectiveness of various improvements to traffic control devices at rural stop-controlled intersections. They also conducted a study of the Texas crash characteristics for this type of intersection. A survey of TxDOT engineers provided insight about their policies and experiences in the use of various traffic control devices at rural intersections. Finally, studies on visibility were conducted in a visibility laboratory and at a closed-course facility at Riverside campus of Texas A&M University. The findings from these efforts were considered when developing guidance material on selecting traffic control device treatments for a rural stop-controlled intersection.

Following is an overview of the research approach and the key findings for the major research efforts within this project.

Literature Review

Overview

The initial task in the project was to gather information from various sources to establish the state-of-the-knowledge on traffic control device alternatives for rural stop-controlled intersections. Several TCD alternatives are available and are being used at rural stop-controlled intersections to improve safety at these intersections.

Findings

Key findings from the literature review are:

- Recently developed methods and documents on predicting crashes include the *Highway Safety Manual* (*51*), the Texas *Roadway Safety Design Workbook* (*50*), and the CMF Clearinghouse (*54*). NCHRP Report 500 Volume 5 provides a range of strategies for unsignalized intersection collisions (*37*).
- Forbes and Garvey (*41*) examined whether LED-embedded traffic signs are appropriate for use on Canadian roadways. One of their conclusions is that while LED-embedded traffic signs offer increased conspicuity over static signs, due to their potential to be distracting and the potential for decrease in effectiveness of similar static signs, the use of LED-embedded traffic sign should be limited.
- A 2008 FHWA study conducted an evaluation of the traffic safety effects of increasing the retroreflectivity of Stop signs, using before-after data from South Carolina and Connecticut (2). The aggregate analysis indicated that higher retroreflectivity may affect the likelihood of crashes at unsignalized intersections, but the effect was not detectable

with the study design and available sample size. The disaggregate analysis concluded that installations at all three-leg intersections had a statistically significant reduction in crashes. The disaggregate analysis also showed that the strategy is more effective at lower traffic volumes for motorists approaching the intersection on the minor road.

- A 2008 FHWA before-after study using data collected in Arkansas, Maryland, and Minnesota evaluated the effectiveness of STOP AHEAD pavement markings (*18*). The results showed a total crash reduction of at least 15 percent with the installation of STOP AHEAD pavement markings. The study concluded that installation of STOP AHEAD pavement markings has the potential to reduce crashes cost effectively, particularly at three-leg and all-way stop-controlled intersections with high crash frequency.
- Harwood in 1993 (*20*) reported that rumble strips placed on intersection approaches can provide a reduction of at least 50 percent in the types of crashes most susceptible to correction, including crashes involving running through a Stop sign.
- A 2008 FHWA study (*23*) explored two concepts to reduce speed and improve safety at rural two-lane roadways with two-way stop-controlled intersections:
    - Concept 1: Rumble strips on outside shoulders and in a painted yellow median island on the major road approaches (see Figure 9).
    - Concept 2: Channelizing separator islands on side road approaches with supplemental Stop signs (see Figure 10).

  The general conclusion from the research was installation of either concept can provide positive operational and safety effects. The authors found a general reduction in crashes associated with the implementation of either concept based on limited after data. For the lane-narrowing concept (Concept 1), total, fatal/injury, and angle crashes decreased in the after period, but rear-end crashes increased at some sites. For the minor road splitter-island concept (Concept 2), the crash rate decreased for all categories in the after period.
- A recent FHWA study (2007) evaluated the safety effectiveness of flashing beacons at stop-controlled intersections (*29*). Three types of flashing beacons—intersection control beacons, beacons mounted on Stop signs, and actuated beacons—were considered collectively at stop-controlled intersections. Although these could be considered three distinct safety strategies with different expected performance, due to sample size limitations, they were analyzed collectively in the study. The study included 64 sites in North Carolina and 42 sites in South Carolina. For the combined results, the following estimates of reduction in crashes per site-year was found to be statistically significant:
    - 21 percent angle.
    - 15 percent injury and fatal.

  The disaggregate analysis found:
    - Flashing beacons seem to be more effective at rural and suburban locations.
    - Beacon types include standard beacons where the beacon flashes all the time and actuated beacons. Some of the actuated flashers are supplemented with a sign that reads, "Vehicle Entering When Flashing." Standard beacons can be located overhead or on a Stop sign. There seems to be a significant reduction in crashes at sites with standard beacons mounted on Stop signs. However, only five sites belonged to this category, and so it was not possible to make definitive conclusions regarding beacon location.

Crash Study

Overview

The crash study investigated the characteristics of crashes at Texas rural stop-controlled intersections and the current knowledge regarding safety at this type of intersection. The review of the literature identified the following variables as important to include in a safety evaluation of rural stop-controlled intersections: major and minor road ADT, presence of turning lanes, number of driveways, presence of skew, median width, and presence of lighting.

Findings

To better identify appropriate treatments for Texas intersections, the research team reviewed the Texas crash data to identify characteristics of crashes at these intersections. Key findings regarding rural stop-controlled intersections with daily entering volume of less than 16,000 include the following:

- The majority of intersections had less than one intersection crash (intersection, intersection related, or driveway access) in six years.
- The presence of a horizontal curve on an approach resulted in an increase in crashes.
- The presence of a turn lane on an approach resulted in a decrease in crashes.
- The two most common types of crash were (a) one moving vehicle going straight and (b) angle crashes. These crash types represented about half of the crashes. When subdivided by number of legs on the approach, a slightly different pattern is revealed. Angle crashes are within the top two crash types for both three-leg and four-leg intersections; however, for four-leg intersections they represent 60 percent of crashes, while they represent only 14 percent of the crashes at three-leg intersections. For three-leg intersections, the most common crash type was one moving vehicle going straight (27 percent). A broader distribution of crash type existed at three-leg intersections with angle (straight/left) and same direction (straight/stopped), also representing more than 10 percent of the crashes.
- A code is available in the crash database for the variable "contributing factor" for about half of the drivers. When a contributing factor was selected, it typically involved failure to yield right-of-way/disregard for the traffic control device or speeding. Alcohol was cited for 3 percent of the drivers. A comparison of the distributions of contributing factors for four-leg and three-leg intersection showed that speed-related contributing factors were selected more often for three-leg intersections. For four-leg intersections, the speed-related contributing factors were selected for approximately 4 percent of the crashes as compared to 17 percent of the crashes at three-leg intersections.
- Almost a third of the crashes occurred during nighttime conditions at the three-leg intersections as compared to only 10 percent for the four-leg intersections.

In general for rural intersections in Texas with entering volumes of less than 16,000 vehicles per day this evaluation revealed different focus areas for three-leg and four-leg intersections.

For three-leg intersections, especially if one of the approaches has a horizontal curve, countermeasures that address the following are appropriate:

- Nighttime.
- Speeding.
- Single-vehicle crashes.

A general conclusion for the four-leg intersections is to identify countermeasures that focus on angle crashes with an emphasis on communicating to drivers the presence of the stop-controlled condition.

TxDOT District Survey to Expand Knowledge of Selected Traffic Control Device Alternatives

Overview

A survey evaluated the enhancements to the Stop signs and Intersection Ahead signs being used by TxDOT districts. The objective of the survey was to determine the treatments being used by TxDOT practitioners, their experiences in using those treatments, and their rationale for selection of the treatments. Responses were received from seven districts.

Findings

Districts appear to use the large (48 in.) Stop sign as the first treatment to improve safety at the intersection. However, if safety problems persist, they implement further improvements. For certain types of intersections, such as intersections with high-speed approaches, some districts implemented the Stop sign with flashing beacons as the first traffic control device enhancement. Stop signs with flags are rarely used as a permanent improvement. However, one district routinely uses flags on new installations of Stop signs. Some districts use Stop signs with reflective tape. There are very few intersections using two Stop signs. Districts have used two Stop signs more often to mitigate unique geometric conditions than to specifically improve safety. The districts believe that the use of beacons has definitely improved intersection safety. Districts tend to prefer to use beacons in a vertical arrangement rather than the horizontal arrangement. Concerns with vandalism to the lower beacon in a vertical arrangement were expressed by some of the survey participants.

Intersection Ahead signs are being used to improve safety on high-speed approaches. Sometimes beacons are used with these signs to improve intersection visibility. The beacons flash in the same pattern as the beacons at the Stop sign.

Cost of the sign assemblies was a concern when solar panels are used. Some districts have started to use Stop signs with embedded LEDs. Use of solar panels has been adopted by some districts when power is not closely available. Electricity is used when a power source is easily available because the start-up cost for solar power is more expensive.

Lab Study to Identify Driver Reaction to Traffic Control Devices with LEDs or Beacons

Overview

The laboratory study provided a cost-effective approach to test many variations of sign design variables in order to narrow which signs to use for the closed-course study. The study was conducted in a 125-ft tunnel-shaped facility. The walls, ceiling, and floor are covered by black non-reflective material to create a pitch black environment to simulate nighttime conditions. For the purpose of this study, at one end of the long room, a flat screen monitor was placed on a table and was connected to a laptop computer at the other end. Images of traffic signs generated on the laptop were displayed on the flat screen monitor. The experiment-running software presented photographs, video clips, and/or text for a set amount of time and the participant's response time was measured. The study obtained response time or answers to the following:

- Are Stop sign sizes the same or different? In some cases the signs were the same size and in other they were different sizes. Also, some of the comparisons included signs with LED lights with different flash rates.
- Response time to shape, color, type recognition for white versus yellow colored lights or Stop signs with beacons. For some of the response time questions, the participants were asked to provide the sign's shape, color, and type or legend after indicating they could identify the sign.

The study was conducted so that participants viewed signs sometimes directly (looking straight ahead) and sometimes peripherally. Due to randomization by the survey software, the event order varied for each participant. The study ended with questions to gather opinions on the use of flashing Stop signs.

Findings

The initial questions asked in the lab study were whether flashing lights affected sign size perception. Participants perceived the lighted signs to be smaller than unlighted signs in 20 percent of the cases. For static unlighted signs, previous studies have shown a direct correlation between size of sign and detection distance. This is why many agencies consider upsizing a sign as a means to increase conspicuity. It may be the case that in the field, the added visibility distance provided by the lights compensates for a reduction in perceived size. This question was carried over to the closed-course study for direct comparisons of lighted and unlighted signs in terms of sign detection and recognition.

The second section in the lab study was whether the color of the embedded lights affected sign perception. The results indicated that the response time to signs without lights was significantly shorter (i.e., faster) than to signs with either white or colored lights (red for Stop sign and yellow for Pedestrian Crossing sign). Since there was not a significant effect for light color, this variable was not carried forward to the closed-course study.

The third section of the lab study addressed different flashing beacon placements. The results showed no significant difference in response time between any of the signs with beacons. However, response times to signs without a beacon were shorter (i.e., faster) than to any of the signs with beacons. Both this result and the previous one suggest that the flashing lights caused participants to hesitate before responding. This may be an artifact of the lighting conditions in the lab study with the bright lights generating a slight startle response in the participants causing them to hesitate before pressing the response button.

The fourth section of the lab study examined various arrangements of embedded LEDs on sign faces of several types. Some of the designs tested were based on actual products and some were variations envisioned by the research team. The results showed that regardless of whether the signs were viewed directly or in peripheral vision, the use of alternating flashing bars along the edge of the sign increased response time. When the bars flashed along all edges simultaneously, the signs performed equally to those with single-point LEDs. White bars caused poorer performance than red bars for Stop signs, most likely due to the brightness of the lights obscuring the sign shape. Because no product currently uses bar lights, this variation was deemed lower priority and was excluded from the closed-course study. Other variations of sequential flashing lights ("marquee lights") along the edge of the signs performed poorly and were also excluded from the field study. Across other sign types, the presence of lights consistently caused slowed sign recognition times.

The last part of the laboratory study asked participants' opinions of application and operation of lighted signs. When asked whether lighted signs would operate all the time or be actuated by approaching vehicles, 85 indicated they believed they would operate continuously. When asked about potential applications, the majority of the responses recommended placing the signs in areas where there is a high number of crashes. Many participant responses included utilizing the signs in areas where either the sign or the intersection would be difficult to see and also using them in rural areas. Finally, a small number of participants mentioned using the signs where there was a high volume of traffic.

Closed-Course Study to Identify Driver Detection of Traffic Control Devices

Overview

The objective for the closed-course study was to evaluate the impact of beacons or LEDs on the detection of signs and on the ability to read the words or symbol on a sign. Participants drove a TTI vehicle accompanied by a TTI employee on a closed course at the Riverside campus while viewing different types of traffic control devices. The location in advance of a sign was noted in the computer file when the driver stated "light" (to indicate when a warning light is seen), stated "sign" (when the sign was seen), or read the message on the sign. Because of the large number of Stop sign types and distractor signs that were used on the course, the route was laid out so that participants drove each runway section in both directions during a single lap, maximizing the total roadway distance. Two laps were designed, using two different sets of signs at the designated sign positions.

An overhead red flashing beacon installed at one intersection accompanied the Stop signs tested at that position; the same overhead assembly included amber flashing beacons that were visible to drivers on the intersecting runway. Besides Stop and Stop Ahead signs, warning signs and Speed Limit signs were placed throughout the course as "distractor" signs. These additional signs helped to maintain participants' attention and interest between Stop signs, distracted participants from the study's focus on the Stop signs, and also provided additional information regarding legibility distance (since drivers couldn't as easily guess at the words/numbers appearing on the distractor signs). One distractor sign position included amber beacons to determine how both daytime and nighttime detection and legibility distances were affected by the beacons.

Findings

Key findings from the study include the following:

- While the reading distance to some of the Stop sign installations was significantly longer than to others, the reading distance for all Stop sign installations tested in this study were very long. The average reading distance for all Stop sign installations exceeded the SSD for 75 mph (820 ft). For several of the Stop sign installations, all of the participants read the words on the Stop sign at a distance greater than the SSD.
- Participants were generally better at reading the word on standard Stop signs than illuminated Stop signs; however, the position of the standard Stop signs may have heavily influenced this result.
- When Stop signs with beacons are compared to Stop signs with LEDs, the only difference in detection distance was identified for the 48-in. Stop with overhead beacons when compared to the 36-in. Stop with overhead beacons, the 36-in. Stop with clusters, and the 36-in. Stop with vertical beacons. In other words, the 36-in. Stop signs with beacons and with LEDs all have similar legibility distances.
- All other things being equal, participants read larger Stop signs earlier than smaller Stop signs.
- Participants detected Stop signs with brighter LEDs better during the day but detected Stop signs with dimmer LEDs better during the night. Increased glare from the brighter LEDs during the night may have obscured the sign.
- The addition of beacons made it more difficult for participants to read the lettering on a sign with words ("loose gravel" and "rough road" in this study). This effect did not interact with age.
- The detection for signs with the same shape as a Stop sign but with SPOT rather than STOP on the sign or with no words on the sign showed average detection distances of greater than 2000 ft. These results demonstrate the importance of the shape, color, and border for sign detection. The majority (56 percent) of drivers did not notice the misspelled Stop message when asked to read the sign, which provides evidence that drivers may not actually read the word on a Stop sign, but rather rely on color and shape for sign identification.

Guidance for Selecting Traffic Control Device Treatments for a Rural, Stop-Controlled Intersection

Overview

One of the objectives of this project was to identify a procedure or an order of escalation of enhancements to Stop signs. The relevant literature and the TxDOT survey conducted within this research along with the findings from the lab and field studies were considered in developing the guidance material.

Findings

Several factors need to be considered in the selection of the appropriate traffic control devices to enhance safety at rural intersections. In addition, if the issue is not resolved with the initial selection, then an iterative approach is needed and another treatment is to be applied until the issue is resolved. Following are suggested principles for consideration in selecting traffic control device treatment(s):

- Select treatment to address conditions at the site.
- Select treatment that is best suited to the visual environment.
- Review the available evidence on treatment effectiveness.
- Conform to local policies.
- Use traffic control devices with beacons or LEDs sparingly.
- Choose lower cost option.

Chapter 7 provides additional discussion regarding advice on selecting traffic control devices for rural stop-controlled intersections.

CONCLUSIONS

The objectives of this research project were to identify and investigate traffic control device alternatives for rural stop-controlled intersections. Further, the project was designed to determine key characteristics of the alternative devices in terms of driver response and cost. These research findings support the guidelines developed on selection and use of the devices.

Adding flashing lights to signs, either through beacons or embedded LEDs, serves two purposes: to attract attention and to convey a message. The findings of this research demonstrate that while the lights do improve detection distance, legibility distance of the message suffers at night due to the glare of the lights. Cautious engineering judgment should be used when adding lights to any word message sign beyond a Stop sign because the legibility distance for the words will be shorter than when lights are not present. For Stop signs, the unique color and shape of these traffic control devices prompts drivers' responses to them long before the word "stop" is actually read. For this reason, the embedded LEDs used on the perimeter of the sign may actually help color and shape recognition and reinforce the message the sign is conveying. The laboratory findings suggest that at great distances, the perimeter LEDs may prompt some people to perceive the shape of the sign as circular, but the red color helps distinguish the Stop sign from the only circular sign, the yellow railroad crossing ahead warning sign.

The driving study found no difference in sign detection at night between those with an overhead flashing beacon and those where the ground-mounted sign has embedded LEDs. This finding suggests that the conspicuity benefits provided by an overhead beacon can be duplicated by the appropriate LED sign. The installation and maintenance cost difference between overhead beacons and LED signs show a lower cost for LED signs.

These conspicuity benefits should be weighed against any decline in the legibility distance for the words on the sign. For Stop signs, the intent of lighting, either through beacons or embedded LEDs, is to improve the detection distance so drivers recognize the upcoming intersection further away and begin slowing. The slight decrease in legibility distance seen when these lights are present is offset by the improved detection distance.

Results showed that when top/bottom beacons were used, the average distance at which the wording of the warning signs ("loose gravel" and "rough road" in this study) could be read decreased (see Figure 77 and Table 103), thus indicating that the addition of beacons reduced the ability of participants to read the signs. Engineers should use caution when deciding which signs to add lights to, as they may adversely affect nighttime legibility.

The detection distances observed for the signs with lights in the current study were extremely long, more than 2000 ft in most cases. While these detection distances may be magnified slightly due to the low driving task workload conditions of a closed-course test, the researchers themselves observed the overall extreme distances. The other general observation regarding the magnitude of the results is that for all of the Stop signs, both lit and unlit, the detection distance for sign recognition was always greater than stopping sight distance. So, the existing static Stop signs are sufficiently visible for an alert driver under clear weather.

The embedded LED products vary in optical design and the viewing distance at which they reach peak brightness. While extensive photometric measurements were not taken as part of this research project, the research staff did observe that the lights on some products were highly visible at great distances and barely noticeable within 100 to 200 ft of the sign. Some venders indicated that they purposely design the optics this way to assure that the LED serves the conspicuity need while not obscuring the text in the legibility range. For this reason, engineering judgment should be used in selecting the product with the desired brightness profile over the approach to the specific site.

The research project found a benefit to detection from dimming the LED brightness at night. The LED sign set on the high brightness setting was detected furthest during the day, while the lower setting was detected best at night.

FUTURE RESEARCH

The current project was able to test only a limited number of features of these new traffic control devices. The main limitation in the field test was that we were not able to accommodate variations in LED color, size, and placement on the sign faces due to time constraints for the testing session. In addition, flashing patterns were not manipulated. The lab study did vary some of these features and helped the research team identify which of these features to include in the field study. Future research should aim to replicate the many manipulations of the lab study in a field setting to discover if an optimal flash pattern and/or arrangement of LEDs can be identified. Some vendors have discussed the idea that flash patterns could be manipulated to signal urgency, for instance, in an active warning system that flashes faster if cross traffic is detected. These types of warning messages embedded in the flash pattern need to be researched before such manipulations are implemented.

The detection distances observed for the signs with lights in the current study were extremely long, more than 2000 ft in most cases. There is some concern that this extreme detection distance may pose a distraction to drivers and direct their attention to the distant cross street rather than to potential hazards along the approach, such as roadway obstacles, driveways, and pedestrians. Future research that examines eye glance behavior on the approach as well as response time to intervening obstacles is needed to address this concern.

The current driving test was conducted in a dark, rural environment where the flashing was very obvious against an uncluttered background. It may be that LED signs could have particularly strong conspicuity benefits when viewed in a cluttered visual environment. Future research could include settings more representative of an urban or suburban installation.

While the current project did include a few warning signs with flashing beacons, the main focus was on the Stop sign. The research team has observed embedded LED signs in Texas and elsewhere used for warning signs for pedestrian crossing, intersection ahead, curve ahead, and signal ahead warning signs. Since Stop signs are unique in color and shape, the slight decrease in legibility distance is not as much of a concern. But with warning signs, the driver must discern the text or symbol in order to respond properly. Previous research on symbol sign recognition suggests that the sign types listed above in general have bold symbols which may be more robust to interference from flashing lights than text signs (*63*). Specific research on chevron signs and synchronized flashing patterns across a series of chevrons is also needed. The observation that LED-enhanced signs provide shape-recognition advantages has resulted in a recommendation of restricting LEDs to Stop signs, Yield signs, and the Stop side of the Stop/Slow paddle by the Project Steering Committee for a project sponsored by the Transportation Association of Canada (*41*). They recognized that certain symbols and pictograms (e.g., chevrons) are unique shapes, and LED-pixelated versions of these images may be identifiable at a glance. They believe, however, that given LED embedded signs are unproven in reducing crash risk and experience is mainly with intersection control, at this time they advised that the use of LED embedded sign be limited to Stop and Yield signs.

Researchers conducted the current field study under clear, dry conditions. It may be that lighted signs have special benefits during rain, fog, or snow conditions, and this could be the subject of future research as well.

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