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16. Abstract

This report describes the methodology and results of analyses performed to determine motorist understanding, as well as the operational and safety effectiveness, of automated flagger assistance devices (AFADs) relative to the use of flaggers at lane closures on two-lane, two-way roadways. Based on the motorist survey and field study findings, researchers recommended the use of both types of AFADs (stop/slow and red/yellow lens) in Texas. Researchers did not make any specific recommendations regarding the red/yellow lens AFADs, since the research findings supported the current language in the 2009 *Manual on Uniform Traffic Control Devices* (MUTCD). For stop/slow AFADs, researchers recommended that a gate arm and alternative symbol supplemental signs be required to reduce violations and improve motorist understanding. In addition, researchers made various recommendations regarding the use of both types of AFADs.

This report also describes the methodology and results of analyses performed to determine the effectiveness of 1) five stop paddles with embedded lights compared to a standard, un-lit stop paddle and 2) a prototype, portable, remotely operated, in-street school children crossing sign with flashing light emitting diodes (LEDs) around the border of each sign face. Based on the research findings, researchers recommended the use of one of the following to improve the conspicuity of crossing guards without negatively impacting a motorist's ability to recognize the three critical characteristics of a stop sign (i.e., red background color, octagon shape, and white STOP legend):

- A stop paddle containing flashing red lights arranged in an octagonal pattern at the eight corners of the paddle.
- A stop paddle containing a series of steady-burn red lights around the border arranged such that the lights clearly convey the octagonal shape of the paddle.
- A stop paddle containing a series of flashing red lights around the border arranged such that the lights clearly convey the octagonal shape of the paddle.

Researchers believed that crossing guards could us the prototype in-street school children crossing sign at school crossings to improve safety. Thus, researchers also made recommendations regarding its future use.

17. Key Words
Automated Flagger Assistance Devices, AFADs, Flaggers, Work Zone Traffic Control Devices, Two-Lane One-Way Operations, School Crossing Traffic Control Devices, Crossing Guards, In-Street Traffic Control Devices, Stop Paddles

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STUDIES TO DETERMINE THE EFFECTIVENESS OF AUTOMATED FLAGGER ASSISTANCE DEVICES AND SCHOOL CROSSING DEVICES

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Melisa D. Finley, P.E. (TX-90937).

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INTRODUCTION

STATEMENT OF THE PROBLEM

When a lane is closed on a two-lane, two-way roadway flaggers are typically used to control the flow of traffic through the work zone. While various measures have been implemented in recent years to improve the safety and effectiveness of flaggers, crashes involving flaggers still occur and quite often result in serious injury to the flagger.

In 2004, the Federal Highway Administration (FHWA) approved the use of automated flagger assistance devices (AFADs), which are designed to be remotely operated by a flagger positioned outside of the travel lane, thereby reducing their exposure to vehicular traffic (*1*,*2*). Since then, provisions for AFADs have been included in the 2009 *Manual on Uniform Traffic Control Devices* (MUTCD) (*3*).

There are two types of AFADs. One type uses a remotely controlled stop/slow sign to alternately control the right-of-way. The other type uses remotely controlled red and yellow lenses and a gate arm to alternately control the right-of-way. Figure 1 contains an example of both types of AFADs.

a) Stop/Slow **b) Red/Yellow Lens**

Figure 1. Examples of AFADs.

While AFADs may increase the safety of flaggers, there were concerns that motorists may misunderstand AFADs; thus, increasing the potential for motorists to enter the lane closure under the stop condition. More specifically, there were concerns that motorists may react to the stop face of the stop/slow AFAD as they do when they encounter a traditional stop sign. So, a motorist may stop and then proceed into the open lane that would contain oncoming traffic instead of waiting for the slow face to display. While flaggers use stop/slow paddles in a similar manner, flaggers also use hand signals to indicate to motorists that they are to stop and remain stopped.

There were also concerns that motorists may misunderstand red/yellow lens AFADs, especially those with color vision deficiencies. Red/yellow lens AFADs use circular red and circular yellow signal indications to control traffic (i.e., a circular green indication is not provided). Subsequently, unlike traditional traffic signals and freeway entrance ramp control signals, red/yellow lens AFADs use a flashing circular yellow indication to notify motorists when they are permitted to proceed.

Besides potential motorist comprehension issues, there were concerns that AFADs may garner less respect, especially without an obvious operator, and thus result in decreased compliance (i.e., motorists deliberately entering the work zone when a stop condition is displayed). Therefore, research was needed to assess motorist understanding and the operational and safety effectiveness of AFADs relative to the use of flaggers at lane closures on two-lane, two-way roadways.

There is a similar issue with the safety of crossing guards trying to stop motorists before school children enter the crosswalk. Over the past few decades, the percentage of children who are dropped off or picked up at school in a private vehicle has increased by approximately 50 percent (*4*). This results in increased traffic through school zones and thereby increased potential for conflicts to occur during pedestrian crossing maneuvers. Research was needed to explore the safety issues encountered by crossing guards and to identify and assess potential portable devices for improving the safety and effectiveness of crossing guards.

CONTENTS OF THIS REPORT

This report describes the methodology and results of analyses conducted to: 1) assess the effectiveness of AFADs relative to the use of flaggers at lane closures on two-lane, two-way roadways, and 2) identify and evaluate portable devices that crossing guards can use to improve their safety and effectiveness. Because of the duality in research project purpose, researchers prepared this report in two distinct parts. Part 1 addresses the research tasks and results pertaining to AFADs, and Part 2 addresses the crossing guard safety issues and portable devices evaluated.

PART 1 – AFADS

CHAPTER 1.1:
STATE-OF-THE-PRACTICE

INTRODUCTION

In order to determine the state-of-the-practice of AFADs across the U.S. and in Texas, researchers:

- Contacted AFAD manufacturers and obtained product literature.
- Reviewed previous research.
- Conducted telephone interviews with representatives from other state agencies that have experimented with AFADs.
- Conducted telephone interviews with Texas Department of Transportation (TxDOT) personnel.

The following sections describe the findings of these activities.

BACKGROUND

Since AFADs are remotely operated, flaggers can position themselves out of the travel lane, thereby reducing their exposure to moving traffic. There are two types of AFADs. One type uses a remotely controlled stop/slow sign to alternately control the right-of-way. The other type uses remotely controlled red and yellow lenses and a gate arm to alternately control the right-of-way. The following sections describe the AFAD provisions included in the 2009 MUTCD (*3*).

Stop/Slow AFADs

Stop/slow AFADs alternately display a stop sign to stop traffic and a slow sign when traffic may proceed. The stop/slow sign must have an octagonal shape, be at least 24 by 24 inches with letters at least 8 inches high, and be mounted such that the bottom of the sign is a minimum of 6 ft above the pavement. The background of the stop sign shall be red with white letters and border, and the background of the slow sign shall be diamond shaped and orange with black letters and border. Both sign faces must be retroreflective. The stop/slow sign must be supplemented with one of the following options:

- White or red flashing lights within the stop face and white or yellow flashing lights within the slow face.
- A stop beacon mounted a maximum of 24 inches above the stop face and a warning beacon mounted a maximum of 24 inches above, below, or to the side of the slow face.

As shown in Figure 2, a WAIT ON STOP (R1-7) sign must be displayed and a GO ON SLOW (R1-8) sign may also be displayed. These signs must be positioned on the same support structure as the AFAD or immediately adjacent to the AFAD such that they are in the same direct line of view of approaching traffic as the sign faces of the AFAD. Both signs shall be rectangular in shape, have black legends and border and white backgrounds, and be at least 24 by 30 inches in size with letters at least 6 inches high.

The stop/slow AFAD may also include a gate arm that descends to a down position across the approaching traffic lane when the STOP face is displayed and ascends to an upright position when the SLOW face is displayed. If used, gate arms must be fully retroreflective on both sides and have vertical alternating red and white stripes at 16-inch intervals (measured horizontally). When the gate arm is in the down position the minimum vertical aspect of the arm and sheeting must be 2 inches and the end of the arm shall reach at least to the center of the lane that it controls.

Red/Yellow Lens AFADs

Red/yellow lens AFADs alternately display a steadily illuminated circular red lens and a flashing circular yellow lens to control traffic. Unlike the stop/slow AFAD, the red/yellow AFAD must include a gate arm. The design of the gate arm is the same for both types of AFADs. To stop traffic, the red/yellow lens AFAD displays the steadily illuminated circular red lens and the gate arm is in the down position. When traffic may proceed, the AFAD displays a flashing circular yellow lens and the gate arm is in the upright position. A change interval must be provided to transition between the display of the flashing circular yellow indication and the display of the steady circular red indication. The circular yellow lens steadily illuminates and the gate arm remains in the upright position during the change interval. The steadily illuminated circular yellow change interval should have a duration of at least 5 seconds unless engineering judgment justifies a different duration. A change interval between the display of the steady circular red indication and the display of the flashing circular yellow indication shall not be provided.

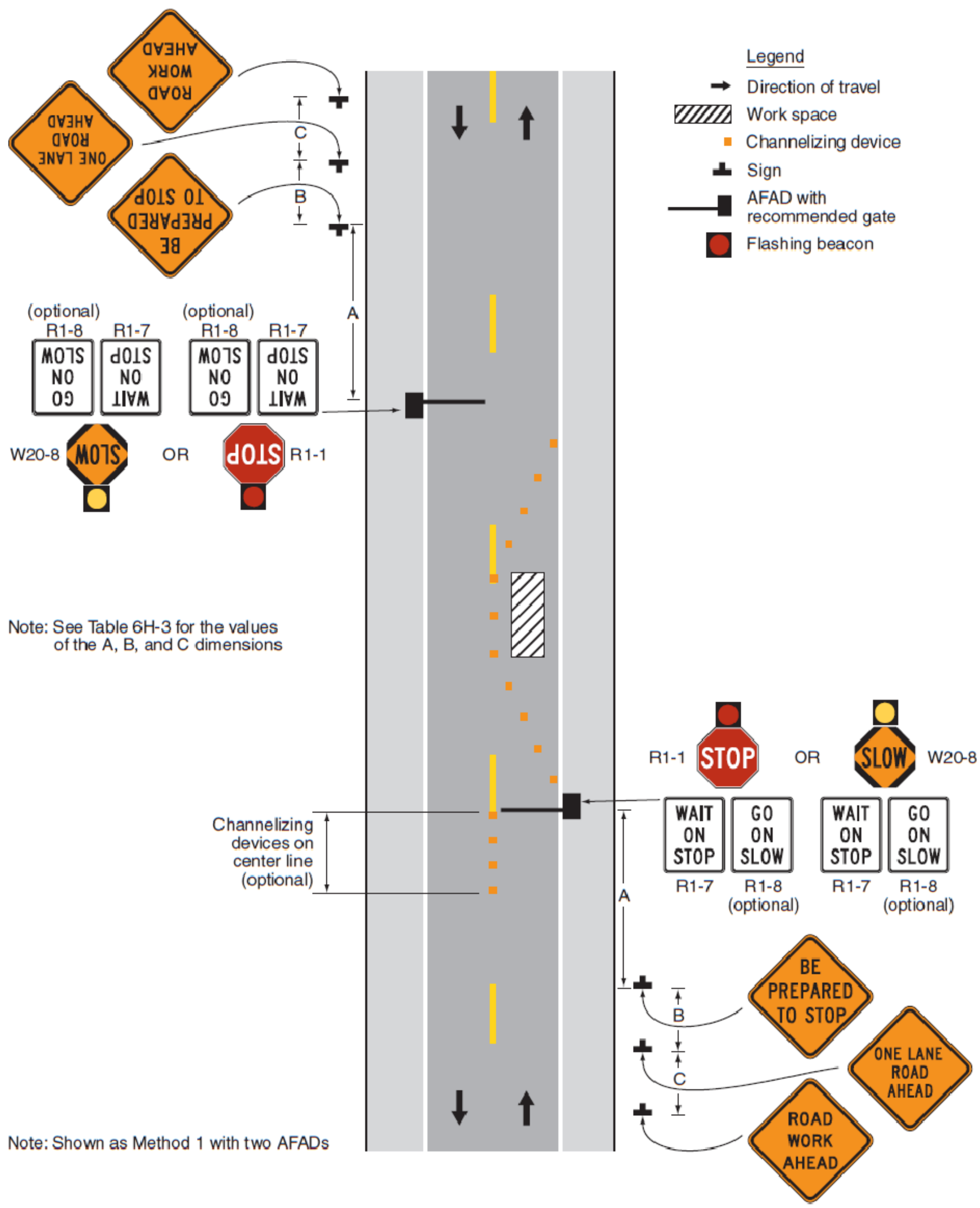


Figure 2. Example of the Use of a Stop/Slow AFAD (*3*).

Each red/yellow lens AFAD must have at least one set of circular red and circular yellow lenses that are 12 inches in diameter and the circular red lens must be on top of the circular yellow lens. If the set of lenses is post-mounted, the bottom of the housing (including brackets) shall be at least 7 ft above the pavement. If the set of lenses is located over any portion of the roadway, the bottom of the housing (including brackets) shall be at least 15 ft above the pavement. Additional sets of lenses may be used overhead or on the left-hand side of the approach to improve visibility and conspicuity of the AFAD. As Figure 3 shows, a STOP HERE ON RED (R10-6 or R10-6a) sign must be installed on the right-hand side of the approach at the point where motorists are expected to stop.

General AFAD Provisions

Agencies can only use AFADs on roadways where there is one lane of traffic approaching the AFAD. AFADs must be operated by a flagger who has been trained on the operation of the device and the flagger operating the AFAD cannot leave the device unattended at any time while the device is being used. AFADs can be used at each end of the work zone or at one end of the work zone with a flagger at the opposite end. Two flaggers must be used with either method, except if both of the following conditions are present:

- The flagger has an unobstructed view of the AFAD(s).
- The flagger has an unobstructed view of approaching traffic in both directions.

AFADs should be located in advance of one-lane, two-way tapers and downstream from the point where approaching traffic is expected to stop. As shown in Figure 2 and Figure 3, the advance warning signs prior to the AFAD should include a ROAD WORK AHEAD sign, a ONE LANE ROAD sign, and a BE PREPARED TO STOP sign.

AFADs might be appropriate for short-term (i.e., daytime work that occupies a location for more than one hour within a single daylight period) and intermediate-term activities (i.e., work that occupies a location more than one daylight period up to three days, or nighttime work lasting more than one hour). However, AFADs should not be used for long-term stationary work (i.e., work that occupies a location more than 3 days). Typical applications of AFADs could include bridge maintenance, haul road crossings, and pavement patching. An agency choosing to use AFADs should adopt a policy governing the application of the devices. The policy should consider the following:

- Conditions applicable for both flagger/AFAD methods.
- Volume criteria.
- Maximum distance between AFADs.

- Conflicting lenses/indications monitoring requirements.
- Fail safe requirements.
- Additional signing and pavement markings.
- Application consistency.
- Larger signs or lenses to increase visibility.
- Use of backplates.

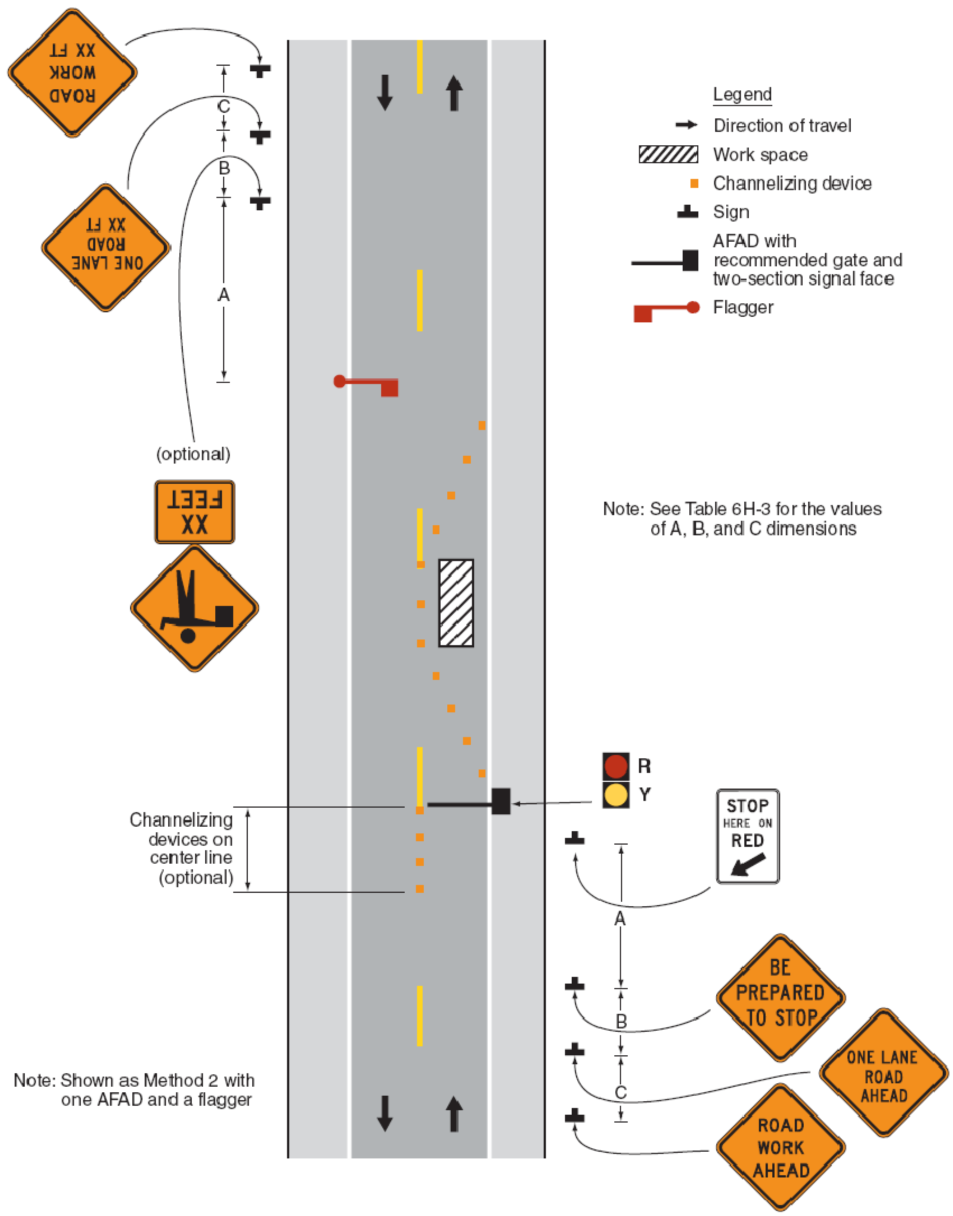


Figure 3. Example of the Use of a Red/Yellow Lens AFAD (*3*).

MANUFACTURERS

In 2009, there were five manufacturers of AFADs in the U.S. One manufacturer only produced stop/slow AFADs (*5*), and three manufacturers only made red/yellow lens AFADs (*6*,*7*,*8*). The other manufacturer produced both types of AFADs (*9*). Based on previous research (*10*), researchers identified a sixth manufacturer; however, researchers could not find current information regarding the device.

NATIONAL AFAD IMPLEMENTATION

In 2009, researchers conducted a literature review and telephone interviews with 21 state departments of transportation (DOTs) to assess the state-of-the-practice nationally. Table 1 contains a summary of the findings. While researchers were able to identify 16 state agencies that have used or plan to use AFADs, the extent of their experience varied from recently purchased or one field implementation to regular use over a multi-year period. Most of these agencies were only using one type of AFAD (either stop/slow or red/yellow lens) and about half of the agencies utilized each type. Four agencies stated that while AFADs were purchased or tested, they no longer used them. Another five agencies responded that while AFADs were allowed they are not currently used. Reasons provided for not using AFADs included:

- Cumbersome to move from site to site.
- Expensive.
- Using portable traffic signals instead.
- Problems with the remote controls and charging the units.

Stop/Slow AFADs

While eight state agencies reported using stop/slow AFADs, literature documenting their implementation and evaluation was only found from Illinois, Minnesota, and Virginia (*10, 11*,*12*). The Illinois DOT started using stop/slow AFADs in 1991. These AFADs included 24-inch stop/slow signs coupled with strobe lights. As of January 2005, in all but two instances motorists stopped within 100 ft of the AFAD with only minimal flagger hand signaling required. The stop/slow AFADs were used in various types of weather including moderate fog, light rain, overcast, intermittent rain, and sunny conditions.

The Minnesota DOT began using stop/slow AFADs in 1996. The original request to experiment required the use of the following actions to indicate to approaching motorists that the AFAD was an active traffic control device used by the flagger rather than a temporary stop sign, which permits a motorist to proceed after stopping:

- The flagger should always remain in a close and safe proximity to the AFAD and remain visible to the motorist.
- The flagger must provide all flagger hand signals.

Table 1. Summary of National AFAD Implementation.

State Agency	Literature Review	Telephone Survey
Alabama DOT		Approved, but not using
Alaska DOT	Red/yellow lens (*10*)	Using stop/slow
Caltrans		Approved, but not using
Delaware DOT		Recently purchased stop/slow
Florida DOT		Contractors using both types
Georgia DOT		Used red/yellow lens on one project
Idaho DOT		Approved, but not using
Illinois DOT	Stop/slow (*10*)	Purchased stop/slow, but no longer using them
Kansas DOT		Using stop/slow
Michigan DOT		Approved, but not using
Minnesota DOT	Stop/slow (*11*)	Purchased stop/slow, but not being used much anymore
Missouri DOT	Red/yellow lens (10)	Using red/yellow lens
New Jersey DOT		Approved, but not using
New York State DOT		Using stop/slow
North Carolina DOT	Red/yellow lens[a]	Using red/yellow lens
Ohio DOT	Red/yellow lens (*10*)	Tested red/yellow lens, but no longer using them
Pennsylvania DOT		Contractors using red/yellow lens
South Dakota DOT		Do not use
Vermont DOT	Red/yellow lens[b]	
Virginia DOT	Stop/slow (*12*)	Using stop/slow
Washington State DOT		Using red/yellow lens
Wisconsin DOT	Red/yellow lens (*10*,*13*)	Tested red/yellow lens, but no longer using them

Shaded area indicates no information identified/provided.
[a] According to unpublished presentation.
[b] According to manufacturer's website.

Over the initial two years of evaluation, the Minnesota DOT used stop/slow AFADs in five work zones over a total of eight days. Motorists' opinions of the AFADs and subjective observations by Minnesota DOT personnel and workers were acquired. The majority of the motorists surveyed felt that the AFAD clearly and effectively controlled the flow of traffic in the work zone. However, 15 percent were confused when they saw the AFAD instead of a person controlling traffic. In addition, 23 percent of the motorists surveyed stated that if the worker had not been located near the AFAD they would have stopped and then proceeded as if it were a standard STOP sign.

In 1999, the Minnesota DOT removed the two testing criteria described above to lower the flagger's exposure to moving traffic and allow for a single flagger to control two AFADs. Motorist behavior data were collected during that same year at four work zones where the stop/slow AFADs were used. Over a 15-hour period, traffic was stopped 313 times during which five violations occurred. Thus, a motorist entered the open travel lane under the stop condition approximately every 3 hours, or 63 stop periods. Fortunately, none of these violations resulted in a crash. Since Minnesota DOT did not collect the same type of data when using a flagger, it is unknown whether this violation rate was about the same, higher, or lower than when using a flagger.

Between 1999 and 2005, the Minnesota DOT continued to use stop/slow AFADs on many maintenance projects. No crashes occurred and motorist compliance was at least as good as with flaggers during this extended time. In the future, the Minnesota DOT will consider using stop/slow AFADs when project conditions fall within the following limits:

- Two-lane, two-way roadways closed to one lane of traffic.
- Average daily traffic (ADT) less than 1500 vehicles per day (vpd).
- Distance of lane closure is 800 ft or less for one operator; engineering judgment is recommended for greater distances and multiple operations.
- Operator(s) has unobstructed view of AFAD and approaching traffic in both directions.

During the first two months of 2006, the Virginia DOT deployed stop/slow AFADs nine times for a total of 59 hours of operation on secondary and frontage roads. The estimated ADT on these roads ranged from 100 to 1600 vpd. During the first four deployments, six violations occurred (i.e., motorists entered the open travel lane when the stop face was displayed). Workers at these sites assumed that these motorists misunderstood the WAIT ON STOP and GO ON SLOW sign combination, since most of the violators would stop and then proceed slowly past the AFAD into the open travel lane (i.e., motorists did not wait for the slow face to display before proceeding). For the remaining five sites, Virginia DOT personnel did not use the optional GO ON SLOW sign. Only one violation occurred at these sites. Later deployments of the stop/slow AFAD in August 2006 did include the GO ON SLOW sign; however, during the 32 hours of operation no violations occurred. All of the deployments of the stop/slow AFADs in Virginia were located in the Wytheville Area Headquarters region. Thus, Virginia DOT personnel speculated that the earlier apparent confusion with the stop/slow AFAD was due more to the novelty of the device than the sign message itself.

Red/Yellow Lens AFADs

According to the FHWA (*10*), four states (Ohio, Missouri, Wisconsin, and Alaska) have experimented with red/yellow lens AFADs; however, no objective data on their effectiveness were collected. No vehicular crashes occurred during any of the evaluations and comments from the public were very favorable. In Missouri, motorists predominately stopped and remained stopped during the steady circular red indication, but some motorists did not. In Wisconsin (*13*), at one site over a six-month period, red/yellow AFADs were deployed at each side of a construction equipment crossing. Unlike traditional flagging operations, both directions of traffic were stopped and released simultaneously. Observations indicated that the red/yellow lens AFADs commanded attention. However, in one instance a motorist did violate the red signal. In addition, anecdotally some motorists commented that they could not explain the differences between the meanings of the flashing yellow and the steady yellow signals. Wisconsin DOT personnel recommended adding a flag to the end of the gate arm to improve the conspicuity of the arm.

TXDOT AFAD IMPLEMENTATION

Researchers conducted telephone interviews with 26 TxDOT personnel, representing 23 of the 25 TxDOT districts. Researchers mainly interviewed maintenance personnel; however, in some cases researchers also interviewed traffic operations and construction personnel. Topics discussed during the telephone interviews included the following:

- Whether or not the district had utilized or planned to utilize AFADs in work zones.
- Characteristics of the AFADs used (i.e., stop/slow, red/yellow lens, gate arm, supplemental signs).
- How the AFADs were used (i.e., only in one direction, in both directions, single or multiple operators).
- Where the AFAD was located (i.e., distance upstream of work area, on shoulder, in travel lane).
- Characteristics of the work zone (i.e., length, duration, sight distance).
- Effectiveness of AFADs.
- Advantages and disadvantages of AFADs.
- Potential AFAD improvements.

In 2009, only the San Antonio District actively used AFADs in work zones. This district purchased its first set of red/yellow lens AFADs in 2004 and now has a total of six sets of portable red/yellow lens AFADs. The Boerne, Floresville, Kerrville, Tilden, and Uvalde maintenance offices actively use the red/yellow lens AFADs. Figure 4 shows examples of the AFADs used by these offices. All of the red/yellow lens AFADs have a gate arm and at least three of the maintenance offices use an orange flag on the end of the gate arm. All of the maintenance offices also use a STOP HERE ON RED sign in conjunction with the red/yellow lens AFADs. Typically this regulatory sign is mounted on a separate stand that is placed in front of the AFAD (see Figure 4). In addition, the red/yellow AFADs include an automatic intrusion alarm and a manual alarm that the flagger can activate. The Floresville and Uvalde maintenance offices also utilize the optional channelizing devices on the centerline shown in Figure 3. Reasons for using these AFADs include:

- Shortage of work personnel (i.e., second flagger no longer needed, so that person can do other job duties).
- Flagger located off the pavement away from traffic.
- Flagger fatigue especially during the summer.
- Flagger can activate intrusion alarm if needed.

AFADs have been used in work zones with the following characteristics:

- Two-lane, two-way roadways that have long straight-aways.
- Average daily traffic from 150 to 8500 vpd.

- The length of the work zones ranged from 300 ft to 2 miles.
- Some type of asphalt work that lasted one day.

a) Boerne

b) Floresville

c) Tilden

d) Uvalde

Figure 4. Examples of AFADs Used in the San Antonio District.

All of the maintenance offices used AFADs at both ends of the work zone. Typically, a single qualified flagger operated both AFADs unless the flagger could not adequately view both AFADs and approaching traffic in both directions. All of the maintenance offices position the AFAD on the shoulder with the gate arm extended across the travel lane. Only the Boerne Maintenance Office has used AFADs at night.

Table 2 shows the advance warning sign sequences used by the five maintenance offices in advance of the AFAD. All of the offices utilize the ROAD WORK AHEAD (CW20-10) sign as the first sign in the series. Four of the five offices use the ONE LANE ROAD AHEAD (CW20-4) sign as the second sign in the series. The remaining office uses a sign to indicate a closed lane ahead. Four of the five offices use the BE PREPARED TO STOP (CW20-7b) sign as the third sign in the series; however, one office noted that its use was optional. Two offices use flagger signs (text or symbol) as the last sign in the sequence, and three offices use signs indicating there is a signal ahead as the last sign in the sequence. Three offices thought that a new warning sign describing the "signal" (i.e., AFAD) should be developed.

Table 2. Advance Warning Sign Sequences Used by TxDOT prior to the AFAD.

Maintenance Office	1st Sign [a]	2nd Sign [a]	3rd Sign [a]	4th Sign [a]
Boerne	ROAD WORK AHEAD	ONE LANE ROAD AHEAD	BE PREPARED TO STOP	FLAGGER AHEAD [b]
Floresville	ROAD WORK AHEAD	ONE LANE ROAD AHEAD	BE PREPARED TO STOP	SIGNAL LIGHT AHEAD
Kerrville	ROAD WORK AHEAD	ONE LANE ROAD AHEAD	BE PREPARED TO STOP [c]	Flagger Symbol (CW20-7A)
Tilden	ROAD WORK AHEAD	ONE LANE CLOSED AHEAD	Signal Ahead Symbol (W3-3) [d]	
Uvalde	ROAD WORK AHEAD	RIGHT LANE CLOSED	BE PREPARED TO STOP	TRAFFIC SIGNAL AHEAD

Shaded area indicates no additional signs used.
[a] Unless otherwise noted, all signs are diamond shape with an orange background and black letters/symbols.
[b] Not mentioned during telephone survey, but shown in video provided to researchers.
[c] Optional.
[d] Diamond shape sign with yellow background and a traffic signal symbol (includes red, yellow, and green indications).

Overall, all five maintenance offices thought the red/yellow lens AFADs were effective at controlling traffic for lane closures on two-lane, two-way roadways. Advantages cited included: flagger located off the pavement away from traffic, frees up personnel to work in other capacities, and easy to maneuver. Disadvantages mentioned included: extra time it takes to setup an AFAD compared to a flagger, occasionally AFADs are blown over by the wind, and an extra trailer is needed. Maintenance issues discussed included: the remote control not working properly, the gate arm getting damaged by motorists that drive through the closed lane, and the need for solar panels to keep the batteries charged.

While no other TxDOT districts were currently using AFADs in work zones, the majority of them (73 percent) would like to use them in the future. One quarter of these districts preferred to use the stop/slow AFAD since motorists are used to seeing the stop/slow paddle utilized by flaggers. However, almost a third of these districts preferred the red/yellow lens AFAD because they felt it would be more visible and capture the motorist's attention better than the stop/slow AFAD and the gate arm would help with compliance. The remaining districts did not express a preference. Implementation challenges noted by TxDOT personnel included:

- Obtaining funding to purchase AFADs.
- Acceptance by field personnel.
- The need to demonstrate the device's effectiveness.
- The current practice of using portable traffic signals.
- Existing service contracts for flaggers with private companies.

DISCUSSION AND RECOMMENDATIONS

While AFADs may increase the safety of flaggers, there are concerns that they may be misunderstood by motorists and thus increase the potential for motorists to enter the lane closure under the STOP condition. TxDOT was also concerned about the use of warning signs notifying motorists of flaggers or signals ahead when using AFADs.

Stop/Slow AFADs

The main concern with stop/slow AFADs is that motorists may react to the stop face of the stop/slow AFAD as they do when they encounter a standard stop sign (i.e., stop and then proceed into the open lane that would contain oncoming traffic). Based on the literature review, violations of this nature did occur in Minnesota and Virginia. In addition, almost one-quarter of the motorists surveyed in Minnesota stated that they would have stopped and then proceeded as if it were a standard stop sign if a worker had not been located near the AFAD.

Researchers believed that changes to the existing supplemental signing used with stop/slow AFADs may improve motorist understanding. In addition, researchers thought that the use of a stop beacon (a flashing circular red signal indication) on the stop/slow AFAD may contribute to the "stop and then proceed" misinterpretation. A gate arm may also be needed to dissuade motorists that may misunderstand the stop/slow AFAD. Although the gate arm is currently optional with the stop/slow AFAD, several states (e.g., Florida, Georgia, and Kansas) require using a gate arm with both types of AFADs.

Red/Yellow Lens AFADs

Researchers were also concerned that motorists may misunderstand red/yellow lens AFADs. These devices look similar to traditional traffic signals and freeway entrance ramp control signals; however, only circular red and yellow signal indications are used to control traffic (i.e., a circular green indication is not provided). So unlike traditional signals, red/yellow lens AFADs display a flashing circular yellow indication to notify motorists that they are permitted to proceed. In addition, while a steady circular yellow indication is displayed to indicate that the permitted movement is being terminated (as done traditionally between the green and red indications of traffic signals), it is displayed after a flashing circular yellow indication. In Wisconsin, some motorists commented that they could not explain the differences between the meanings of the flashing yellow and the steady yellow signals.

Advance Warning Sign Sequence

According to TxDOT standards (*14*), the following advance warning sign sequence is used for a one-lane closure on a two-lane roadway:

- ROAD WORK AHEAD (CW20-1D) sign.
- ONE LANE ROAD XXX FT (CW20-4) sign.
- A BE PREPARED TO STOP sign (FCW20-7B) (optional).
- Flagger symbol (CW20-7A) sign with distance plaque.

Similarly, the 2009 MUTCD (*3*) recommends that the advance warning sign sequence prior to the AFAD include a ROAD WORK AHEAD sign, a ONE LANE ROAD sign, and a BE PREPARED TO STOP sign (see Figure 2 and Figure 3). According to discussions with FHWA personnel, the flagger symbol/text sign was removed since an AFAD was being used. However, to date the advance signing sequence for AFADs in the MUTCD has not been evaluated.

Recommendations

Based on the state-of-the-practice findings and input from TxDOT, researchers decided to administer motorist surveys to determine motorists' understanding of both types of AFADs and the advance warning sign sequence used. In addition, researchers conducted field studies to assess the operational and safety effectiveness of AFADs relative to the use of flaggers.

CHAPTER 1.2: MOTORIST SURVEYS

INTRODUCTION

To determine motorists' understanding of both types of AFADs and the advance warning sign sequence used, researchers developed and administered motorist surveys at the Department of Public Safety (DPS) offices in Texas. Due to survey duration limitations, researchers could not address all of the topics of interest at once. Thus, researchers developed and conducted the motorist surveys in two phases. Researchers also believed that this approach would provide an opportunity to determine conditions that might potentially be eliminated from further evaluation; therefore, eliminating unnecessary data collection and reduction.

In Phase 1, researchers created four separate surveys:

- One to address motorist comprehension of the stop/slow AFAD.
- One to address motorist comprehension of the red/yellow lens AFAD.
- Two to address advance warning signs (i.e., one for each type of AFAD).

Researchers surveyed a total of 266 participants in Bryan, Texas. Each participant completed only one survey.

In Phase 2, researchers created three separate surveys that addressed the following topics:

- Motorist comprehension of the stop/slow AFAD.
- Motorist comprehension of the red/yellow lens AFAD.
- Advance warning signs.

Researchers conducted the surveys in San Angelo, Lubbock, and Tyler, Texas, and surveyed a total of 544 participants. Each participant first completed one comprehension survey, either on the stop/slow or the red/yellow lens AFADs. Next, all participants completed the advance warning sign survey.

Participants were required to be at least 18 years old and have a current Texas driver's license. Researchers based the demographics on the age and gender of the Texas driving population (*15*) and the education level on data from the U.S. Census Bureau (*16*). Table 3 summarizes the demographic distribution obtained for each survey in each phase, as well as the Texas-based demographics. Overall, researchers believe that the results obtained in this study represent Texas drivers reasonably well.

Table 3. AFAD Motorist Survey Participant Demographics.

Sample	Gender		Age Group		Education Level	
	Male	Female	18–54	55+	High School Diploma or Less	Some College (2 yrs+) & More
2008 Texas Data (*15,16*)	50%	50%	75%	25%	51%	49%
Phase 1						
Stop/Slow AFAD (n=156)	49%	51%	67%	33%	49%	51%
Red/Yellow Lens AFAD (n=50)	50%	50%	76%	24%	52%	48%
Advance Warning Signs						
- Stop/Slow AFAD (n=30)	53%	47%	77%	23%	53%	47%
- Red/Yellow Lens AFAD (n=30)	53%	47%	77%	23%	53%	47%
Phase 2						
Stop/Slow AFAD (n=320)	51%	49%	75%	25%	51%	49%
Red/Yellow Lens AFAD (n=224)	50%	50%	75%	25%	49%	51%
Advance Warning Signs (n=544)	49%	51%	75%	25%	50%	50%

STOP/SLOW AFADS

The following sections describe the experimental design and results for each phase of the AFAD motorist survey.

Phase 1 Study Design and Protocol

It is a concern that motorists approaching a stop/slow AFAD may stop and then proceed (as at a standard stop sign) instead of waiting for the device to change to the slow sign. Based on previous research (*10,11,12*), researchers believed that the current supplemental signs (i.e., WAIT ON STOP [required] and GO ON SLOW [optional]) may not be understood by motorists. So in Phase 1, researchers developed and evaluated motorist comprehension of 13 new supplemental signing treatments designed to inform motorists of the need to stop and remain stopped until the slow sign was displayed. As Figure 5 shows, all of the supplemental signing treatments utilized symbols of the stop and/or slow signs instead of text. Researchers thought symbols would improve motorist understanding of the device (i.e., two signs were used to direct traffic [just like a flagger] even though only one sign is shown at a time). Researchers did not include the current supplemental signs in Phase 1 since the goal of the first phase was to reduce the number of new supplemental signing options for evaluation in Phase 2.

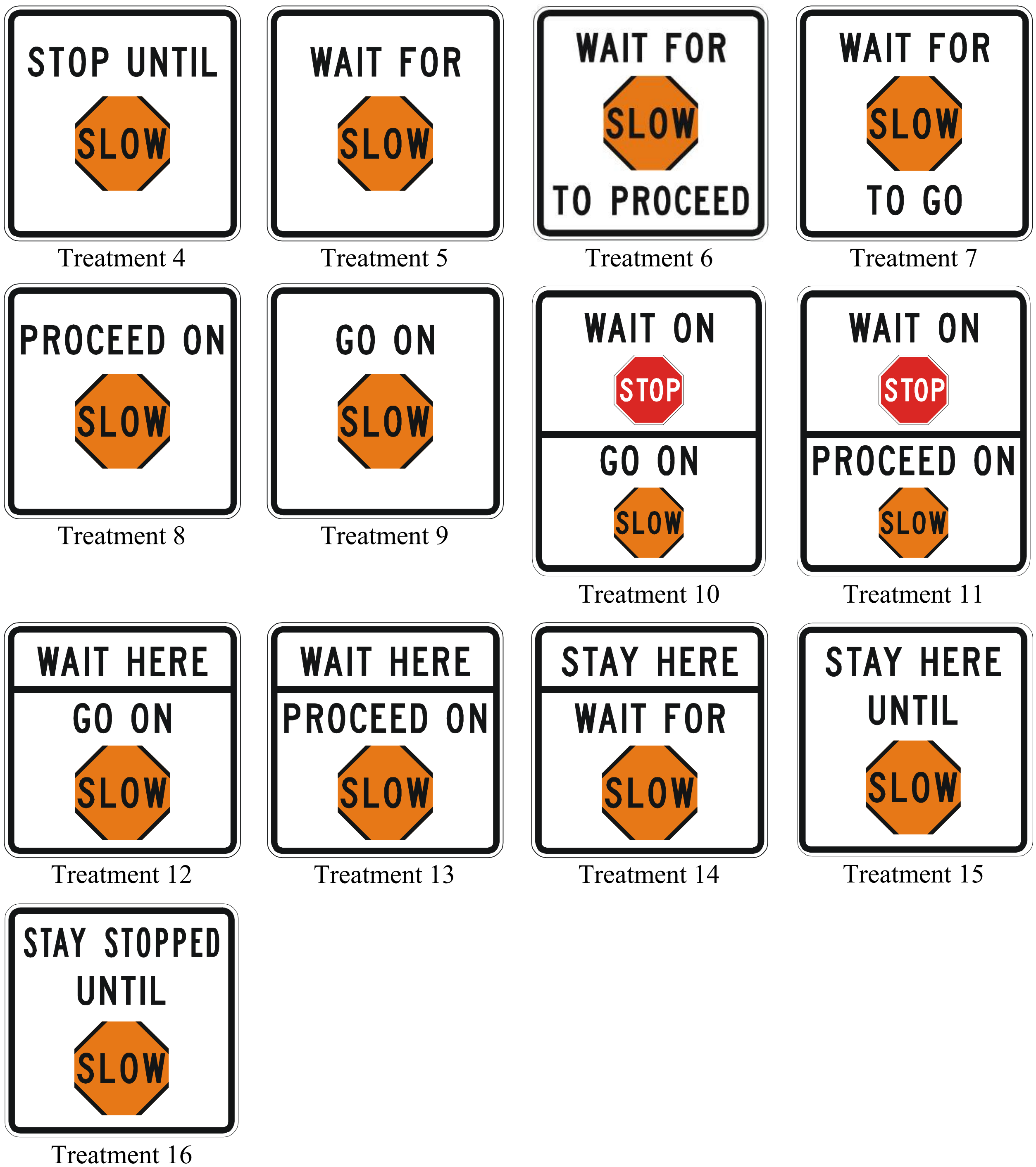


Figure 5. Phase 1 Supplemental Signing Treatments.

Researchers were also concerned that the flashing red beacon used with some stop/slow AFADs may further convey the "stop and then proceed" message to motorists, since this type of beacon is mainly used with standard stop signs. According to the MUTCD (*3*), when a flashing red signal indication is displayed as a beacon to supplement another traffic control device, motorists are notified that there is a need to pay extra attention to the message. The MUTCD also states that the right to proceed shall be subject to the rules applicable after making a stop at a stop sign, which in the case of stop/slow AFADs would be to wait until the slow sign is displayed to proceed. So while the use of a flashing red beacon may be appropriate, researchers did not know whether the beacon impacted motorist understanding of the AFAD.

Due to time limitations, each participant saw only one of the new supplemental signing treatments displayed in a static graphic with a stop/slow AFAD (Figure 6). After the participant viewed the graphic, researchers asked the following series of questions to determine if the participant understood the device and to gather information regarding the use of a flashing red beacon with the device.

- What would you do?
- How long would you remain stopped?
- Assume the red beacon light shown in the picture is flashing; would that have changed what you would do? Why or why not?
- Do you think a flashing beacon is telling you the same thing or something different than a steady beacon? Why or why not?
- Do you prefer the red beacon light to be flashing or steady? Why?

Researchers then asked a series of questions to determine the participant's interpretation and preference for the terms GO and PROCEED. Finally, researchers showed the participant two groups of similar supplemental signs (one at a time). Researchers divided the supplemental signs into two groups based on the similarities of the sign design. For each group, the participant ranked the signs from best to worst according to their ability to inform motorists to stop and remain stopped until otherwise indicated. Then each participant chose the best overall supplemental signing treatment.

Figure 6. Example of Phase 1 Stop/Slow AFAD Graphic.

Phase 1 Results

Comprehension

For each of the 13 supplemental signing treatments, researchers identified whether each participant's action would be considered correct or incorrect. The only correct action was to stop and wait for an indication from the AFAD of when it was safe to proceed. Incorrect actions included stopping and then proceeding (like at a standard stop sign) and stopping and waiting on a flagger to tell them to proceed. Researchers considered any indication of waiting for a flagger to direct traffic as an incorrect action since AFADs can operate without a flagger in the immediate vicinity.

As Table 4 shows, there was no one signing option that completely eliminated the possibility of motorists stopping and then proceeding like at a standard stop sign. However, Treatment 10 resulted in only 17 percent of the participants choosing this incorrect action. In addition, 50 percent of the participants understood that they were to stay stopped until the slow sign was displayed with Treatment 10. Treatment 10 was similar to the supplemental signs currently used, but instead of all text, Treatment 10 utilized symbols for stop and slow.

Treatment 7 resulted in the second highest percentage of the participants understanding that they were to stay stopped until the slow sign was displayed (42 percent). However, the percentage of participants choosing the incorrect action of stopping and then proceeding slightly increased (33 percent).

Table 4. Phase 1 Participant Actions for Stop/Slow AFADs.

Supplemental Signing Treatment (n=12 per sign)	Correct Actions			Incorrect Actions		
	Stop Until Slow Sign Displayed	Stop Until Indicated	Total	Stop & Proceed	Wait Until Directed By Flagger	Total
 4	17%	0%	17%	50%	33%	83%
 5	17%	25%	42%	50%	8%	58%
 6	17%	17%	42%[a]	25%	33%	58%
 7	42%	0%	50%[a]	33%	17%	50%
 8	9%	8%	17%	50%	33%	83%
 9	8%	0%	8%	50%	42%	92%
 10	50%	0%	58%[a]	17%	17%	42%[a]
 11	25%	0%	25%	50%	25%	75%
 12	0%	17%	25%[a]	50%	25%	75%
 13	25%	33%	58%	33%	9%	42%
 14	33%	17%	58%[a]	9%	33%	42%
 15	34%	8%	42%	17%	41%	58%
 16	25%	0%	25%	33%	42%	75%

[a] Action categories do not add up to total percent, since researchers categorized 8 percent of the actions as "other."

Treatment 14 resulted in the lowest percentage of participants choosing the incorrect action of stopping and then proceeding (9 percent). In addition, more than 50 percent of the participants chose a correct action for Treatment 14. Treatment 13 produced similar findings to Treatment 14, except the percentage of participants that would stop and then proceed was higher (33 percent compared to 9 percent, respectively) and the percentage of participants that would stop until the slow sign was displayed was slightly lower (25 percent compared to 33 percent, respectively).

GO versus PROCEED

Comparing Treatments 6 and 7 in Table 4 the use of the term GO resulted in a higher percentage of participants choosing to stop until the slow sign was displayed. The same trend is evident with Treatments 10 and 11. In contrast, the term PROCEED resulted in a higher percentage of participants choosing to stop until the slow sign was displayed when comparing Treatments 12 and 13. Neither Treatment 8 nor Treatment 9 was understood by participants.

For the participants who viewed a supplemental sign that contained either the word GO or PROCEED, researchers asked if the use of the opposite word (e.g., PROCEED if originally shown GO) would change their actions at the AFAD. The majority of participants indicated that there was no difference in the meanings of the two terms and, therefore, would not change their actions. When asked to identify a preference between the two terms, the participants were equally split between the two.

Steady versus Flashing Red Beacon

Overall, 58 percent of participants believed that the flashing red and steady-burn beacon had the same meaning. The majority of these participants thought that any red light indicated that motorists should stop. However, with the stop/slow AFAD motorists need to remain stopped until the slow sign is displayed. Unfortunately, the series of questions used by researchers did not address the participants subsequent decision to remain stopped or proceed.

Forty-two percent of the participants thought that the flashing red and steady-burn beacon had different meanings. However, the main difference cited was that the flashing red beacon was more conspicuous. Only 16 percent of these participants thought that a flashing red beacon meant for the motorist to stop and then proceed, while a steady-burn red beacon meant for the motorist to stop and stay until otherwise indicated.

As further investigation, researchers asked participants to identify their preference for either a flashing or steady-burn beacon. Not surprisingly, the majority of participants (69 percent) indicated that they preferred a flashing beacon because it was more conspicuous.

Preferences

Researchers determined the overall sign rankings using a rank score, which was computed by assigning one point each time a treatment was ranked first (best), two points for second place rankings, etc., with the maximum number of points assigned each time a treatment was ranked worst. Thus, the treatment perceived to be the best would have the lowest score.

Table 5 contains the rank score for the first group of supplemental sign treatments. The best rank scores were given to Treatment 6 (3.21) and Treatment 16 (3.31). The participants preferred these supplemental signs since they contained a wait or stop component and told motorists what would happen next (i.e., sign would change to slow sign). However, the percent of participants that were judged to correctly interpret the meaning of the stop/slow AFAD was less than 50 percent for these two treatments.

Table 5. Phase 1 Stop/Slow AFAD Group 1 Supplemental Signing Preference.

	Treatment							
	 **4**	 **5**	 **6**	 **7**	 **8**	 **9**	 **15**	 **16**
Rank Score	4.71	5.88	**3.21**	**3.76**	4.74	5.67	4.72	**3.31**

Bolded font indicates the best treatments (i.e., lowest rank scores).

As Table 6 shows, each supplemental sign in the second group contained two informational segments (top and bottom). Participants gave the best rank scores to Treatment 10 (1.92) and Treatment 11 (1.96), which were identical except for the words GO and PROCEED. The participants preferred these supplemental signs since they contained both a stop sign symbol and a slow sign symbol. For Treatments 12 and 13, participants did not feel that the WAIT HERE phrase adequately explained the stop and stay condition. For Treatment 14, the STAY

HERE phrase made participants desire information about how long they would need to stay before proceeding.

Table 6. Phase 1 Stop/Slow AFAD Group 2 Supplemental Signing Preference.

	Treatment				
	 **10**	 **11**	 **12**	 **13**	 **14**
Rank Score	**1.92**	**1.96**	3.58	3.53	4.01

Bolded font indicates the best treatments (i.e., lowest rank scores).

Once participants had selected the best sign from each of the two sign groups, researchers showed them their two best selections together and had them select the overall best sign. The majority of participants (76 percent) selected Treatment 10 or 11 as the overall best sign. Again, these signs included both sign symbols (stop and slow) and directions on the desired actions for each condition.

Phase 2 Study Design and Protocol

Based on the findings from the first phase of the stop/slow AFAD motorist comprehension surveys, researchers decided to further evaluate Treatments 7, 10, and 14. All of these supplemental signs used a symbol of the slow sign instead of text. In addition, Treatment 10 used a symbol of the stop sign instead of text. As Figure 7 shows, researchers also included the two current supplemental signing options (Treatments 1 and 2) in Phase 2.

Researchers evaluated each of the supplemental sign treatments with two different operational conditions for the red beacon: flashing and steady-burn. Researchers still believed that there was a question as to which of these operational conditions would garner better compliance with the AFAD.

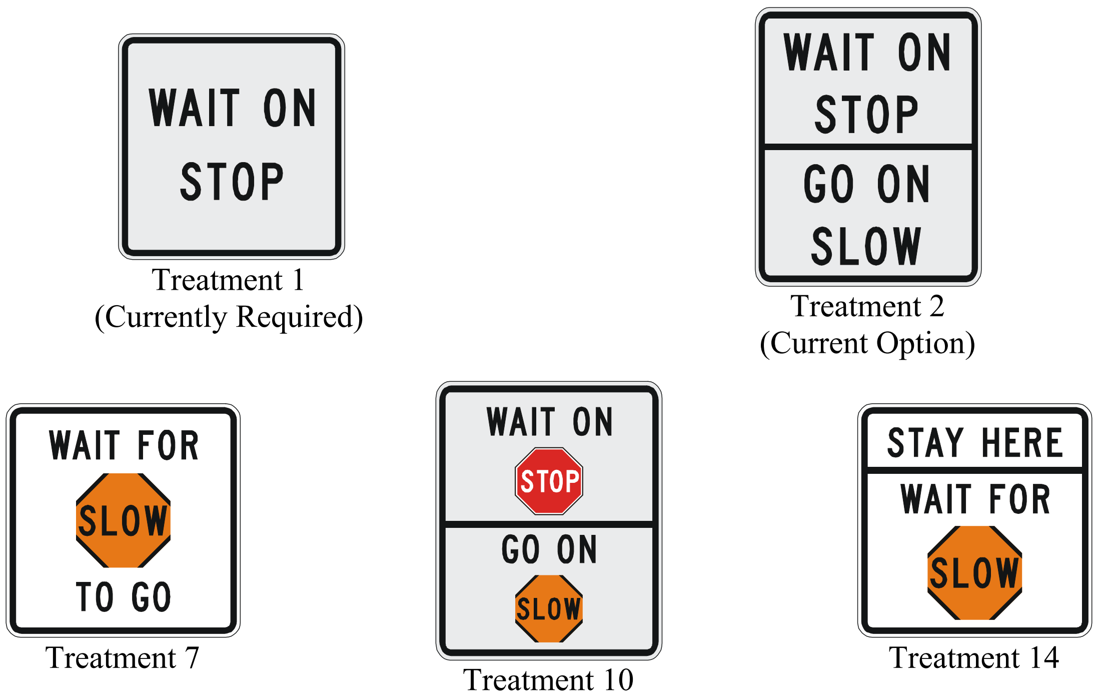


Figure 7. Phase 2 Supplemental Signing Treatments.

Due to the desire to reduce learning effects, each participant only viewed one of the supplemental signing treatments displayed in a graphic with a stop/slow AFAD and either a flashing or steady-burn red beacon (similar to Figure 6). After the participant viewed the graphic on a laptop computer, researchers asked the following series of questions to determine if the participant understood the device and to gather information regarding the use of a flashing or steady-burn red beacon with the device.

- What is the device telling you to do?
- How will you know when to proceed?
- Would you stop and go or remain stopped until otherwise indicated? Why?
- Do you think the sign changes? Why or why not?
- How well do you think this device informs motorists that they need to stop and remain stopped until otherwise indicated?

Next, researchers showed each participant a graphic that contained all five supplemental signing treatments. The order of the treatments was randomized to reduce placement bias. The participants ranked the signs from best to worst according to their ability to inform motorists to stop and remain stopped until otherwise indicated. Each participant provided reasons why they liked and disliked the best and worst treatments, respectively, in their ranking. Finally, researchers asked the participants to rate the use of a stop/slow AFAD compared to the use of a flagger using the following scale: much better, better, the same, not better, or terrible.

Phase 2 Data Reduction and Analysis

Researchers entered all the data collected into spreadsheets, categorized participant answers to all questions, and computed percentages to assess motorist comprehension of the stop/slow AFADs. As in Phase 1, the only correct action was to stop and wait for an indication from the AFAD of when it was safe to proceed. Incorrect actions included stopping and then proceeding (like at a standard stop sign) and stopping and waiting on a flagger to tell them to proceed.

Researchers then used a chi-square test of homogeneity to determine whether the red beacon (flashing or steady) impacted the proportion of motorists that chose a correct action. The null hypothesis is that the two variables (supplemental sign treatment and beacon mode) are independent. The alternative hypothesis is that the two variables are dependent. Since the chi-square test statistic was less than the chi-square tabulated value (α=0.05 and degrees of freedom=4), researchers determined that the two variables were independent. So, the beacon mode (flashing or steady) did not affect the proportion of motorists that chose a correct action for each treatment. In addition, review of the participants' comments showed that only 1 percent of the participants actually distinguished between the flashing and steady-burn red beacon. Instead, almost all of the participants based their decision upon the supplemental sign message. Thus, researchers decided to combine the flashing and steady-burn red beacon data for each supplemental sign treatment to assess motorist comprehension.

With respect to comprehension, a device was considered acceptable for use in Texas when 85 percent of the total survey participants correctly interpreted the meaning of the device (*17*). When the comprehension level was less than 85 percent, researchers used a confidence interval test with a 5 percent significance level (α=0.05) to determine if the comprehension percentage was statistically different from the 85 percent criterion. If 0.85 fell within the boundaries of the confidence interval, then the level of comprehension for the tested device was not statistically different from 85 percent.

Phase 2 Results

Comprehension

Table 7 summarizes the participants' open-ended answers to the following two questions: "What is the device telling you to do?" and "How will you know to proceed?" Based on these data, Treatment 10 had the highest correct comprehension level (89 percent) and was the only supplemental sign that had a correct comprehension level greater than 85 percent (threshold criterion). All of the other supplemental sign treatments had correct comprehension levels statistically less than the 85 percent criterion. In addition, Treatment 10 had the highest percentage of participants that stated they would wait until the slow sign was displayed before proceeding (50 percent). In contrast, for Treatments 1 and 2 (current signing) the percentage of participants that stated they would wait until the slow sign was displayed to proceed was 14 percent and 22 percent, respectively. These values were lower than those for all three of the new supplemental signs that displayed the slow symbol on the sign. Researchers believe that these data indicate that the participants better understood that the stop sign on the AFAD would change to a slow sign when the supplemental sign message contained the slow symbol instead of text.

With respect to incorrect actions, Treatment 10 had the lowest percentage of participants that would have stopped and then proceeded like at a standard STOP sign (8 percent). Again, researchers believe the use of the stop and slow sign symbols on the supplemental sign may have contributed to this. In contrast, Treatment 2 (the same sign but all text) resulted in the highest percentage of participants that would have stopped and then proceeded (24 percent).

Treatment 10 also had the lowest percentage of participants that would wait until directed by a flagger (2 percent). This is important since a flagger does not have to be located in the immediate vicinity of the AFAD. Treatment 1 (currently required) resulted in almost one-quarter of the participants waiting until directed by a flagger. Treatments 7 and 14 yielded similar findings. For all three of these treatments (1, 7, and 14), researchers believe that participants were waiting for a flagger to display the slow sign because the supplemental sign said "wait for slow" instead of "go on slow."

Table 7. Phase 2 Participant Actions for Stop/Slow AFADs.

Supplemental Signing Treatment (n=64 per sign)	Correct Actions			Incorrect Actions		
	Stop Until Slow Sign Displayed	Stop Until Otherwise Indicated	Total	Stop & Proceed	Wait Until Directed by Flagger	Total
 Treatment 1	14%	47%	61%	16%	23%	39%
 Treatment 2	22%	48%	70%	24%	6%	30%
 Treatment 7	44%	22%	66%	19%	15%	34%
 Treatment 10	50%	39%	**89%**	8%	2%	11%[a]
 Treatment 14	33%	27%	60%	13%	23%	40%[b]

Bolded text indicates comprehension levels greater than 85 percent or not statistically different from 85 percent.
[a] 1 percent of the subjects were not sure what to do.
[b] 4 percent of the subjects were not sure what to do.

Table 8 shows the results for when the participants were asked directly if they would stop and then proceed or if they would remain stopped until otherwise indicated (i.e., participants were forced to choose between the two actions provided). Again, Treatment 10 yielded the highest correct comprehension level (92 percent). However, unlike for the open-ended question responses, the other two new supplemental sign treatments (7 and 14) and the sign treatment currently required (Treatment 1) also had correct comprehension levels greater than or not significantly different from the 85 percent criterion.

Table 8. Phase 2 Participants' Responses to "Would You Stop and Go or Would You Remain Stopped until Otherwise Indicated?"

Supplemental Signing Treatment (n=64 per sign)	Stop and Remain Stopped	Stop and Proceed
 Treatment 1	**77%**	23%
 Treatment 2	69%	31%
 Treatment 7	**84%**	16%
 Treatment 10	**92%**	8%
 Treatment 14	**86%**	14%

Bolded text indicates comprehension levels greater than 85 percent or not statistically different from 85 percent.

Treatment 10 also had the lowest percentage of participants that would have stopped and then proceeded (8 percent). For all of the new supplemental sign treatments (7, 10, and 14), a portion of the participants stated they would have stopped and then proceeded. Thus, researchers believe a gate arm is needed to help ensure that motorists who misinterpret the stop/slow AFAD directions will remain stopped and not proceed through the work zone.

Treatment 2 had the lowest correct comprehension level, which resulted in 31 percent of the participants stating they would stop and then proceed. Researchers attribute these findings to the misinterpretation of the phrase GO ON SLOW. Participants commented that they thought this phrase meant to proceed with caution or go slowly through the work zone.

Table 9 contains the results for when the participants were directly asked if they thought the stop sign would change. None of the signing treatments resulted in correct comprehension levels greater than or equal to the 85 percent criterion. This is not surprising since the stop/slow AFAD depicted on the laptop did not look like it had moving parts or the ability to change. The new supplemental sign treatments all resulted in higher levels of comprehension that the stop sign would change to a slow sign. Again, Treatment 10 yielded the highest percentage of participants that understood the sign would change to slow (58 percent). For the sign treatments currently available (Treatments 1 and 2), only 5 percent and 28 percent, respectively, thought the sign would change to a slow sign. Instead, 87 percent and 62 percent, respectively, thought the stop condition displayed on the AFAD was a standard stop sign that did not change.

Preferences

As in Phase 1, researchers determined the overall ranking using a rank score. Again, the treatment perceived to be the best would have the lowest score. Table 10 contains the rank score for the five treatments. Participants gave the best rank score to Treatment 10 (1.5). The participants preferred Treatment 10 because it contained directions on the desired actions for each condition (stop and go) and contained symbols. Treatment 1 (currently required) was ranked as the worst sign (4.5). Participants felt Treatment 1 was confusing and not clear on when they should proceed. In addition, several participants commented that they did not like Treatment 1 since it did not contain symbols.

Rating Stop/Slow AFAD Compared to Flagger

Finally, researchers asked the participants to rate the use of a stop/slow AFAD compared to the use of a flagger using the following scale: much better, better, the same, not better, or terrible. For analysis, researchers combined the much better and better categories, as well as the not better and terrible categories. Overall, 54 percent of the participants liked the use of a stop/slow AFAD better than the use of a flagger. The reasons for this preference were divided into four main categories: safer for the flagger and motorists, easier to understand, better than a flagger, and people pay more attention to signs. Twenty-seven percent of the participants thought the stop/slow AFAD was not better or worse than a flagger. The main reasons provided were: flaggers get your attention better, some motorists may not understand the stop/slow AFAD, and the AFAD may malfunction.

Table 9. Phase 2 Participants' Responses to "Do You Think the Sign Changes?"

Supplemental Signing Message (n=64 per sign)	YES			NO		
	To SLOW	To Other[a]	Total	Standard Stop Sign	Other[b]	Total
 Treatment 1	5%	5%	10%	87%	3%	90%
 Treatment 2	28%	5%	33%	62%	5%	67%
 Treatment 7	48%	2%	50%	48%	2%	50%
 Treatment 10	58%	0%	58%	42%	0%	42%
 Treatment 14	51%	2%	53%	47%	0%	47%

[a] Participants responded either GO or YIELD.
[b] Participants responded the sign could not change because it was not electronic or digital.

Table 10. Phase 2 Rank Score for Stop/Slow AFAD Supplemental Sign Treatments (n=320).

<table>
<tr><th></th><th>Treatment 1</th><th>Treatment 2</th><th>Treatment 7</th><th>Treatment 10</th><th>Treatment 14</th></tr>
<tr><td>Rank Score</td><td>4.5</td><td>3.0</td><td>3.2</td><td>1.5</td><td>2.9</td></tr>
</table>

Bolded text indicates the best treatment (i.e., lowest rank score).

RED/YELLOW LENS AFADS

The following sections describe the experimental design and results for each phase of the red/yellow lens AFAD motorist survey.

Phase 1 Study Design and Protocol

Researchers were concerned that the signal indications used with the red/yellow lens AFAD may cause confusion since they differ from traditional signal displays (i.e., red, yellow, and green [traffic signal] or red and green [freeway entrance control signal]). Based on this concern, researchers initially showed each participant a static graphic of a red/yellow lens AFAD that had blank displays (i.e., neither the red nor the yellow lights were illuminated) and the gate arm down (Figure 8). Researchers also altered the legend on the required supplemental sign so it did not contain any signal color information (i.e., removed ON RED). While viewing this graphic, a researcher asked each participant to identify the following for each of the three operational conditions (stop, proceed, and transition).

- Which light would be illuminated (top or bottom)?
- What color would the light be (open ended)?
- Would the light be flashing or steady?
- Would the gate arm be up or down?

Researchers then showed each participant separate static graphics of the red/yellow lens AFAD during the stop (steady red light on top and gate arm down), proceed (flashing yellow light on bottom and gate arm up), and transition (steady yellow light on bottom and gate arm up) conditions. Researchers asked participants if they believed that each display shown adequately indicated the desired conditions. Finally, researchers asked participants if they felt the red/yellow lens AFAD could be used to replace a flagger at a work zone lane closure.

Figure 8. Phase 1 Blank Red/Yellow Lens AFAD Graphic.

Phase 1 Results

Participant Expectations for Displays

Table 11 shows there was a great deal of consensus among the participants' expectations for the stop and proceed conditions. For the stop condition, the majority of the participants correctly thought the AFAD would display a steady red signal in the top location and the gate arm would be down. For the proceed condition, a majority of the participants thought the AFAD would display a signal indication in the bottom location and the gate arm would be raised during the proceed condition. However, 80 percent of the participants thought the signal indication would be green (instead of yellow) and 76 percent of the participants thought the signal indication would be steady-burn (instead of flashing). Only about one-quarter of the participants thought the proceed condition would consist of a flashing yellow signal. This is not surprising considering that traffic and freeway entrance ramp control signals utilize steady-burn green indications to inform motorists when to proceed.

Table 12 shows there was less agreement when the participants were questioned about the transition period between the proceed and stop conditions. Currently, during the transition condition, the red/yellow lens AFAD displays a steady-burn yellow indication on bottom and the gate arm is raised. The variety of expectations indicates that the transition condition could garner a significant amount of confusion among motorists.

Table 11. Phase 1 Red/Yellow Lens AFAD Interpretation of Stop and Proceed Conditions.

Question	Stop Condition	Proceed Condition
What indication would be on?	Top – 82% Bottom – 18%	Top – 22% Bottom – 78%
What color would it be?	Red – 100%	Green – 80% Yellow – 20%
Do you think it should be steady or flashing?	Steady burn – 76% Flashing – 24%	Steady burn – 76% Flashing – 24%
What position would the gate arm be in?	Down – 100% Up – 0%	Down – 4% Up – 96%

Table 12. Phase 1 Red/Yellow Lens AFAD Interpretation of Transition Condition.

Question	Transition Condition
What indication would be on?	Top – 52% Bottom – 46% Both – 2%
What color would it be?	Yellow – 58% Red – 30% Green – 10% Red or Yellow – 2%
Do you think it should be steady or flashing?	Steady burn – 30% Flashing – 70%
What position would the gate arm be in?	Down – 54% Up – 46%

Participant Assessment of Standard Displays

For the stop condition, all of the participants believed that the standard display (steady-burn red signal with gate arm down) indicated they should stop and remain stopped. Table 13 shows the primary device components that contributed to this consensus were the red signal indication and the gate arm being down.

Table 13. Phase 1 Device Components Contributing to Participant Interpretation of the Stop Condition.

Display Component	Percent of Participants[a]
Red Light	92%
Gate Arm Down	66%
Sign Legend	32%
Flag on Gate Arm	10%
Steady-Burn Light	8%

[a] Total responses will be more than 100 percent since participants could provide multiple responses.

For the proceed condition, 78 percent of the participants thought that the AFAD display (flashing yellow signal with gate arm up) indicated they should progress through the work zone. Fifty-one percent of these participants also indicated that the device was telling them to proceed with caution. Table 14 shows that the yellow signal indication and the gate arm being up were the primary device components that contributed to this interpretation.

Table 14. Phase 1 Components Contributing to Participant Interpretation of the Proceed Condition.

Display Component	Percent of Participants[a]
Yellow Light	77%
Gate Arm Up	51%
Flashing Light	13%

[a] Total responses will be more than 100 percent since participants could provide multiple responses.

Twenty-two percent of participants believed that they could not proceed when the AFAD displayed a flashing yellow signal indication and the gate arm was up. Fifty-five percent of these participants thought the signal indication should be green if they were supposed to proceed. Another 27 percent of these participants thought the yellow signal indication meant the device was about to change to a red signal indication (stop). Again, the comments regarding the signal colors are not surprising considering that traffic signals utilize green and yellow indications to inform motorists when to proceed and when the signal is about to change to the stop condition, respectively.

Finally, for the transition condition only 10 percent of the participants believed that the AFAD display (steady-burn yellow signal with gate arm up) was warning them to stop. Ninety percent of the participants believed that the transition condition display did not indicate that they needed to stop. As Table 15 shows, the reasons included: yellow means to go slow (69 percent), gate arm is up (24 percent), and supplemental sign only indicates to stop on red (16 percent). Again, these data show that the current transition condition could garner a significant amount of confusion among motorists.

Table 15. Phase 1 Reasons for Proceeding during Transition Condition.

Response	Percent of Participants[a]
Yellow means go slow	69%
Need to use caution	27%
Gate arm is up	24%
Display is confusing	22%
Sign only indicates stop on red	16%
Not like a traditional signal	11%
Light should be flashing if need to stop	11%
Unsure if changing to red or green	2%

[a] Total responses will be more than 100 percent since participants could provide multiple responses.

Red/Yellow Lens AFAD Compared to Flagger

Researchers asked participants if they believed that the red/yellow lens AFAD could replace a flagger at a work zone lane closure on a two-lane, two-way road. Eighty-four percent of participants thought the red/yellow lens AFAD could replace a flagger because they felt it was understandable and safer for the flagger. Sixteen percent of the participants did not think the red/yellow lens AFAD could replace a flagger. Reasons included: AFAD is confusing, did not trust the AFAD, and flaggers get your attention better.

Phase 2 Study Design and Protocol

The results from the first phase confirmed that motorists understood the stop phase, but also showed that motorists may misinterpret the proceed and transition phases. Thus, researchers created seven video sequences (shown in Table 16) to evaluate motorist comprehension of the red/yellow lens AFAD. Each participant only viewed one video sequence on a laptop computer. While each phase was shown, researchers asked the participant what the device was telling them to do. Figure 9 shows a screenshot from the video.

Table 16. Phase 2 Red/Yellow Lens AFAD Video Sequences.

Video Number	Phase 1	Phase 2	Phase 3
1	Stop	Proceed	Transition
2	Proceed	Transition	Stop
3	Transition	Stop	Proceed
4	Stop	Proceed	NA
5	Proceed	Stop	NA
6	Stop	Transition	NA
7	Transition	Stop	NA

NA = Not Applicable

Figure 9. Screenshot from Phase 2 Red/Yellow Lens AFAD Video.

After the video portion of the survey, researchers asked participants how well the device informed motorists when they needed to stop and when it was safe for them to proceed through the work zone. In addition, researchers asked the participants to rate the use of the red/yellow lens AFAD compared to the use of a flagger using the following scale: much better, better, the same, not better, or terrible.

Phase 2 Results

Comprehension

Table 17 shows that all participants understood that the steady red signal with the gate arm down meant stop. No matter the order shown, almost all of the participants thought the flashing yellow signal with the gate arm up meant to proceed with caution. Additionally, for all of the scenarios except Scenario 2 at least 94 percent of the participants felt like the steady yellow signal with the gate arm up also meant to proceed with caution. For Scenario 2 (flashing yellow, steady yellow, and then steady red), 41 percent of the participants commented that the steady yellow signal meant that the signal was about to turn red and they should prepare to stop. Researchers believe that more participants correctly interpreted the transition condition in Scenario 2 because they saw transition condition between the proceed and stop conditions. When only two phases were shown (one red and one yellow), both yellow signals (flashing and steady) were interpreted to mean proceed with caution by 100 percent of the participants.

Table 17. Phase 2 Red/Yellow Lens AFAD Interpretation of Signal Meaning.

Scenario	Steady Red Light and Gate Arm Down (n=224)	Flashing Yellow and Gate Arm Raised (n=160)		Steady Yellow and Gate Arm Raised (n=160)		
	Stop	Proceed with Caution	Gate Arm Up, Can Go	Proceed with Caution	Not Sure	Arm Coming Down or Light about to Turn Red
1	100%	100%	0%	94%	3%	3%
2	100%	100%	0%	53%	6%	41%
3	100%	97%	3%	94%	0%	6%
4[a]	100%	100%	0%			
5[a]	100%	100%	0%			
6[b]	100%			100%	0%	0%
7[b]	100%			100%	0%	0%
Total	100%	99%	1%	88%	2%	10%

Shaded cells indicate that the signal indication was not evaluated.
[a] Only the steady red and flashing yellow phases were displayed.
[b] Only the steady red and steady yellow phases were displayed.

Effectiveness

Next, the participants were asked how well the red/yellow lens AFAD informed motorists of the need to stop and indicate when it was safe for them to proceed through the work zone. Overall, 79 percent of participants thought the red/yellow lens AFAD did extremely well or well at informing the motorists of these conditions. The main reasons provided were that the AFAD did a good job of informing motorists of what actions to take, motorists could see the AFAD better than a flagger, and using an AFAD was safer than a flagger. Twenty-one percent of participants did not think the red/yellow lens AFAD did a good job informing motorists of the correct driving actions. The main reasons provided were that they prefer flaggers, the AFAD was confusing, and motorists would not understand the difference between the steady yellow and flashing yellow signals.

Rating Red/Yellow Lens AFAD Compared to Flagger

Finally, participants were asked to rate the use of a red/yellow lens AFAD compared to the use of a flagger using the following scale: much better, better, the same, not better, or terrible. For analysis, researchers combined the much better and better categories, as well as the not better and terrible categories. Overall, 56 percent of the participants liked the use of a red/yellow lens AFAD better than the use of a flagger. The main reasons for this preference included: safer for the flagger, gets your attention better, and easier to understand. One-quarter of participants thought a red/yellow lens AFAD was not better than a flagger. The main reasons provided were: having a flagger is better and some motorists may not understand the difference between the flashing and steady yellow signal.

ADVANCE WARNING SIGN SEQUENCE

The following sections describe the experimental design and results for each phase of the advance warning sign sequence motorist survey.

Phase 1 Study Design and Protocol

In the case of a lane closure on a two-lane, two-way road, the advance warning sign sequence needs to notify motorists about the work ahead and the possibility that they may need to stop. In Phase 1, researchers designed two motorist surveys (one for each type of AFAD) to determine:

- If the MUTCD advance signing sequence for AFADs was sufficient.
- If a standard flagger symbol sign can be used when an AFAD was controlling traffic.
- If any additional warning signs were needed to convey to motorists that AFADs were directing traffic.

Each participant only participated in one advance warning sign sequence survey (either stop/slow or red/yellow lens).

Researchers began both surveys with a description of the work zone and the AFAD. Researchers then handed each participant the four advance warning signs shown in Figure 10 and instructed the participant to select the signs needed to inform motorists that there was work activity with a lane closure ahead, as shown in Figure 11. Participants then placed the selected signs in the order desired on a tabletop road graphic. Researchers asked each participant why they did or did not select each sign.

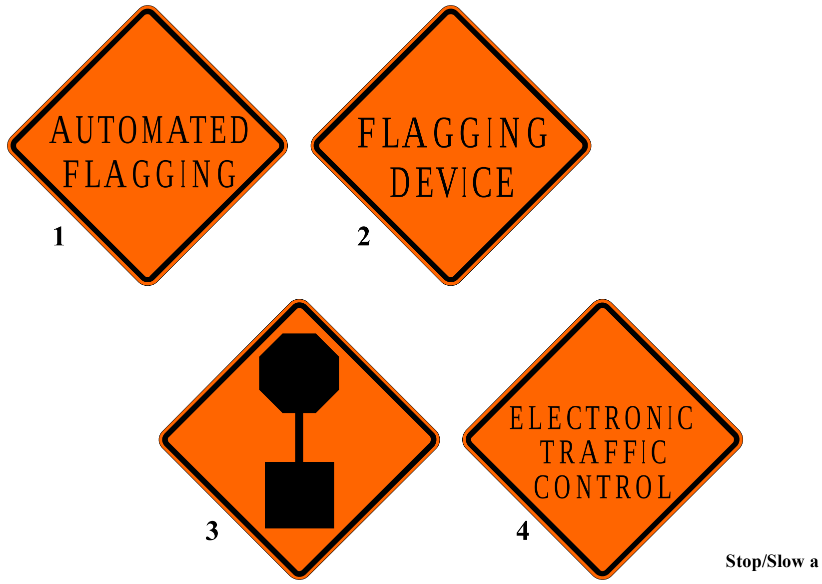
Figure 10. Phase 1 Advance Warning Signs.

For those participants that used the flagger symbol sign, researchers asked if the sign was acceptable to use with the AFAD shown even though a flagger was not always present to direct traffic. If the participant answered "no," the researcher gave them a blank orange diamond sign and asked them to design a sign that would let motorists know the AFAD shown was controlling traffic in lieu of a flagger. For those participants that did not use the flagger symbol sign, researchers asked if another sign was needed for the situation displayed in Figure 11. If the participant answered "yes," the researcher gave them a blank orange diamond sign and asked them to design a sign that would let motorists know the AFAD shown was controlling traffic in lieu of a flagger. Next, researchers showed all participants a group of alternative warning signs developed by researchers (Figure 12). Participants ranked the signs from best to worst according to their ability to inform motorists about the upcoming AFAD. Researchers altered the order of the alternative warning signs to reduce placement bias.

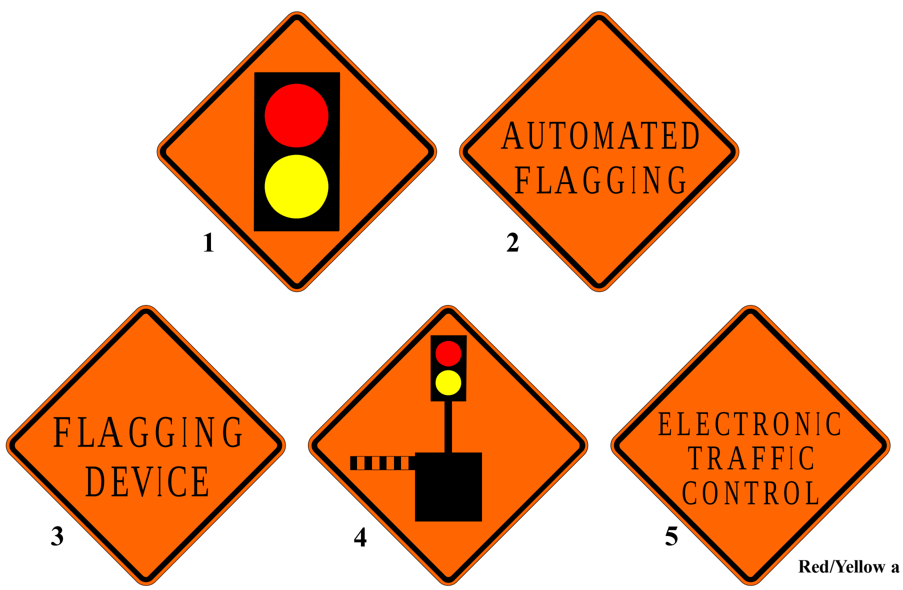
a) Stop/Slow AFAD Work Zone.

b) Red/Yellow Lens AFAD Work Zone.

Figure 11. Phase 1 Work Activity Graphics.



(a) Stop/Slow AFAD Alternative Warning Signs.



(b) Red/Yellow Lens AFAD Warning Signs.

Figure 12. Phase 1 Alternative Warning Signs.

Phase 1 Results

Advance Warning Signs Used

Table 18 shows that the majority of participants chose to use the ROAD WORK AHEAD, ONE LANE ROAD AHEAD, and BE PREPARED TO STOP signs, independent of the type of AFAD. Most participants also chose to utilize these signs in this order, which is the same order recommended in the MUTCD for AFAD operations (*3*). The primary reasons why participants included these signs were:

- ROAD WORK AHEAD – the sign identifies that there is work activity ahead.
- ONE LANE ROAD AHEAD – the sign informs motorists of the need to adjust their driving for a lane closure.
- BE PREPARED TO STOP – the sign clearly indicates what to do.

Table 18. Phase 1 Advance Warning Sign Placement.

Responses (n=30 per AFAD)		**Advance Warning Signs**							
									
AFAD Viewed		R/Y	S/S	R/Y	S/S	R/Y	S/S	R/Y	S/S
Percent of Participants that Included Sign		100%	87%	97%	77%	100%	93%	70%	50%
Sign Position In Sequence[a]	1	**74%**	**81%**	17%	9%	10%	11%	0%	27%
	2	20%	15%	**59%**	**47%**	13%	36%	14%	**33%**
	3	3%	0%	21%	35%	**67%**	**46%**	14%	13%
	4	3%	4%	3%	9%	10%	7%	**72%**	27%

R/Y = Red/Yellow Lens AFAD; S/S = Stop/Slow AFAD
Bolded font indicates the most frequent sign placement.
[a] Sign position 1 is the first sign encountered by the approaching motorist. Sign position 4 is the last sign encountered by the approaching motorist.

Comparatively, fewer participants chose to use the flagger symbol sign because there was not a flagger directing traffic. Participants that did utilize the flagger symbol sign stated that the sign informed motorists to look for a person at the lane closure. So, researchers further asked these participants if the flagger symbol sign would be acceptable to use if there was not a person directing traffic. For both types of AFADs, approximately 40 percent of these participants stated that the flagger symbol sign would not be appropriate in these circumstances.

Alternative Advance Warning Signs

For those participants that originally used the flagger symbol sign but did not think it would be appropriate if a flagger was not always present near the AFAD, researchers asked them to design a sign that would let motorists know the AFAD shown was controlling traffic in lieu of a flagger. Unfortunately, there was no consensus among participants as to what the design of this sign would look like.

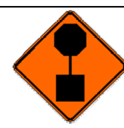
Similarly, researchers asked participants who did not include the flagger symbol sign in the initial sign sequence if a different sign was needed to represent the AFAD shown. Approximately 60 percent of these participants indicated that a new sign was not needed. For those participants who did believe a new sign was needed, researchers had them design a sign that would let motorists know the AFAD shown was controlling traffic in lieu of a flagger. Again, there was no consensus among participants as to what the design of this sign would look like.

Finally, researchers showed all the participants a group of alternative warning signs developed by researchers to represent either a red/yellow lens or stop/slow AFAD (dependent upon the survey). Participants ranked the signs from best to worst according to their ability to inform motorists about the upcoming AFAD. Again, researchers utilized a rank score to determine the best treatment (lowest score). Table 19 shows the rank score for each alternative sign. For the red/yellow lens AFAD sign, the best rank score (1.36) was for Treatment 4, which showed a symbol representation of the AFAD. This was not surprising since a significant number of the signs drawn by participants included a symbol of some type.

For the stop/slow AFAD, the best rank score (1.82) was for Treatment 1, which was a text based sign that could be used with either type of AFAD. This was unexpected based on participants' preference and use of symbols with the red/yellow lens AFAD. Further review of the participants' comments associated with their preference showed that participants did not like Treatment 3 (stop/slow AFAD symbol sign) because it looked like it depicted a traditional stop sign and therefore did not adequately convey the work zone situation to approaching motorists.

Participants believed that Treatment 1 was simple to understand and clearly indicated that a device was controlling traffic.

Table 19. Phase 1 Alternative Advance Warning Sign Rankings.

Red/Yellow AFAD Sign Options	Rank Score	Stop/Slow AFAD Sign Options	Rank Score
 1	3.64	 1	**1.82**
 2	3.36	 2	2.55
 3	3.14	 3	3.27
 4	**1.36**	 4	2.36
 5	3.50		

Bolded font indicates the best treatments (i.e., lowest rank scores).

Phase 2 Design and Protocol

The MUTCD recommends using the advance warning sign sequence shown in Figure 13 with AFADs (*3*). So in the Phase 2 survey, researchers showed each participant a video of the advance warning sign sequence shown in Figure 13. All participants viewed the same video on a laptop computer and were told the advance signing was leading up to an AFAD (type dependent upon the previous survey completed). After the video stopped the researcher asked the following questions.

- Do you think the signs you just saw let you know what to expect up ahead? Why or why not?
- Do you think that any additional signs are needed to alert motorists of the device ahead and that they may need to stop? Why or why not?

a) Sign 1 b) Sign 2 c) Sign 3

Figure 13. MUTCD Recommended Advance Warning Sign Sequence.

Phase 2 Results

Overall, 98 percent of participants thought the advance warning signs for AFADs recommended in the MUTCD adequately informed motorists of the conditions ahead. In addition, only 4 percent of participants thought an advance warning sign was necessary to indicate that a device, instead of a flagger, controlled traffic ahead.

SUMMARY AND RECOMMENDATIONS

To determine motorists' understanding of both types of AFADs and the advance warning sign sequence used with these devices, researchers developed and administered motorist surveys to 810 participants in Texas. The following sections summarize the motorist survey findings and recommendations regarding the design of the field studies.

Stop/Slow AFADs

When researchers directly asked participants how they would react to a stop/slow AFAD with the supplemental sign currently required (i.e., WAIT ON STOP), approximately one-quarter stated they would stop and then proceed like at a standard stop sign. In addition, only 5 percent of participants understood that the stop sign would change to a slow sign when they were allowed to proceed. While the percentage of participants that understood the AFAD sign would change from stop to slow increased when the GO ON SLOW sign was added (28 percent), more participants stated they would stop and then proceed like at a standard stop sign (31 percent).

In contrast, only 8 percent of participants stated that they would stop and then proceed with the WAIT ON STOP/GO ON SLOW symbol sign (shown in Figure 14). In addition, 58 percent of participants understood the AFAD sign would change. Overall, the WAIT ON STOP/GO ON SLOW symbol sign resulted in the highest percentage of participants who understood to stop and remain stopped until the AFAD indicated that it was safe to proceed (92 percent). Thus, researchers decided to evaluate the WAIT ON STOP/GO ON SLOW symbol sign during the field studies.

Figure 14. Alternative Supplemental Sign for Stop/Slow AFADs.

The majority of participants thought the flashing and steady-burn red beacon on a stop/slow AFAD had the same meaning. In addition, researchers did not find that the beacon mode (either flashing or steady-burn) impacted motorists' understanding of the stop/slow AFAD. Thus, researchers felt that a flashing red beacon could be used with stop/slow AFADs. Researchers did not believe that further evaluation of the impact of the beacon on motorist compliance was needed.

For all of the treatments evaluated, a portion of the participants indicated they would have stopped and then proceeded instead of waiting until the AFAD displayed the slow sign. Researchers believed a gate arm was needed to help ensure that motorists who misinterpreted the stop/slow AFAD instructions would remain stopped and not proceed through the work zone until allowed. Therefore, researchers also decided to investigate the impact of the gate arm on compliance in the field studies.

Red/Yellow Lens AFADs

Participants understood that the steady red signal with the gate arm down meant stop. However, the majority of participants thought both yellow signals (flashing and steady-burn) meant proceed with caution. Even though there is evidence of a lack of understanding of the difference between the proceed and transition phases, the use of the gate arm informs motorists when to proceed and when to stop (raised when the signal changes to the flashing yellow signal and lowered when the signal changes to steady red). Also, motorists stopped at the AFAD typically do not view the steady-burn yellow signal (assuming the queue of vehicles waiting is completely discharged). In addition, more participants understood the difference between the two yellow signals when they observed the AFAD cycle from the proceed condition, to the transition condition, and then to the stop condition. This is important because motorists approaching the AFAD during the proceed condition need advance warning that the AFAD is about to change to the stop condition.

While researchers did not specifically evaluate the impact of color vision deficiencies, all of the participants understood that when the top signal indication was illuminated and the gate arm was lowered they were to stop and when the bottom signal indication was illuminated and the gate arm was raised they could proceed. Researchers felt that the use of the gate arm was the most critical component to motorist understanding of the red/yellow lens AFAD. Based on all the findings, researchers decided to evaluate the current three-phase design of red/yellow lens AFAD in the field studies.

Advance Warning Signs

Ninety-eight percent of participants thought the advance warning signs for AFADs recommended in the MUTCD adequately informed motorists of the conditions ahead. In addition, there was a strong indication from participants that the flagger symbol sign should not be used if a person was not visibly controlling traffic at the AFAD location. Thus, researchers recommended using the following advance warning sign sequence with the AFADs in the field studies:

- ROAD WORK AHEAD (CW20-1D).
- ONE LANE ROAD AHEAD (CW20-4D).
- BE PREPARED TO STOP (CW20-7B).

CHAPTER 1.3: FIELD STUDIES

INTRODUCTION

To assess the operational and safety effectiveness of AFADs relative to the use of flaggers, researchers conducted field studies at lane closures on two-lane, two-way roadways in Texas. Researchers performed the field studies during the summers of 2010 and 2011. The following sections describe the treatments, sites, experimental design, and results of the field studies.

TREATMENTS

Researchers evaluated the following treatments during the first summer, which are also shown in Figure 15:

- A flagger with a stop/slow paddle at both ends of the lane closure.
- A stop/slow AFAD with a WAIT ON STOP sign at both ends of the lane closure.
- A red/yellow lens AFAD with a STOP HERE ON RED sign and a gate arm at both ends of the lane closure.

The AFAD treatments initially studied represented the minimum requirements in the MUTCD (*3*). The only exception was the design of the alternating red and white stripes on the red/yellow lens AFAD gate arms. TxDOT purchased its red/yellow lens AFADs during the interim approval period, prior to the MUTCD provisions requiring that alternating red and white stripes on the gate arm slope downward at a 45 degree angle. So, instead of vertical stripes on the gate arm, they sloped downward at a 45 degree angle. Researchers do not believe that this minor difference impacted the results of the field study.

After reviewing the stop/slow AFAD motorist comprehension survey results and the initial field study data, researchers decided to evaluate the following treatments during the second summer to assess the impact of the supplemental signs and gate arm:

- A stop/slow AFAD with a WAIT ON STOP sign and a gate arm at both ends of the lane closure (shown in Figure 16).

- A stop/slow AFAD with WAIT ON STOP and GO ON SLOW signs at both ends of the lane closure.
- A stop/slow AFAD with WAIT ON STOP and GO ON SLOW signs and a gate arm at both ends of the lane closure (shown in Figure 16).
- A stop/slow AFAD with alternative supplemental signs at both ends of the lane closure.
- A stop/slow AFAD with alternative supplemental signs and a gate arm at both ends of the lane closure (shown in Figure 16).

a) Flagger **b) Red/Yellow Lens AFAD** **c) Stop/Slow AFAD**

Figure 15. Initial Field Study Treatments.

Since the last two treatments included signing not approved in the MUTCD (*3*), TxDOT submitted a request to FHWA to experiment with the alternative supplemental signing. FHWA approved this request on June 1, 2011. Figure 17 shows the alternative supplemental sign designs approved by FHWA and used in the field evaluations.

TxDOT personnel in the San Antonio District attach a flag to the end of the gate arm on the red/yellow lens AFAD to increase the visibility of the gate arm. These personnel also use four to six cones spaced 10 to 20 ft apart on the centerline immediately upstream of the red/yellow lens AFAD to deter motorists from going around the gate arm. Based on TxDOT's experience, all treatments with a gate arm included a flag on the end of the gate arm and all treatments included cones on the centerline immediately upstream of the treatment (the exact number and spacing of cones varied). As discussed previously, researchers used the recommended advance warning sign sequence in the MUTCD (*3*) with all treatments.

a) WAIT ON STOP

b) WAIT ON STOP and GO ON SLOW

c) Alternative Signs

Figure 16. Supplemental Signs Evaluated in the Second Field Study.

EXPERIMENTAL DESIGN

The primary measure of effectiveness for the field studies was whether or not the first vehicle in the queue complied with the treatment's (flagger or AFAD) instructions. Researchers were typically located near the work area and were always out-of-view from motorists. In addition, the flagger controlling the AFAD(s) was not in the immediate vicinity of the treatment. Instead, the flagger was usually located at the midpoint of the work area so he/she could see both directions of traffic.

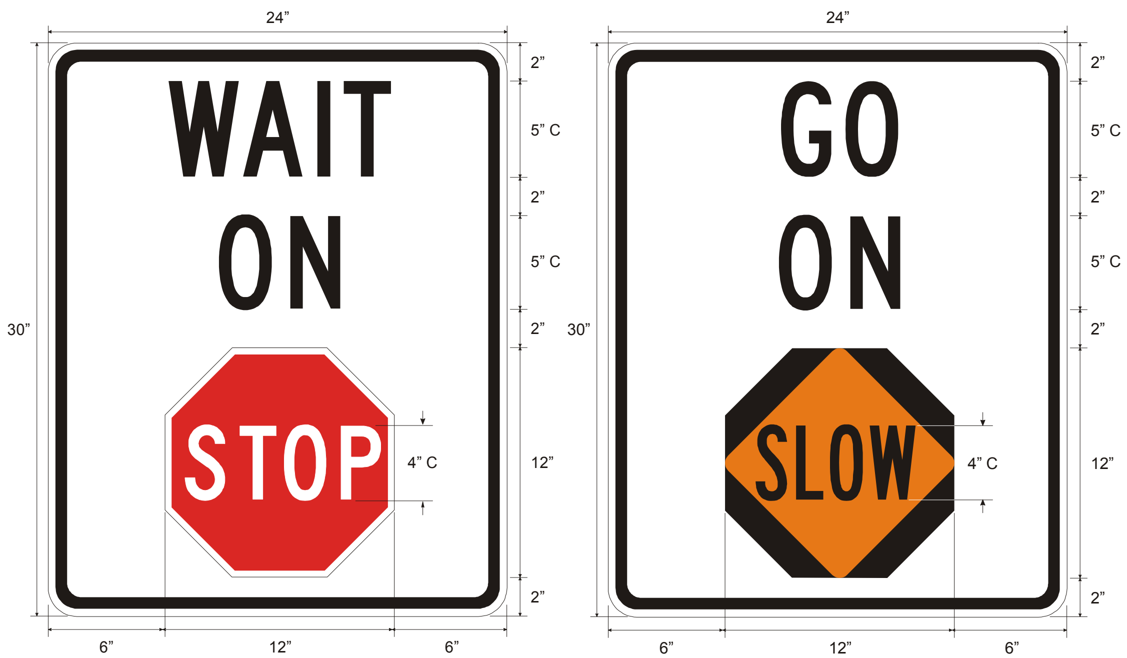


Figure 17. FHWA Approved Alternative Supplemental Signs for Use with Stop/Slow AFADs.

For each treatment, researchers observed the compliance of the first vehicle in the queue under the stop condition. If the first vehicle did not comply with the treatment's instructions, researchers described the non-compliance and noted the actions of the other vehicles in the queue. Researchers also documented:

- The arrival and departure times of the first vehicle in the queue (i.e., length of the stop condition).
- Whether opposing traffic was visible to the first vehicle in the queue.
- The total number of vehicles in the queue.

When researchers were not collecting observation data, they verbally administered surveys to the driver of the first vehicle in the queue. While the driver viewed the treatment (i.e., stopped at the lane closure), researchers asked the following series of questions to determine if the driver understood the treatment and to gather the driver's opinion about the treatment.

- What is the flagger/device at the lane closure telling you to do?
- How long would you remain stopped?

- How will you know when to proceed?
- Do you think the sign changes? Why or why not? (Note: This question was only asked for the flagger and stop/slow AFAD treatments.)
- Did you find the flagger/device easy to understand or confusing? Why?
- How do you rate the use of the AFAD compared to the use of a flagger using the following scale: much better, better, the same, not better, or terrible? (Note: This question was only asked for the AFAD treatments).

SITES

Researchers collected data at sites where work was already planned and TxDOT personnel or traffic control contractor personnel agreed to try AFADs. As Table 20 shows, researchers collected data at 12 sites during the first summer. At three of these sites researchers only administered motorist surveys. Researchers collected data at eight more sites during the second summer. Overall, researchers collected observation data at 17 sites and survey data at six sites.

Table 20. Field Study Site Treatments.

Treatment	Site																			
	First Summer												Second Summer							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Flagger	O	S	O	S	O	S	O	O		O	O	O								
Red/Yellow Lens AFAD	O	S	O	S	O	S	O		O		O									
Stop/Slow AFAD WOS	O	S	O	S	O	S		O			O	O								
Stop/Slow AFAD WOS and Gate Arm													B		O	O	B		O	O
Stop/Slow AFAD WOS/GOS													B							
Stop/Slow AFAD WOS/GOS and Gate Arm													B	O	O	O		O	B	O
Stop/Slow AFAD Alternative Signs													B							
Stop/Slow AFAD Alternative Signs and Gate Arm													B	O		O	B		O	

WOS = WAIT ON STOP; GOS = GO ON SLOW; O = Collected observation data; S = Collected survey data; B = Collected both observation and survey data; Shading indicates treatments that were not evaluated

Researchers made every effort to collect data for each treatment at each site. However, due to weather, duration of work, traffic volume, equipment malfunctions, etc. this was not possible at all sites. In addition, during the second summer non-compliance at the stop/slow AFAD treatments without a gate arm raised safety concerns that led researchers and TxDOT to terminate further field evaluations of AFADs without a gate arm. Overall, researchers collected observation data for 102 hours and 1708 stop periods. In addition, researchers administered 389 motorist surveys.

The sites were located on two-lane, two-way farm-to-market and state highways in the Bryan, Lufkin, Paris, and San Antonio Districts. Most of the sites were in rural locations, but some sites were in urban areas. The work activities consisted of ditch maintenance, chip seal, grading, patching, base repair, and bridge work. The 2009 average annual daily traffic (AADT) ranged from 220 to 5100 vpd, with the majority of the sites (55 percent) having less than 2000 vpd. The length of the lane closures ranged from approximately 300 ft to 1 mile, with three-quarters of the sites less than 2500 ft in length. The speed limit ranged from 35 to 70 mph. While traffic volume, lane closure length, and speed limit varied among the sites, researchers did not specifically design the study to examine the impacts of these variables.

RESULTS

Motorist Compliance

Table 21 summarizes the statistics associated with the stop cycle characteristics for each treatment. In general, the stop cycle duration ranged from less than 1 minute to 16 minutes and averaged between 1 to 2 minutes. The number of vehicles in queue ranged from one to 60 and averaged between two and seven. The stop cycle duration and the number of vehicles in the queue varied more during the second summer. This is most likely due to the fact that there was more diversification in the traffic volumes during the second summer (280 to 5100 vpd compared to 220 to 3650 vpd).

Table 21. Field Study Stop Cycle Characteristics.

Treatment	Stop Cycle Duration (min)				Number of Vehicles in the Queue			
	Avg.	Std. Dev.	Min	Max	Avg.	Std. Dev.	Min	Max
Flagger	1	0.9	<1	8	2	1.8	1	12
Red/Yellow Lens AFAD	1	0.9	<1	7	2	1.9	1	20
Stop/Slow AFAD WOS	1	1.6	<1	9	3	2.5	1	16
Stop/Slow AFAD WOS and Gate Arm	2	2.2	<1	12	6	7.5	1	46
Stop/Slow AFAD WOS/GOS and Gate Arm	2	3.3	<1	16	7	11.5	1	60
Stop/Slow AFAD Alternative Signs and Gate Arm	2	1.8	<1	9	6	6.1	1	33

WOS = WAIT ON STOP; GOS = GO ON SLOW; Avg. = Average; Std. Dev. = Standard Deviation

Table 22 contains the violation rate for each treatment. The violation rate represents the number of violations per 100 stop cycles. All of the motorists stopped by a flagger complied with the flagger's instructions; thus, the violation rate was zero. The violation rate for the stop/slow AFAD with a WAIT ON STOP sign and no gate arm was the highest (6.7), and was significantly different from the violation rate for the red/yellow lens AFAD (2.2) (based on a test of proportions using a 5 percent significance level [α=0.05]). Adding a gate arm to the stop/slow AFAD decreased the violation rate to 4.0, which was not significantly different from the red/yellow lens AFAD. Once a gate arm was added to the stop/slow AFAD, all of the treatments resulted in similar violation rates (3.2, 3.8, and 4.0), independent of the supplemental signs used. Thus, the supplemental signs did not appear to impact compliance.

Table 22. Field Study Violation Rate Statistics.

Treatment	Hours of Study	Stop Cycles	Violations	Violations per 100 Stop Cycles[a]
Flagger	13.7	294	0	0.0
Red/Yellow Lens AFAD	19.4	367	8	2.2
Stop/Slow AFAD WOS	20.7	360	24	6.7[b]
Stop/Slow AFAD WOS and Gate Arm	13.0	198	8	4.0
Stop/Slow AFAD WOS/GOS and Gate Arm	18.0	190	6	3.2
Stop/Slow AFAD Alt. Signs and Gate Arm	13.0	264	10	3.8
Total AFADs	84.1	1379	56	4.1

WOS = WAIT ON STOP; GOS = GO ON SLOW
[a] Rate computed as violations/stop cycles x 100
[b] Significantly different from red/yellow lens AFAD.

As discussed previously, researchers did not specifically design the study to examine the impacts of traffic volume and work zone length; however, researchers did examine the general trends associated with these variables. As Figure 18 shows, it appears that the violation rate at AFADs may decrease as the traffic volume increases. While this may appear counterintuitive, discussions with TxDOT personnel revealed that motorists on low-volume roads are typically locals who know the small likelihood of encountering an oncoming vehicle and thus may choose to disregard the AFAD's instructions, especially when there is no apparent oncoming traffic. As Figure 19 shows, as the work zone length increased so did the violation rate, which researchers would expect. This trend may be attributed to the longer wait times motorists incur as the work zone length is increased. While researchers can identify general trends from the relationships in these figures, the findings were highly variable. In addition, it appears that the two relationships conversely impact the violations. So, a long work zone on a low-volume roadway may incur more AFAD violations than a short work zone on a higher-volume roadway. Therefore, researchers could not define thresholds for traffic volume and work zone length for the implementation of AFADs. Instead, researchers recommend that supervisors and on-site personnel use their judgment to select sites that are appropriate for AFADs.

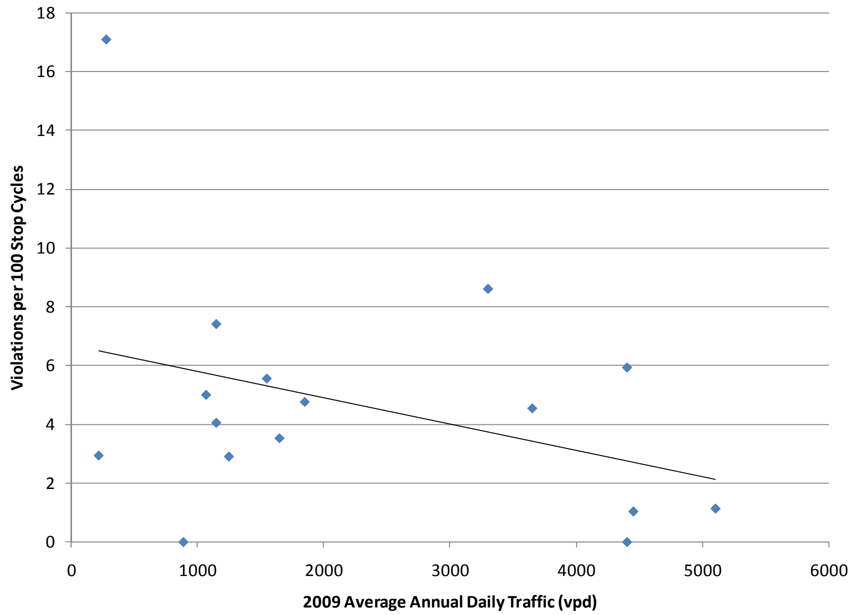


Figure 18. AFAD Violations per 100 Stop Cycles by Traffic Volume.

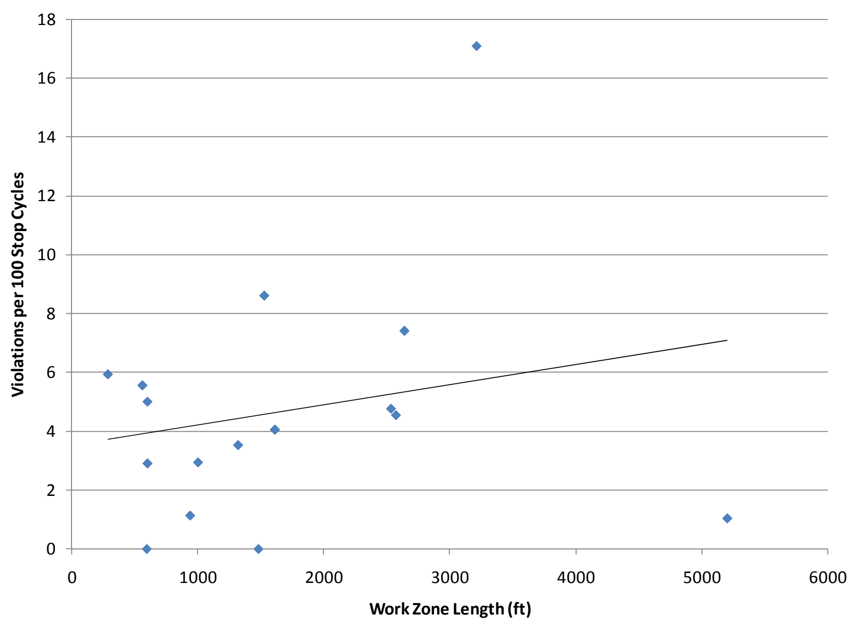


Figure 19. AFAD Violations per 100 Stop Cycles by Work Zone Length.

Motorist Surveys

With all of the treatments, at least 95 percent of participants waiting at the lane closure thought the treatment indicated that they were to stop. The majority of participants also stated that they would wait for a flagger or the device to tell them to proceed. With a flagger, participants indicated that they would proceed when:

- The sign the flagger was holding changed to a slow sign (47 percent).
- The flagger told them to proceed (39 percent).
- A combination of the previous two (10 percent).
- The pilot car arrived (4 percent).

With the red/yellow lens AFADs, the majority of participants (88 percent) thought the light would change from red to green when they were allowed to proceed. Even though a majority of participants expected the AFAD to display a green indication (instead of yellow), the participants understood that when the gate arm was raised they could proceed.

With the stop/slow AFAD with a WAIT ON STOP sign and no gate arm, 13 percent of participants stated they would either stop and then proceed or wait until there was no oncoming traffic and then proceed. The addition of the optional GO ON SLOW sign did not improve motorist understanding of the proper action, as 22 percent of participants stated that they would either stop and then proceed or wait until there was no oncoming traffic and then proceed. The addition of a gate arm to these two treatments reduced the portion of participants who stated they would proceed before they were supposed to do so to 5 percent, which was similar to the 2 percent found for the red/yellow lens AFAD. For both stop/slow AFAD treatments with the alternative supplemental sign (with and without a gate arm), none of the participants indicated they would proceed before instructed to do so.

Table 23 shows the participants' responses to how they would know when to proceed for the stop/slow AFAD treatments. In general, for treatments without and with a gate arm, as more information was provided (i.e., adding a GO ON SLOW sign or the use of alternative supplemental signs), the percentage of participants that expected a person to tell them to proceed decreased. Also, the percentage of participants that understood the sign would change increased with the addition of more information. Specifically, less than one-quarter of the participants thought the AFAD would change to a slow sign when only the WAIT ON STOP sign was used. In contrast, when the optional GO ON SLOW sign was used, at least one-half of participants thought the AFAD would change to a slow sign. When the alternative supplemental signs were used, more than three-quarters of the participants thought the AFAD would change to a slow sign. As discussed previously, the alternative signs also decreased the likelihood that participants would proceed when they were not supposed to (i.e., stop and then proceed or proceed when there was no oncoming traffic). The impact of the gate arm can also be seen in the results shown in Table 23. Overall, between 37 and 53 percent of participants indicated they would proceed when the gate arm was raised. The impact of the gate arm was the greatest with the WAIT ON STOP sign and WAIT ON STOP/GO ON SLOW sign treatments, reducing the reliance on a flagger, incorrect actions (i.e., stopping and then proceeding and proceeding when there was no oncoming traffic), and other miscellaneous indications of when to proceed.

Table 23. "How Will You Know to Proceed?" – Stop/Slow AFADs.

Response	Without Gate Arm			With Gate Arm		
	WOS (n=84)	**WOS/GOS (n=9)**	**Alt. Signs (n=20)**	**WOS (n=40)**	**WOS/GOS (n=40)**	**Alt. Signs (n=40)**
When someone tells me	33%	11%	5%	18%	5%	8%
When the pilot car arrives	1%	0%	5%	2%	0%	0%
When the sign changes (When the sign changes to slow)	31% (7%)	44% (22%)	85% (65%)	13% (0%)	27% (15%)	47% (37%)
When the gate arm is raised	NA	NA	NA	53%	48%	37%
When there is no oncoming traffic	7%	11%	0%	5%	3%	0%
Stop and then proceed	4%	0%	0%	0%	0%	0%
Other	24%	34%	5%	9%	17%	8%

WOS = WAIT ON STOP; GOS = GO ON SLOW; NA = Not Applicable

When asked directly if the stop sign the flagger was holding changed, 98 percent of participants said yes. In contrast, only 60 percent of participants thought the stop sign on the stop/slow AFAD with the WAIT ON STOP sign changed. The percent of participants who thought the stop sign on the stop/slow AFAD changed did increase with the use of the optional GO ON SLOW sign (71 percent) and alternative supplemental signs (80 percent), but none of the stop/slow AFAD treatments resulted in the same comprehension level as the flagger treatment.

These results show that although two types of temporary traffic control may be similar (a flagger stop/slow paddle and a stop/slow AFAD), motorists may not initially interpret them the same.

Almost all participants (99 percent) thought the flagger and stop/slow paddle were easy to understand. Ninety-three percent of participants thought the red/yellow AFAD was easy to understand and 68 percent thought this AFAD was better than a flagger. For the stop/slow AFAD the opinions varied by supplemental sign treatment. For both text supplement sign treatments (WAIT ON STOP and WAIT ON STOP/GO ON SLOW), 84 percent of participants thought the AFAD was easy to understand. When the alternative supplemental signs were used with the stop/slow AFAD, this percent of participants that thought the AFAD was easy to understand increased to 90 percent. Overall, approximately half of participants (51 percent) thought the stop/slow AFAD was better than a flagger.

Ease of Use and Other Considerations

Initially, TxDOT personnel felt that the AFADs took more time to setup and were harder to setup than a typical flagger operation. However, the more the crews used the AFADs the more proficient they became at setting up the AFADs and the time needed for setup decreased. TxDOT personnel felt that the AFADs improved worker safety since the flagger was located away from traffic. In addition, the flagger could activate an intrusion alarm if needed to alert other workers to potentially dangerous situations.

Very few malfunctions occurred with the AFADs during the first summer of data collection and these were mainly attributed to low batteries. During the second summer of data collection, the stop/slow AFADs malfunctioned frequently until the manufacturer was able to perform maintenance on the devices. The malfunctions mainly involved the gate arm not raising or a delay in the gate arm raising (i.e., the raising of the gate arm would occur sometime after the stop sign would change to a slow sign), which in some cases led to a vehicle hitting the gate arm.

TxDOT personnel also noted that the delay between pressing the button on the remote and the stop/slow AFAD changing was too long. This particularly impacted operations on higher-volume roadways. With a flagger, changing the paddle from the slow sign to the stop sign can occur quickly between vehicles. However, the delay between the signal and the AFAD changing the signs and lowering the gate arm caused the flagger to miss the opportunity to stop traffic as desired on a regular basis and in some instances resulted in vehicles hitting the gate arm. After more use, the operators became more accustomed to the delay, but occasionally it still caused problems.

When more than one supplemental sign was used (i.e., WAIT ON STOP/GO ON SLOW and alternative signs), TxDOT personnel thought the process of setting up the signs on temporary supports next to the AFADs was cumbersome. TxDOT personnel recommend designing the dual message such that it would fit on one sign and thus one sign stand, instead of the dual message being shown on two signs that requires two sign stands. TxDOT personnel also recommended making the signs from flexible, roll-up sign material (similar to the advance warning signs used) instead of rigid sheeting on a rigid substrate.

Researchers and TxDOT personnel noted that without a gate arm, motorists stopped closer to the stop/slow AFAD. This action, coupled with the height of the stop/slow AFAD signs used in this study (9 ft from the ground to the bottom of the sign), made it difficult for passenger car drivers to see the stop sign change to the slow sign (i.e., the vehicle itself blocked the view of the AFAD). According to the MUTCD (*3*), the height of the stop/slow AFAD sign should be at least 6 ft, so the height of the stop/slow AFAD signs evaluated in the field were 3 ft higher than required. The manufacturer mounted the stop/slow sign at a higher height so commercial vehicle drivers could more easily see the sign, but this may negatively impact the ability of passenger car drivers to view the sign. When a gate arm was added, motorists stopped farther back from the AFAD and thus reduced the potential of the vehicle itself blocking the stop/slow sign from the driver's view.

Researchers and TxDOT personnel also noted that without a gate arm there were more deliberate violations of the stop/slow AFAD when the queue of vehicles going in the same direction was visible to approaching motorists. On several occasions, a motorist would approach the stop sign displayed on the AFAD, hesitate, and then decide to proceed to catch up with the back of the queue. This behavior did not occur when the gate arm was used, since the gate arm and channelizing devices on the centerline blocked the motorist's path.

SUMMARY AND RECOMMENDATIONS

To assess the operational and safety effectiveness of AFADs relative to the use of flaggers, researchers conducted field studies at lane closures on two-lane, two-way roadways in Texas. Overall, the violation rate for the stop/slow AFAD with a WAIT ON STOP sign without a gate arm was the highest and was significantly higher than the violation rate for the red/yellow lens AFAD (which requires a gate arm). Adding a gate arm to this stop/slow AFAD decreased the violation rate such that it was not significantly different from the red/yellow lens AFAD. Once a gate arm was added to the stop/slow AFAD, the supplemental signs evaluated did not appear to impact compliance. However, the alternative supplemental signs shown in Figure 17 did increase motorist understanding that the stop sign would change when they were allowed to proceed. In addition, the alternative supplemental signs increased motorist comprehension that a slow sign would be displayed when motorists were allowed to proceed.

Based on the field study findings, researchers made the following recommendations.

- A gate arm should be required when using stop/slow AFADs.
- The alternative supplemental signs shown in Figure 17 should be used with stop/slow AFADs (instead of the current recommended signing).
- TxDOT should use public outreach techniques such as news stories, the internet, and social media in areas where is will deploy AFADs to notify and educate motorists.
- TxDOT should investigate the potential to combine the two alternative supplemental signs into one sign and the potential to use flexible, roll-up sign material instead of rigid sign sheeting on a rigid substrate to improve the ease of installation and removal of the AFADs and related devices.

PART 2 – SCHOOL CROSSING DEVICES

CHAPTER 2.1: CROSSING GUARD SAFETY ISSUES

INTRODUCTION

Researchers first worked to identify the issues and concerns inherent to crossing guard operations. The following sections detail the work performed by researchers during three separate sub-tasks: telephone interviews, field observations, and focus groups.

TELEPHONE INTERVIEWS

Procedure

Researchers conducted telephone interviews to identify: 1) locations experiencing problems with motorist compliance at school crossings and 2) locations that have used or are considering the use of innovative crosswalk devices. In addition, researchers wanted to discuss the concerns or problems that crossing guards have experienced during their work. Initially, researchers contacted the Safe Routes to School Coordinators for each of the 25 TxDOT districts. Once researchers had discussed with these contacts the nature of the information desired, they were frequently referred to officials within the city government, local police, or a specific school where concerns had been raised. The central questions posed to the interviewees were:

- What are the primary concerns identified within your district regarding school crossings?
- Is motorist compliance with crossing guards an issue in your district (that you are aware of)?
- Do you know of any locations within your district that have used or are thinking of using innovative or supplemental crosswalk devices?

Results

Researchers contacted all 25 TxDOT districts with varying degrees of success. At the end of this effort, researchers had conducted interviews with personnel representing areas within 13 of the districts. The following sections identify the key points gathered during these interviews.

General Information

Researchers used the initial questions of the survey to identify concerns or problems that needed to be addressed at school crossing locations within the districts contacted. The information that was identified from this line of questioning fell into the following three groups.

- Motorist behavior concerns:
    - Motorist inattention.
    - Right turns through the crossings.
    - Speeding.
    - Stopping in the crosswalk.
    - Motorists ignoring traffic signs.
- Site concerns:
    - Visibility of the crossing guard.
    - Angle of sun during morning school zone time makes it difficult to see the crossing guard.
    - Crosswalk markings needing to be re-applied.
    - Signage not adequate to protect children.
    - Construction around school crossings causes hazardous conditions.
    - High traffic flow not creating adequate gaps in traffic to cross children.
- Crossing guard training concerns:
    - Knowledge of operations.
    - Understanding of how to react to motorist non-compliance.

The concerns that were most commonly mentioned by the interviewees were those related to motorist behaviors. This was also the category most directly associated with the scope of this research project. When questioned further about motorist compliance or behavior concerns, seven of the agencies indicated that they have had problems with motorist compliance at school crossings. These agencies indicated that they have used the following methods to address motorist non-compliance.

- Installed in-pavement lights at the crosswalk that are on throughout the school zone time.
- Used a whistle in conjunction with a raised hand to remind motorists to remain stopped.

- Installed overhead illumination at crossing (concerns before daylight hours).
- Increased visibility of crossing guards (no specifics given).
- Used light-emitting diode (LED) stop paddles and vests.
- Installed SCHOOL ZONE pavement markings.
- Trained crossing guards with regard to compliance issues.
- Active and passive enforcement.

In addition, some agencies expressed interest in using the following means of increasing motorist compliance at school crossings in the future.

- Rumble strips or speed bumps at the school crossing.
- Public information campaigns/public service announcements (PSAs)/motorist education.
- Increased training of crossing guards.
- Increased enforcement.

Although not all of the ideas are within the scope of this project, which is to identify and assess potential portable devices for improving the safety and effectiveness of crossing guards, researchers used all ideas offered when identifying potential viable solutions for improving motorist compliance of school crossing operations.

Site Specific Information

The second objective of the interviews conducted was to identify specific sites where there were known concerns regarding motorist compliance at school crossings. Through this effort, researchers identified 14 sites. These sites represented a wide range of roadway configurations and unique devices that agencies had implemented at the school crossings. Given the diversity found in the identified sites, researchers selected a sampling of six sites at which to conduct field observations. A later section discusses this study in further detail.

Device Information

Finally, researchers wanted to gather information about innovative or unique devices used by crossing guards. Researchers sought to identify possible devices or strategies for future evaluation during this project. Six agencies indicated that there were locations within their areas that have used or were planning to use innovative or supplemental traffic control devices at school crossings. These devices included the following items:

- Cones in the road.
- Portable fluorescent yellow-green (FYG) pedestrian crossing signs.
- PEDESTRIAN CROSSING AHEAD sign with flashing lights.
- Stop paddles with embedded LED lights.
- Overhead school zone flashers.
- In-pavement LED lighting.
- Flashlights.
- Two crossing guards at one location.

Obviously, there is a wide range of devices and strategies that could potentially improve motorist compliance with crossing guard instructions. Researchers used these ideas as a stimulus for decisions regarding devices to evaluate later in this project.

FIELD OBSERVATIONS

Procedure

Researchers took the list of sites identified during the telephone interviews and selected sites where researchers could observe the current operations at those crossings. Researchers wanted to conduct site visits at areas with motorist compliance concerns to identify specific factors that might contribute to this safety concern. In addition, researchers chose sites where the crossing guards were using different innovative traffic control devices, as well as several different road configurations, to gain a diverse sampling of data regarding school crossing operations. Researchers gathered data on the following during the field observations:

- Site layout.
- Current traffic control devices used by (or in-conjunction with) the crossing guard.
- Crosswalk markings.
- Traffic volume during school zone times.
- Observed crossing guard events (i.e., times that the crossing guard actively assisted children across the street).
- Erratic motorist behavior or non-compliance at crossing guard location.

At each location, researchers conducted an initial site evaluation outside of school hours to identify the location of the school crossing in relation to driveways, cross-streets, warning signs, etc. The researchers then returned during active school zone times to observe the behavior of both the crossing guard and the motorists during crossing events. At most locations data were collected during both the morning and afternoon school zone times. This was not possible at two of the locations due to weather conditions that interrupted data collection.

For this task researchers attempted to start data collection in October 2010. However, due to unusually cold and wet weather experienced during the fall, this effort had to be extended and was not completed until February 2011. The weather conditions affected not only data collection efforts but also the amount of pedestrian traffic that was observed during these visits. Upon discussion with the site crossing guards they stated that the pedestrian volume was especially low and that it is significantly higher during spring and summer months. Although this was not unexpected by researchers, it did hinder the amount of data that could be gathered at each site.

Results

Researchers gathered data at six sites in four different cities in Texas. The sites were at both rural and urban locations for a diversity of crossing conditions. Table 24 provides information regarding each of the sites visited. In this table there is an observed traffic flow for the time the school zone was active, as well as counts of the number of crossing and erratic events observed at each site. Table 25 provides additional information regarding the current devices and personal protection equipment (PPE) used at each location. All of the stop paddles were less than 18 inches in diameter (i.e., the minimum size required in the Texas MUTCD [*18*]).

As Table 24 shows, most of the sites had very low numbers of children crossing while the crossing guard was on duty. However, researchers did observe a total of 83 crossing events (i.e., times when the crossing guard was active in assisting children across the street). During these events there were three erratic or non-compliance observations; this translates to a rate of 3.6 percent of the events having compliance problems during this task.

Table 24. School Crossing Field Observation Site Data.

Site	City	Total Observation Time (Minutes)	Time of Day (AM or PM)	Observed Hourly Flow Rate (vph)[a]	Total # of Pedestrians Observed	Total # of Crossing Events	Total # of Erratic Maneuvers
1	Bryan	25	PM	362	9	4	1
		20	AM	642	1	1	0
2	College Station	40	PM	360	56	12	1
		45	AM	845	9	6	0
3	Killeen	70	AM	564	77	30	0
4	Killeen	60	PM	1354	19	5	0
5	College Station	45	PM	583	15	7	0
		45	AM	1028	4	3	0
6	Valley Mills	65	AM	622	13	8	0
		60	PM	630	30	7	1

[a] vph = vehicles per hour

Table 25. Crossing Guard Devices and PPE.

Site	Stop Paddle	Crossing Guard PPE	Other Equipment
1	12 inch	Orange & yellow vest with CROSSING GUARD on front & back	1 cone at roadway median
2	12 inch white LEDs in STOP legend	Fluorescent yellow-green vest with CROSSING GUARD on front & back	None
3	12 inch red LEDs centered above and below legend	Fluorescent yellow-green vest with CROSSING GUARD on front & back and a fluorescent hat	Cones at each edge of crosswalk near school
4	12 inch	Fluorescent yellow-green vest with CROSSING GUARD on front & back	Pink flashlight in morning
5	15 inch	Fluorescent yellow-green vest with CROSSING GUARD on front & back	None
6	15 inch	Fluorescent yellow-green vest with SCHOOL GUARD on the back	Construction barrel with red lights in the middle of the road Also had a portable fluorescent yellow-green sign with four yellow LEDs that stated STATE LAW YIELD (symbol) TO PEDESTRIANS (symbol) WITHIN CROSSWALK

Researchers observed the first of the non-compliance events at Site 1. During this event, a passenger vehicle was in the outside lane of a four-lane, two-way road with a center turn lane. After the crossing guard had raised the stop paddle, but before the crossing guard entered the road, the vehicle continued past the guard and through the school crossing. The crossing guard let the car continue through and then stepped out into the roadway to assist the children in crossing. This was considered to be motorist non-compliance as the motorist should stop as soon as they notice the paddle being raised (within reason for stopping distance). At this site, the crossing guard was wearing an orange and yellow vest with CROSSING GUARD on the back and front of the vest and was carrying a 12-inch stop paddle. Additionally, the crossing guard had placed a cone at the median point of the crosswalk. Unfortunately, researchers could not determine whether the motorist intentionally ignored the crossing guard's direction to stop or if the motorist did not notice the crossing guard.

The second erratic maneuver occurred at Site 2 that was on a two-lane road when the crossing guard was in the middle of the lane with the stop paddle raised. An approaching vehicle turned onto the side-street at the crossing location in front of the crossing guard. The crossing guard let the vehicle go and fortunately there was no incident. At this site, the crossing guard wore a fluorescent yellow-green vest with CROSSING GUARD on the front and back and carried a 12-inch stop paddle with white LEDs in the STOP legend. In this circumstance, researchers believed that the motorist did observe the crossing guard in the roadway but still chose to make the turning maneuver. One additional observation made by researchers that could have significant impacts on crossing guard safety and effectiveness concerned the stop paddle with white LEDs in the STOP legend. On observing this paddle, researchers found that the over-glow from the LEDs made it difficult not only to read the STOP legend but also to identify the color and shape of the stop paddle. This concerned researchers regarding the appropriate use of LEDs in stop paddles to help improve safety without having a negative impact on recognition of the signing.

The third erratic maneuver was observed at Site 6 that was on a two-lane road. During this event an approaching truck drove through the crosswalk after the crossing guard had the stop paddle raised and had stepped out into the road, but before the crossing guard reached the center of the crosswalk. This vehicle drove past the crossing guard and researchers observed no hard braking to imply that they had made an effort to stop prior to the crossing. At this site, the crossing guard wore a fluorescent yellow-green vest with SCHOOL GUARD on the back and had a 15-inch stop paddle. Additionally, there was a construction barrel with red lights in the middle of the road and a portable sign that stated STATE LAW YIELD (symbol) TO PEDESTRIANS (symbol) WITHIN CROSSWALK. In summary, each of the erratic or non-compliance events was resolved with no incident occurring; however, all of these events placed the crossing guards in harm's way as they either began or conducted their crossing procedure.

Finally, researchers made a point to detail the specific operating procedures of each of the crossing guards observed. Researchers hoped to gain a better understanding of how to assist the crossing guards in safely and effectively conducting crossing events through new devices for use at the school crossing. Researchers observed that for the majority of the crossing guards, the standard crossing procedure was to place the stop paddle in the air while stepping off the curb and then proceeding to the middle of the crosswalk. Crossing guards also blew whistles (where available) to help stop traffic. Once the crossing guard had arrived at the mid-point of the street and traffic had stopped, they then waved the children through the crosswalk. After the children had crossed the street, researchers observed that 33 percent of the crossing guards held up the stop paddles while they walked back to the curb and lowered the paddle when they returned to the curb, while the remaining 67 percent of crossing guards lowered the paddles before returning to the original curb. Researchers believe lowering the paddle while still in the roadway could negatively impact crossing guard safety.

FOCUS GROUPS

As the final component to understanding crossing guard operations and identifying concerns during these types of operations, two focus groups were conducted in Texas cities. Researchers used the focus group method to obtain current crossing guards' safety concerns during operations and discuss how these issues could be addressed. Researchers hoped using the focus group method would also help stimulate new ideas for devices and/or creative concepts that could improve the safety of crossing guards and children.

Protocol

Upon arrival, participants were provided with an explanation of the study and a short questionnaire to obtain background information. Participants were asked to identify their years of experience as a crossing guard, what types of traffic control devices they currently used, and what percentage of the time they believed that motorists complied with their instructions.

A focus group guide was used to set the agenda for the focus group discussion so that each relevant topic would be introduced for discussion. Further, the guide provided direction for the participants during the group discussion. To begin the discussion, participants were asked to introduce themselves, state how long they had been employed as a crossing guard, and briefly describe a situation where they had been concerned for their or the children's safety.

Locations and Demographics

Focus groups were conducted in Bryan/College Station and Killeen, Texas. A total of 21 crossing guards participated. Demographics were recorded for the participants, although the primary demographic of concern for this focus group was the number of years of experience each participant had as a crossing guard. Figure 20 shows that a diverse range of experience levels was garnered during these focus groups. The majority of participants were female (76 percent) and were between the ages of 39 and 64 (76 percent). All but 14 percent of the participants had at least a high school diploma.

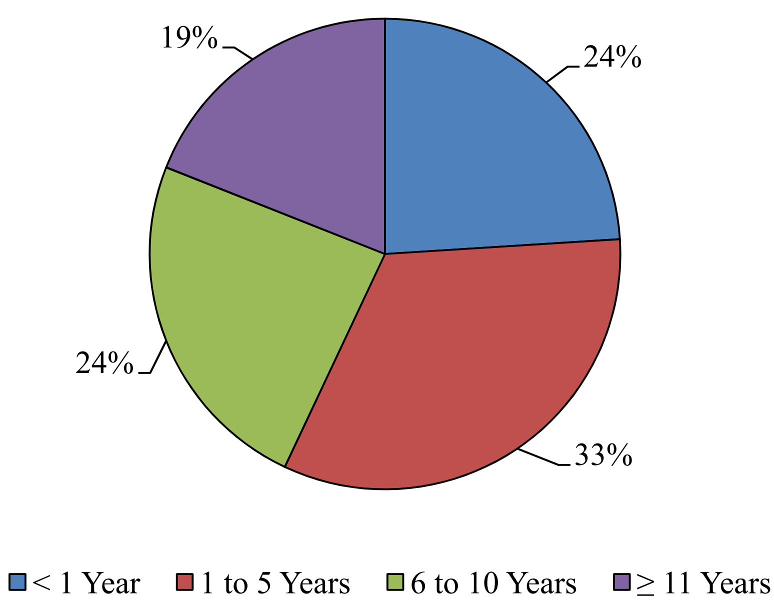


Figure 20. Focus Group Participants' Years of Crossing Guard Experience (n=21).

Results

Current Traffic Control Devices

When the participants were asked what type(s) of traffic control device(s) they currently use, all indicated that they used some type of stop paddle. Seventy-six percent were using a 12-inch stop paddle and 24 percent were using a 15-inch stop paddle. Two of the 12-inch paddles contained flashing lights on the sign face; one had white LEDs in the STOP legend and the other one had red LEDs centered above and below the STOP legend. Approximately half of the participants also used cones in the crosswalk.

Perceived Compliance

The next question asked of participants was what percentage of the time they felt motorists obeyed their instructions. There were four selections for the participants to choose from: 25, 50, 75, or 100 percent of the time. Figure 21 shows that only 10 percent of the participants felt motorists were always in compliance with their instructions. However, over half of the participants indicated that motorists did in fact obey their instructions 75 percent of the time and none of them felt that the compliance was as low as 25 percent.

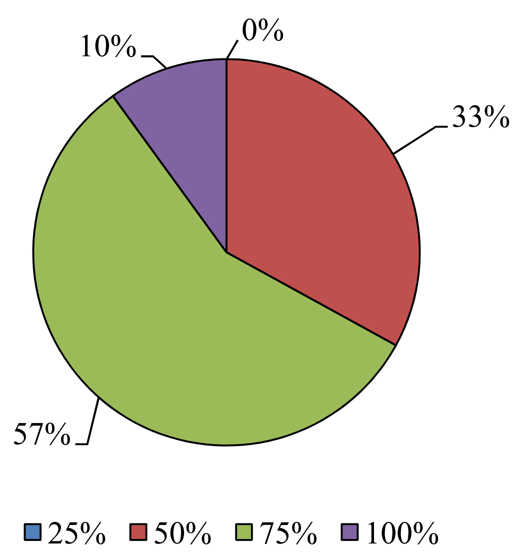


Figure 21. Focus Group Perceived Percent of the Time Motorists Comply with Crossing Guard Instructions (n=21).

Identified Incidents

The participants were then asked to briefly describe a situation they had experienced while working as a crossing guard where they were concerned for their safety or the children's safety. As Table 26 shows, the crossing guards attributed the majority of the incidents (88 percent) to motorist inattention. Nineteen percent of the crossing guards also attributed incidents to motorists not being able to see them.

Table 26. Focus Group Percent of Incidents by Category (n=21).

Incident Category	Percent Response
Motorist inattention	88%
Did not see crossing guard	19%
Speeding	14%
Motorist confusion	10%

NOTE: Total does not equal 100 since responses could be placed in more than one category for each incident.

Current Operations

Once the group discussion was opened, the first topic introduced identified what types of traffic control devices the participants were currently using as well as identifying what they felt were the main concerns for their current operations. As reflected from the incidents related previously, the crossing guards identified their main safety concern as motorists not paying attention and not seeing them.

As discussed previously, all of the crossing guards indicated that they used some type of stop paddle during their operations. Several members of the group mentioned that the use of a larger paddle would be too difficult to handle. Also, all participants wore a safety vest. One group commented that they also wore fluorescent yellow-green baseball caps with SAFETY PATROL written on them. The other group did not have any official cap but several did use personal caps of their own.

The use of cones at a crossing drew divided remarks from the groups. About half of the participants felt that cones could help in controlling traffic; however, the other half believed that they got in the way and were more trouble than help.

There was some confusion with respect to traffic signals located at intersections where crosswalk guards were located. Several participants felt it was difficult to get the children across while sequencing with the traffic signal. The guards explained that frequently children only got half way across the street on a green light before it changed to red. Another problem identified was the vehicles turning from the cross street that have the green light while children try to cross the street. One participant recommended having control over the traffic signals in order to manage the children crossing as warranted and help alleviate congestion build up. Other items suggested that would help the participants with the crossing guard operations were:

- More law enforcement.
- Use of whistles.
- Speed bumps (however some felt these could negatively impact safety because motorists who do not slow down may lose control of their vehicles).

Researchers specifically asked participants to identify how they gained motorists' attention during a crossing event. The majority of the participants used whistles or shouting to gain motorists' attention. Another strategy employed was to add an additional guard at a crossing where there was a significant safety concern. All of the participants felt there needed to be some type of device installed that would flash to get motorists' attention and possibly lower their speeds.

Motorist Behavior

This section was dedicated to determining if the crossing guards felt that the motorists currently have a good understanding of how they should behave in school zones. As such, researchers asked participants the following question: "Do you feel that the motorists are confused or do they just not pay attention to the crossing guards?"

Over half of the participants (66 percent) felt that the motorists did not have a good understanding of how they should behave near crossings in school zones. The remaining 34 percent felt that the motorists did in fact understand how they should behave but just did not pay attention or were too impatient.

Those participants that indicated that motorists did not have a good understanding all felt that additional law enforcement, the installation of speed bumps, and the addition of flashing school zone signs would get motorists' attention and hopefully inform them that they were in a school zone area where they needed to slow down. Additional suggestions included the following:

- Stop signs at school driveways.
- Change streets to one-way during school times.
- More traffic control devices.
- Ability to direct traffic when needed.
- Larger flashing advance signs.
- Ability to control traffic signal lights.
- Radios for communication between crossing guards and law enforcement.
- Lighted stop paddles.

Potential Traffic Control Devices

The next section focused on what other devices or equipment the crossing guards would like to have to help address concerns and/or to improve the safety of the school crossing operation. Suggestions for improvements included the following:

- Use of flashing lights on stop paddles. One individual that was currently using a flashing stop paddle stated that he felt speeds reduced when the lights were flashing on the paddle.
- Paint SCHOOL CROSSING pavement markings on the road.
- All participants felt that a sign located overhead was more noticeable and easier to see than those located on the side of the road due to bus traffic.
- Some participants felt there was confusion with the turn lane traffic, and there needed to be better delineation.
- All participants felt that a flashing LED vest may help with motorists seeing the guards, especially during dusk and dawn conditions.
- When a crossing is not within a school zone, participants felt that advance warning signs with flashing beacons should be placed in advance of the school crossing location.
- Use a mechanical arm to stop vehicles like at railroad crossings.
- Approximately half of the participants felt that uniforms would give the crossing guard more authority, respect, and show unity. Some of these individuals felt that if they wore uniforms it would not be necessary to wear the reflective vest.

The participants were then asked to think beyond what they normally see at school crossings and identify any type of device, garment, or tool they would like to have to help ensure safety at the school crossing. Once they had developed their ideas, researchers asked the participants to create drawings of how these items would be used in their operations.

Researchers took the consensus of the drawings and summarized the different types of items that the participants felt would help with school crossing safety. The top items developed by the participants were:

- Flashing lights on stop paddles (52 percent).
- Installing speed bumps (48 percent).
- Orange lighted vest (33 percent).
- Official uniforms (29 percent).
- One-way traffic in front of schools (19 percent).
- In-pavement lights at school crosswalks (19 percent).

The consensus of the group was that they desired devices or strategies that made them more visible before they stepped into the roadway. Only two strategies did not fit this categorization: installing speed bumps and one-way traffic in front of schools.

Researchers then showed the participants groupings of different types of devices including:

- Safety apparel.
- Lighted stop paddles.
- Cones.
- Signs.

For each grouping of items displayed, researchers asked several questions to determine the participants' preferences.

First, researchers showed the participants images of available safety apparel including vests, headwear, pants, and options of lighting, color, and reflective striping. Researchers asked participants questions regarding their thoughts as to how different safety apparel (or PPE) could affect their safety. All of the participants agreed that more retroreflective material on the apparel helped to make the crossing guard more visible. Over 50 percent preferred an orange colored vest, feeling it was the most visible, while 29 percent liked fluorescent yellow-green, and the remaining 21 percent preferred the color red for a vest. Additionally, 95 percent of the participants felt a vest with LED lights would be beneficial to increase the crossing guard's visibility.

When asked if any of the participants would wear reflective pants, 71 percent stated they would not as they were unnecessary and/or uncomfortable, while 29 percent said that they would wear reflective pants, especially in inclement weather conditions, to increase their visibility. Finally, when asked about headwear all felt some type of hat would help visibility as well as show more authority. There were 62 percent that preferred a fluorescent yellow-green color cap, with the remaining 38 percent selecting an orange color. No one in the groups felt that wearing gloves would help their visibility.

The second discussion of possible devices focused on the use of LED lights on stop paddles. Researchers showed the group a selection of lighted stop paddles including lighting patterns with LEDs at the eight corners of the sign, in the STOP legend, vertically centered above and below the STOP legend, and as a continuous border around the sign.

All of the participants felt that LED lights on the stop paddles would help the crossing guard be more visible and get the motorists' attention. Seventy-six percent of the participants liked the stop paddle with the flashing lights above and below the STOP legend; while the remaining 24 percent preferred the stop paddle that had the lights in the STOP legend.

When asked what color they felt the lights on the stop paddle should be, 62 percent preferred red lights because it would be harder to see white lights during rain or foggy conditions. Twenty-eight percent of the participants preferred white lights, and the remaining 10 percent suggested amber lights.

As mentioned previously, there were mixed feelings among the groups as to whether or not cones improved safety, with close to half stating that the cones could become hazardous if motorists ran over them, which happens occasionally. However, when presented with the options for cones (including ones with CROSSING text, a flag, or LED beacon on top) the percent of participants who felt that cones would improve safety increased to 71 percent. Participants preferred an orange cone with CROSSING text since it emphasized warning. The participants also agreed that a flag or light added to the top of a cone could add to the warning emphasis. All of the participants felt if cones were used they should be located at the midpoint or median of a road.

Last, researchers presented five different types of school crossing signs to the focus groups. Each sign was discussed to determine if the group felt a particular sign would help increase their safety and the safety of the children. The following bullet items discuss each sign presented to the groups.

- In-street, portable pedestrian crossing sign – Half of participants stated that they liked this device and felt it would get more attention than standard cones. The other half felt the sign was acceptable but did not provide any additional comment one way or the other.
- In-street, portable reduced size school crossing symbol – None of the participants liked this sign, stating it was too plain.
- STATE LAW YIELD TO PEDESTRIANS overhead sign – The majority of the participants preferred this sign. They liked that it had the STATE LAW text, and that it was a permanent sign. All stated they would like this sign to have flashing beacons that were activated during school zone hours only.
- Child shaped "cone" – None of the participants liked this device. They felt that it would not be effective and would get stolen or fall over.
- School crossing sign with LED lights in the border – Forty-three percent of the participants felt that this sign would be very helpful near the crosswalk, while 10 percent felt it should not be in the school zone but located somewhere in advance of the school zone location. All of these participants thought that the sign should be illuminated during the school zone times only. The remaining 47 percent were not in favor of using this sign since they preferred the overhead sign which they felt would be more visual.

Other Comments

Several of the focus group participants made additional general comments on ways to improve the safety at school crossings. These ideas included the following:

- All agreed the cell phone law has not helped or slowed down motorists.
- Need additional device or something flashing to get motorists' attention.
- Need strobe light on crossing guard vehicle (parked nearby) to catch motorist attention.

SUMMARY

Once all the above information had been gathered, researchers reviewed the identified issues and potential strategies/devices that could potentially improve the safety and effectiveness of crossing guard operations. From the three activities undertaken researchers identified the following common threads of concern:

- The most hazardous time for a crossing guard is while they are in the active process of helping children cross the roadway.
- Catching the attention of motorists before a crossing guard is required to step into the street is critical to improving safety.
- Keeping motorists stopped throughout an active crossing event is a problem for crossing guards.

In addition, adding LEDs or flashing beacons to current devices is one solution that appeals to both the crossing guards and other contacts within the districts.

Given the concerns above, researchers decided to investigate two aspects of improving the safety and effectiveness of crossing guard operations: 1) improving the conspicuity of crossing guards so they are more easily detected within the environment and 2) improving the advance warning provided to motorists before the crossing guard enters the crosswalk. With these ideas in mind, researchers discussed options with TxDOT and identified two paths to follow:

- Evaluation of stop paddles with embedded lights to assess the effectiveness of different lighting patterns currently allowed by the Texas MUTCD (*18*).
- Deployment of a user activated in-street sign for use at school crossings to gain motorist attention prior to a crossing guard stepping into the road.

CHAPTER 2.2: STOP PADDLES WITH EMBEDDED LIGHTS

INTRODUCTION

Given the safety concerns discussed in the previous chapter, researchers decided to investigate methods to improve the conspicuity of crossing guards so they are more easily detected within the environment, especially as they enter the crosswalk to stop traffic. Researchers found that crossing guards were very interested in using stop paddles with embedded lights to improve their conspicuity before entering the crosswalk and during active operations. However, researchers were concerned that some of the embedded light configurations may negatively impact a motorist's ability to recognize the three critical characteristics that define a stop sign: red background color, octagon shape, and white STOP legend. Thus, researchers decided to conduct a closed-course human factors study to determine the effectiveness of five stop paddles with embedded lights compared to a standard, un-lit stop paddle.

BACKGROUND

According to the Texas MUTCD (*18*), stop paddles must be octagonal in shape with a red background and a white border. The paddle must be at least 18 inches in diameter and have a white STOP legend on both sides with at least 6-inch capital letters. Stop paddles may be modified to improve conspicuity by incorporating white or red flashing lights on both sides of the paddle. The flashing lights may be arranged in the following configurations:

- Two white or red lights centered vertically above and below the STOP legend.
- Two white or red lights centered horizontally on each side of the STOP legend.
- One white or red light centered below the STOP legend.
- A series of eight or more white or red lights (less than 1/4 inch in diameter) along the outer edge of the paddle, arranged in an octagon pattern at the eight corners of the paddle. More than eight lights may be used only if the arrangement of lights is such that it clearly conveys the octagon shape of the paddle.
- A series of white lights forming the shapes of the letters in the legend.

When flashing lights are used, the flash rate shall be at least 50 flash periods per minute (fpm) but not more than 60 fpm. While researchers identified prior research concerning the use of embedded lights to enhance standard stop signs and stop/slow paddles operated by flaggers in work zones, researchers did not find any documentation of previous research concerning the use of embedded lights to enhance stop paddles operated by crossing guards in school zones.

Stop Signs

In a previous project performed by the Texas Transportation Institute (TTI) (*19*), researchers investigated the impacts of various higher-conspicuity sign materials on traffic operations and motorist behavior, including a standard stop sign (not a handheld stop paddle) with eight flashing red LEDs embedded in the corners of the sign. Researchers collected and analyzed traffic operations data at field sites before and after the installation of the LED stop signs. The research concluded that the flashing red LED stop signs were beneficial in reducing stop sign violations (i.e., blow-throughs and roll-throughs) during both daytime and nighttime conditions. However, the flashing red LED signs did not impact vehicle speeds or decelerations on the approach to the intersections.

Arnold and Lantz (*20*) also investigated the use of standard stop signs with eight flashing red LEDs embedded at each corner. Similar to the TTI study, researchers collected data on vehicles approaching the stop sign both before and after installation of the LED signs. Researchers concluded that the flashing red LED stop signs were effective in reducing average speeds of vehicles approaching an intersection. However, the effects of LED signs on compliance were inconclusive.

Stop/Slow Paddles

Stop/slow paddles are similar to stop paddles, except one side has an orange background with a black SLOW legend and a black border. In 1996, Agent and Hibbs (*21*) evaluated the use of various work zone devices developed by the Strategic Highway Research Program (SHRP). One of the devices studied was a flashing handheld stop/slow paddle. Researchers evaluated six different models of stop/slow paddles; however, all of the paddles contained one or two flashing white lights (either halogen or strobe) on the stop face of the sign. Researchers found the overall experience with the flashing stop/slow paddles to be very positive and that motorists were able to observe the flashing paddle sooner than a standard, un-lit paddle. Workers had varied opinions about the different flashing paddles, mainly concerning cost, durability, reliability, and usability of the paddles.

Morena (*22*) also evaluated five different flashing stop/slow paddles for a group of federal, state, and local highway safety workers. In bright sunlight, the observers thought that the paddle with halogen lights was the only paddle that would be able to draw a motorist's attention from 285 ft or farther away. Subsequent tests with two halogen paddles confirmed these findings.

More recently, Schrock et al. (*23*) evaluated the usefulness and workability of several technology-enhanced flagging devices, including three handheld LED enhanced stop/slow paddles and a standard, un-lit paddle. All the stop/slow paddles were 24 inches in diameter and fabricated with engineer grade sign sheeting (ASTM International [formally known as the American Society for Testing and Materials] Type I). Researchers tested the following LED lighting configurations on the stop face of the sign.

- Flashing red lights at the eight corners of the paddle.
- A series of flashing red lights forming the shapes of the letters in the STOP legend (not currently included in the Texas MUTCD [*18*]).
- Flashing red lights centered vertically above and below the STOP legend.

Researchers used responses from maintenance personnel in focus groups, as well as field surveys of motorists who viewed the devices in active work zones to gauge the usefulness of each device. While maintenance personnel thought that the flashing lights would increase the conspicuity of the paddle, they expressed concern regarding the durability and usability of the LED enhanced paddles, such as recharging batteries, fragile components, and increased weight. Only 15 percent of the motorists surveyed stated that they saw the stop/slow paddle (independent of the type) and the distribution among the four types of paddles was similar. It should be noted that each motorist only saw one type of paddle. Interestingly, 54 percent of those surveyed did not think the flashing lights indicated a more important situation, and only 26 percent of motorists thought they drove differently when they saw the LED enhanced stop/slow paddles (e.g., drove slower, slowed down earlier, more cautious). Motorists liked the stop/slow paddle with the red flashing LED lights above and below the STOP legend the best (79 percent), closely followed by the stop/slow paddle with red lights forming the STOP legend (72 percent).

Motorists disliked the stop/slow paddle with the red lights at the eight corners the most (38 percent) because they either did not see it or found it difficult to see.

EXPERIMENTAL DESIGN

Researchers conducted the closed-course human factors study on the roadway network at the Texas A&M University Riverside Campus, which is a 2000-acre complex of research and training facilities located 10 miles northwest of the university's main campus. Researchers decided to conduct the study on the roadway network since it more closely replicated an urban environment with driveways and cross-streets but still provided less traffic than an actual urban street. While data collected in response to simulated crossing guard operations cannot be directly compared to data collected during an actual crossing guard operation at a school, researchers can use closed-course study data to compare the relative differences in performance among the various treatments evaluated. The following sections describe the treatments, time periods, study procedure, and participants.

Treatments

An extensive internet search and discussions with manufacturers revealed that not all of the light configurations listed in the Texas MUTCD (*18*) were readily available. Researchers could not identify a current manufacturer of a stop paddle with lights centered horizontally on each side of the STOP legend or a stop paddle with one light centered below the STOP legend (even though the latter of these devices appears to have been developed during the SHRP study [*21*]). Researchers also could not find any manufacturers that had "off-the-shelf" stop paddles with white lights, except in the letters of the STOP legend. Researchers did discover several manufacturers that offer steady-burn lights within stop paddles, even though currently the Texas MUTCD only addresses the addition of flashing lights to improve conspicuity. Due to time, budget, and "off-the-shelf" availability constraints, researchers decided to include the following devices in the study:

- A standard, un-lit stop paddle.
- A stop paddle containing eight flashing red LED lights around the border, one in each corner.
- A stop paddle containing a series of steady-burn red LED lights around the border.

- A stop paddle containing a series of flashing red LED lights around the border.
- A stop paddle containing flashing red LED lights centered vertically above and below the STOP legend.
- A stop paddle with a series of steady-burn white LED lights forming the letters of the STOP legend.

All paddles were 18 inches in diameter (the minimum size required by the Texas MUTCD [*18*]) and fabricated with high intensity sign sheeting (ASTM Type III). Figure 22 shows the six stop paddle designs, and Table 27 summarizes additional characteristics of each paddle.

Treatment 1
Standard
Un-Lit

Treatment 2
Eight Flashing Red
Border Lights

Treatment 3a
Steady-Burn Red
Full Border Lights

Treatment 3b
Flashing Red
Full Border Lights

Treatment 4
Flashing Red
Vertically Centered

Treatment 5
Steady-Burn White
STOP Legend

Figure 22. Stop Paddle Treatments.

Researchers defined a flash period to be from the beginning of a flash to the beginning of the next flash. However, several of the stop paddles had flash patterns that contained multiple successive flashes within a flash period that were difficult for the human eye to distinguish. For example, Treatment 3b actually has four quick successive flashes in every visible flash. So, researchers used a high-speed photodetector with a V-Lambda photopic filter coupled with a digital oscilloscope and a computer to measure the actual flashes per minute, number of successive flashes within one visible flash, and the flash periods per minute, and intensity. Overall, Treatment 2 and Treatment 3b both produced approximately 60 flash periods per minute (fppm). For Treatment 4, the lights above the STOP legend flash twice and then the lights below the STOP legend flash twice. Researchers assumed one flash period to be from the beginning of the top light flash sequence to the end of the bottom light flash sequence, which yielded approximately 70 fppm. Treatment 4 produced the highest intensity light, followed by Treatment 3a, Treatment 3b, and Treatment 2. Unfortunately, researchers were unable to measure the intensity of Treatment 5 since the prototype had to be returned to the manufacturer before researchers could acquire the equipment necessary to conduct the measurements.

Table 27. Stop Paddle Characteristics.

Trt	LED Color	Mode	Weight (lbs)	Number of LEDs[b]	Actual Flashes Per Minute	# of Successive Flashes	Flash Periods Per Minute	Intensity (lx*s)
1	NA	NA	2.4	NA	NA	NA	NA	NA
2[a]	Red	Flashing	2.3	8	60	1	60	0.0075
3a	Red	Steady-burn	2.4	112	NA	NA	NA	0.0486
3b	Red	Flashing	2.4	112	235	4	59	0.0262
4	Red	Flashing	3.2	16[c]	280	4	70	0.1567
5	White	Steady-burn	2.5	52	NA	NA	NA	--

Trt = Treatment; NA = Not Applicable; -- Unable to measure
[a] Single flash mode
[b] Per side
[c] 8 above and 8 below the legend

Researchers were primarily concerned with the safety of crossing guards when they begin to enter the travel lanes from the shoulder to stop traffic. So, the researcher holding each treatment was positioned on the left or right side of the road, instead of in the middle of the roadway. This researcher wore a fluorescent yellow-green vest and displayed only one treatment at a time.

To reduce learning effects, researchers utilized six different treatment orders. Each participant saw each treatment once on either the left or right side of the road. Thus, approximately half of the participants saw the treatments on the left side of the road and the other half saw the treatments on the right side of the road. The road chosen was ideal for the study due to the fair pavement conditions, lack of stop signs at the cross streets, low volume of traffic in the surrounding area, and also the direction in relation to the sun.

Time Periods

Based on discussions with crossing guards, researchers found that crossing guards working during early morning hours and those located directly in front of the sun in the morning (i.e., backlit) experience more motorist non-compliance. Researchers believe this is due to the low visibility conditions before sunrise and the sun "blinding" motorists when it is near the horizon early in the morning. Thus, researchers decided to conduct the study during low light conditions and when the sun was near the horizon. In order to complete the study in a timely manner, researchers collected data during both morning and evening time periods by reversing the travel direction along the selected roadway.

Based on previously conducted field observations, the earliest school zone time started at 7:00 a.m. Researchers compared this time period to the sunrise times for the entire year (*24*) to determine the proportion of time crossing guards were active during twilight and early morning time periods. Based on this information and the sunrise/sunset times during the study period, researchers planned to conduct the morning portion of the study from 6:00 a.m. to 7:00 a.m. (i.e., 30 minutes before and after sunrise), and the evening portion of the study from 8:00 p.m. to 9:00 p.m. (i.e., 30 minutes before and after sunset). The actual study times were 6:00 a.m. to 6:45 a.m. (sunrise approximately 6:30 a.m.) and 8:00 p.m. to 8:45 p.m. (sunset approximately 8:30 pm). Researchers made every attempt to collect data during the same time periods each day. During each time period, participants drove toward the sun (i.e., east in the morning and west in the evening). However, for half of the data collection periods, there were overcast conditions.

Study Procedure

Upon arrival, researchers provided participants with an explanation of the study, including their driving task. Participants then completed screenings for standard visual acuity, contrast sensitivity, and color blindness. These screenings provided comparison information for data reduction and ensured that all participants had at least minimal levels of acceptable vision prior to beginning the study. No participants were disqualified from the study based on these screenings.

Participants were told that they would drive an instrumented state-owned passenger vehicle (i.e., Ford Taurus) on the roadway network where researchers had setup a simulated school crosswalk. They were told to obey all traffic control devices and to drive at the posted speed limit (i.e., 30 mph).

While planning the study, researchers realized that the LED enhanced stop paddles could be detected farther away than the standard, un-lit stop paddle. Thus, researchers did not evaluate detection distance of the stop paddle treatments (i.e., a measure of conspicuity). As previously indicated, researchers were interested in assessing the impact of the embedded lights on a motorist's ability to recognize the red background color, octagon shape, and white STOP legend of the stop paddles. Due to the design of the LED enhanced stop paddles, researchers could not alter the legend (e.g., TOPS) to evaluate legibility. In addition, researchers acknowledged that the majority of motorists know the background color, shape, and legend of a stop sign. Therefore, researchers decided to inform the participants that they would need to identify these three characteristics of a stop paddle prior to the study. Researchers instructed participants to verbally acknowledge when they could clearly identify the red background color of the sign, the octagon shape of the sign, and completely read the STOP legend on the sign. Researchers also instructed participants not to guess or assume any of the responses, but to make sure they could clearly see the desired characteristic before verbally acknowledging it.

Researchers recorded the background color recognition distance, the shape recognition distance, and the legend legibility distance, as well as any comments made by the participants. The participants were instructed not to stop, but to continue traveling straight past the simulated crossing guard. After each treatment, researchers asked participants a series of follow-up questions. Each participant repeated this process for each stop paddle treatment. At the end of the study, researchers asked participants to rank the six treatments from best to worst on their ability to catch motorists' attention and inform them to stop.

Participants

Researchers recruited 36 people from the Bryan/College Station, Texas, area to participate in the closed-course study. Participants were required to be at least 18 years old and have a current Texas driver's license. Table 3 shows the demographic sample obtained and needed based on the gender and age of the Texas driving population (*15*).

Table 28. Stop Paddle Study Participant Demographics.

Sample	Male		Female	
	18–39	55+	18–39	55+
Study Sample	31%	19%	31%	19%
2008 Texas Data (*15*)	22%	14%	21%	14%

DATA REDUCTION AND ANALYSIS

Following the data collection, each participant's raw data were screened and reduced into a fully formatted data set to obtain the necessary information for analysis. During the data screening process, any anomalous data (e.g., misidentifications, malfunctioning treatment) were eliminated.

Table 29 contains the variables considered in the analyses. Researchers considered three response variables to assess the effectiveness of the stop paddles, as well as the effect of other variables of interest (i.e., treatment, time period, roadside location, age, and gender). Researchers used a split-plot design analysis to cope with driver-to-driver variability, with participant as a whole-plot and each treatment combination as a split-plot. The demographic variables (gender and age) served as whole-plot factors, while the treatment, time period, and roadside location served as split-plot factors. Researchers conducted the analyses separately for each of three response variables. A 5 percent significance level (α=0.05) was used for all statistical analyses.

Researchers also analyzed the participants' subjective opinions regarding the advantages and disadvantages of each treatment. Researchers calculated the average rating for each treatment with respect to how well the participant could recognize and read the paddle. Since one was very well, two was well, and three was not well, a treatment perceived to do well would have a lower average rating. In addition, researchers computed the overall ranking of the treatments from the best to worst. Researchers determined the overall ranking using a rank score, which was computed by assigning one point each time a treatment was ranked first (best), two points for second place rankings, etc. with the maximum number of points g assigned each time a treatment was ranked worst. Thus, the treatment perceived to be the best would have the lowest score.

Table 29. Variables Used in the Stop Paddle Study Analysis.

Class	Variable	Data Set Values
Response variables	Background color Recognition distance	20~1770 (ft)
	Shape recognition distance	128~1313 (ft)
	Legend legibility distance	118~908 (ft)
Factors	Treatment	Standard, un-lit (n=36) Eight flashing red border (n=26) Steady-burn red full border (n=36) Flashing red full border (n=36) Flashing red vertically centered (n=36) Steady-burn white STOP legend (n=36)
	Time period	Morning (n=101) Evening (n=105)
	Roadside location	Left (n=100) Right (n=106)
	Age category	18 to 39 (n=126) 55 plus (n=80)
	Gender	Male (n=101) Female (n=105)
	Participant	1, 2, …, 36

RESULTS

The following sections contain the results of the analyses on the background color recognition distance, shape recognition distance, and legend legibility distance. Researchers used the predicted values (least squares means) for each response variable to compare different treatments. When there are multiple factors in the model, it is not fair to make comparisons between raw cell means in data because raw cell means do not compensate for other factors in the model. The least squares means are the predicted values of the response variable for each level of a factor that have been adjusted for the other factors in the model. Trends found in the subjective data are also reported.

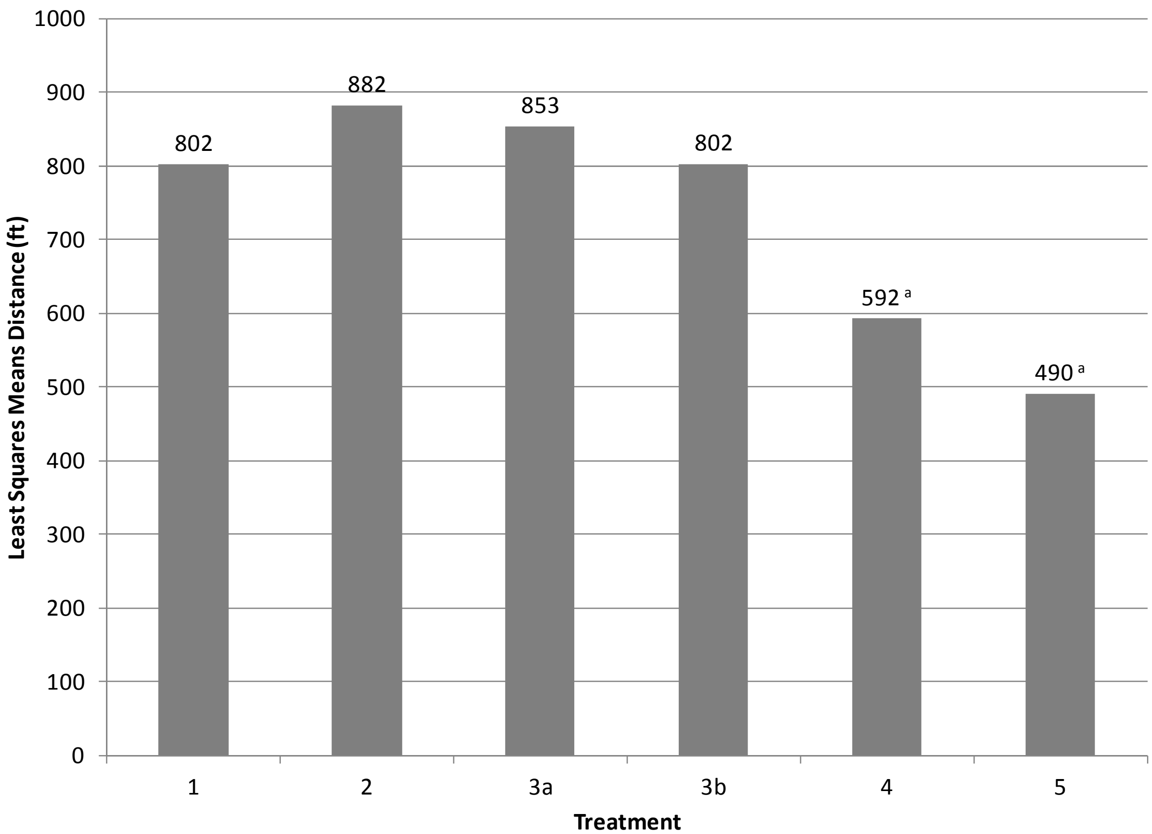
Background Color Recognition

Researchers initially fit a model with all main effects and possible two-way interactions. The statistical analysis results obtained by the restricted maximum likelihood (REML) method showed that the two-way interaction between age and time period was statistically significant (α=0.05). Tukey's Honestly Significant Difference (HSD) multiple comparison procedure showed that during the evening period the predicted background color recognition distance for the younger age category (823 ft) was statistically farther than that for the older age category (616 ft). However, during the morning period the difference between the two age categories was not statistically significant. Based on these data, the final model included all of the main effects (i.e., treatment, time period, roadside location, age category, and gender) and the two-way interaction between age and time period as fixed effects, and participants nested within age category and gender as random effects. The final model found the treatment to be the only statistically significant factor (α=0.05) other than the aforementioned two-way interaction between age and time period.

Figure 23 presents the predicted means for the background color recognition distance for each treatment. Researchers used Tukey's HSD procedure to determine which treatment factor levels were statistically different. Treatment 2 was found to have the farthest predicted mean background color recognition distance (882 ft). However, this distance was not significantly different from the predicted mean background color recognition distances for Treatments 1, 3a, and 3b (802 ft, 853 ft, and 802 ft, respectively).

The predicted mean background color recognition distances for Treatments 4 and 5 (592 ft and 490 ft, respectively) were found to be significantly less than those for Treatments 1, 2, 3a, and 3b. Based on the predicted means, participants traveled 210 to 392 ft closer to the crossing guard before being able to recognize the red background color of the stop paddle for Treatments 4 and 5. Treatment 4 did output the highest light intensity; yielding an intensity 3 to

20 times higher than the other stop paddles with embedded lights (see Table 27). Unfortunately, data regarding the light intensity of Treatment 5 were unavailable.



[a] Treatments 4 and 5 were significantly different from Treatments 1, 2, 3a, and 3b.

Figure 23. Comparison of the Background Color Recognition Distance Data by Treatment.

The subjective data for Treatment 4 showed that 17 percent of participants thought red flashing lights above and below the STOP legend were blinding or distracting. In addition, 6 percent of the participants specifically stated that the red flashing lights above and below the STOP legend made it difficult to discern the red background color of the stop paddle. The subjective data for Treatment 5 showed that 42 percent of participants thought that the white lights forming the STOP legend made it more difficult to distinguish the red background color of the stop paddle. Overall, the light configurations in Treatments 4 and 5 did appear to negatively impact a motorist's ability to recognize the red background color of the stop paddle compared to the standard, un-lit stop paddle.

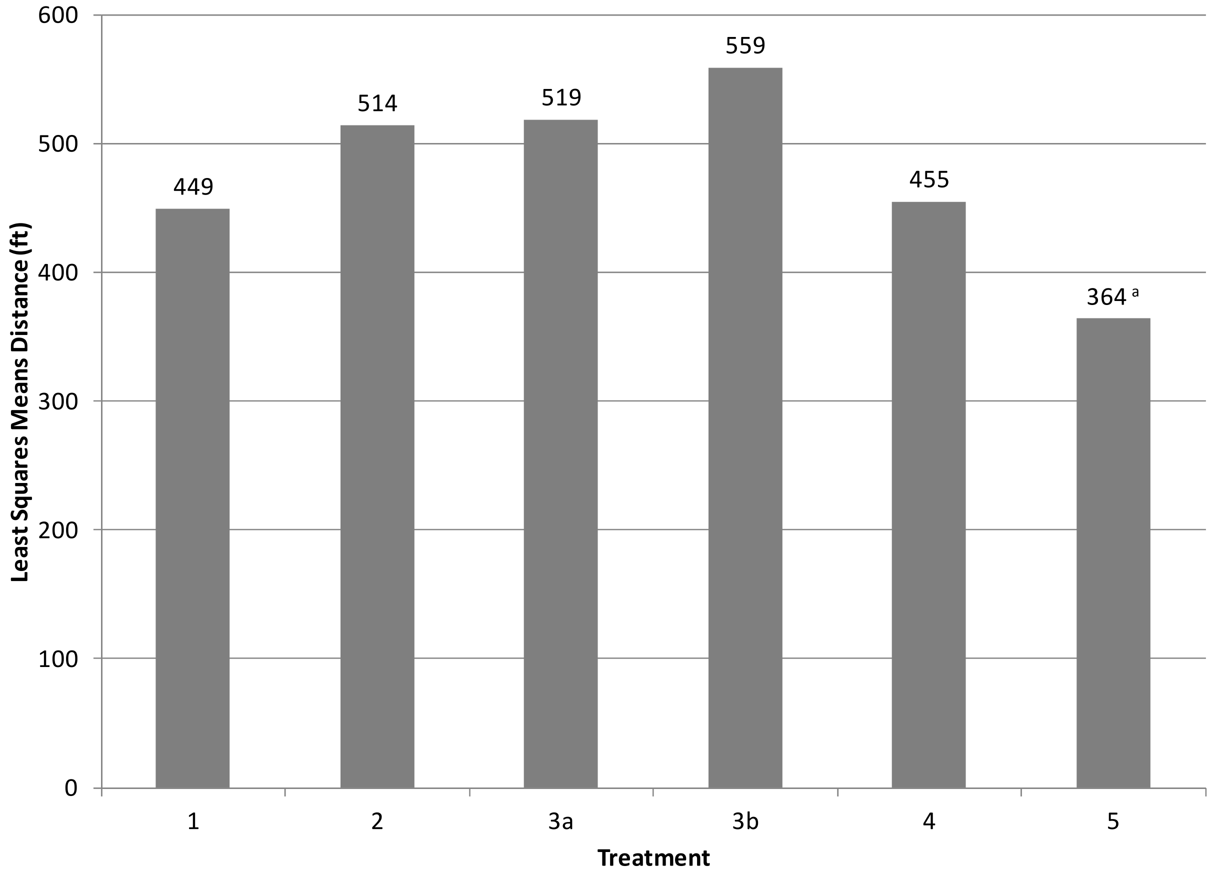
Shape Recognition

Again, researchers initially fit a model with all main effects and possible two-way interactions. The statistical analysis results obtained by the REML method showed that none of the two-way interaction effects were statistically significant. Therefore, the final model included all of the main effects (i.e., treatment, time period, roadside location, age category, and gender) as fixed effects and participants nested within age category and gender as random effects. The final model found the treatment to be the only statistically significant factor ($\alpha=0.05$).

Figure 24 presents the predicted means for the shape recognition distance for each treatment. Researchers used Tukey's HSD procedure to determine which treatment factor levels were statistically different. Treatment 3b had the farthest predicted mean shape recognition distance (559 ft). However, this distance was not statistically significant from the other treatments, with the exception of Treatment 5 (364 ft). Treatments 2 and 3a were also found to have a predicted mean shape recognition distance significantly greater than Treatment 5. The subjective data for Treatment 5 showed that 25 percent of participants thought the white lights forming the STOP legend made it more difficult to identify the octagon shape of the stop paddle. The predicted mean shape recognition distances for Treatments 1 and 4 (449 ft and 455 ft, respectively) were not significantly different from any of the other stop paddles studied. While there were significant differences among some of the stop paddles with embedded lights, none of the stop paddles with embedded lights impacted a motorist's ability to recognize the octagon shape of the stop paddle compared to the standard, un-lit stop paddle.

Legend Legibility

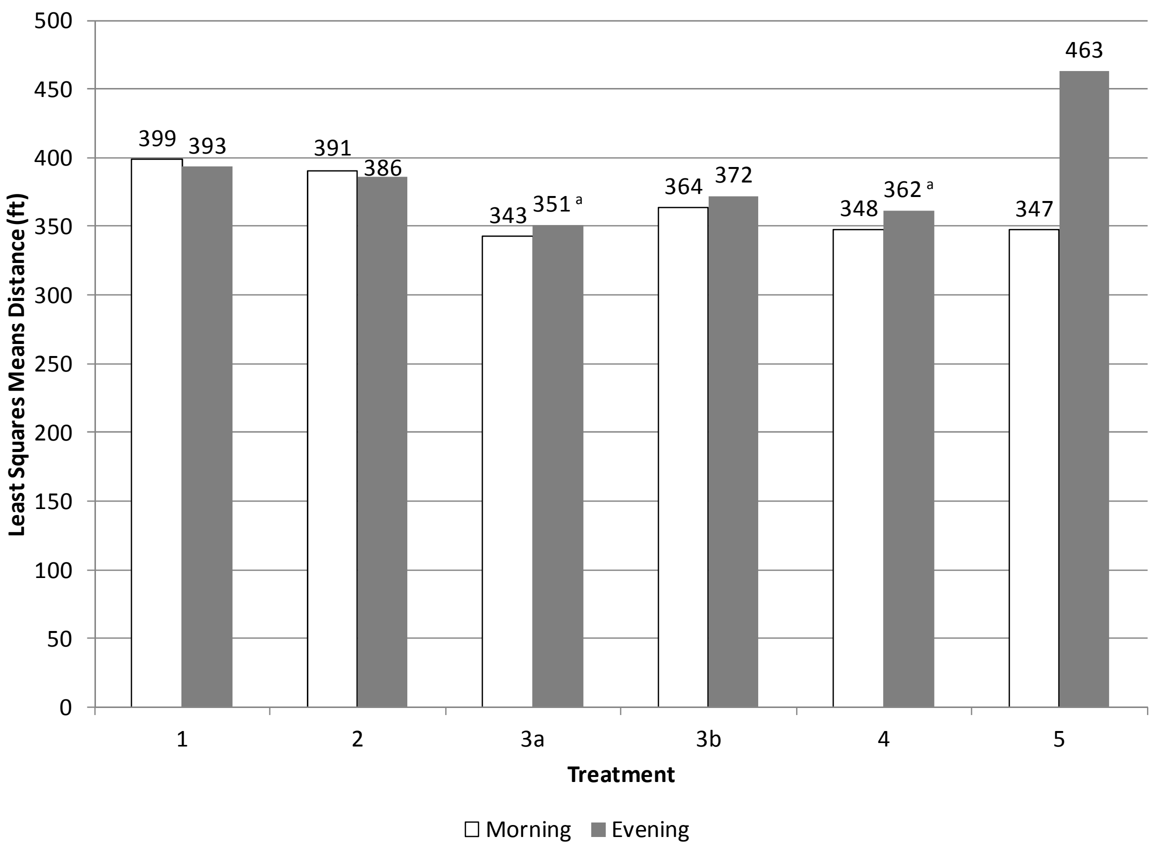
As with the other two response variables, researchers initially fit a model with all main effects and possible two-way interactions. The statistical analysis results obtained by the REML method showed that the age/time period and treatment/time period two-way interactions were statistically significant ($\alpha=0.05$). However, the effect of the age and time period interaction did not seem to be practically significant, and Tukey's HSD procedure did not find any of the levels of the two-way interaction to be significantly different. Therefore, researchers did not retain the age and time period interaction in the final model. The final model included all the main effects (i.e., treatment, time period, roadside location, age category, and gender) and the two-way interaction between treatment and time period as fixed effects, and participants nested within age category and gender as random effects. The final model found the treatment, as well as the treatment and time period interaction, to be statistically significant (α=0.05).



[a] Treatment 5 was significantly different from Treatments 2, 3a, and 3b.

Figure 24. Comparison of the Shape Recognition Distance Data by Treatment.

Because the treatment/time period interaction effect was significant, the effect of treatment was assessed for each time period (i.e., morning and evening). Figure 25 presents the predicted means for the legend legibility distance for each treatment during each time period. Researchers used Tukey's HSD procedure to determine which treatment/time period factor level combinations were statistically different. For the morning period, there were not any statistically significant differences among treatments. For the evening period, the predicted mean legibility distance for Treatment 5 (463 ft) was significantly farther than Treatments 3a and 4 (351 ft and 362 ft, respectively), but not statistically different from the other treatments. For Treatment 4, 50 percent of the participants thought that the flashing red lights vertically centered above and below the STOP legend made it difficult to read the legend. In contrast, for Treatment 3a only 11 percent of the participants thought that the steady-burn red border lights negatively impacted their ability to read the STOP legend.



[a] During the evening period, Treatments 3a and 4 were significantly different from Treatment 5.

Figure 25. Comparison of the Legend Legibility Distance Data by Treatment and Time Period.

Also, as shown in Figure 25, the time period only affected the predicted mean legibility distance of Treatment 5. In the evening period, the predicted legibility distance was 116 ft farther than in the morning period. During two-thirds of the evening data collection periods the weather was clear and sunny. Under these conditions, the light produced by Treatment 5 was most likely less than the ambient light conditions and the treatment would have been back-lit by the setting sun; thus, decreasing the potential for over-glow. In contrast, during two-thirds of the morning data collection periods the weather was overcast. Under pre-dawn and overcast conditions, the light produced by Treatment 5 was most likely greater than the ambient light conditions that resulted in over-glow of the STOP legend. The subjective data support this hypothesis, since 31 percent of participants stated that Treatment 5 was more difficult to read because the white lights were too bright and blended together (i.e., over-glow). While the time period appears to have affected the predicated mean legibility distance of Treatment 5, Tukey's HSD procedure found that the difference was not statistically significant.

Overall, while there were significant differences among some of the stop paddles with embedded lights, there were no significant differences between the standard, un-lit stop paddle and the stop paddles with embedded lights. So, none of the stop paddles with embedded lights impacted the predicted mean distance at which the participants could read the STOP legend compared to the standard, un-lit stop paddle.

Stopping Sight Distance

Typically, in Texas the maximum speed limit in a school zone on an urban road is 30 mph. According to the *A Policy on Geometric Design of Highways and Streets* (*25*), the stopping sight distance required for a vehicle traveling at 30 mph is 200 ft. While several significant differences were found among the treatments, the predicted recognition and legibility distances for all treatments were found to be greater than the required stopping sight distance. Although a small percentage of participants did have recognition or legibility distances that were below the required stopping sight distance, a test of proportions between all treatments determined that there were no significant differences.

Additional Subjective Data

As discussed previously, the participants rated each treatment independently according to their ability to recognize and read each stop paddle. The lowest rating (one) corresponded with the highest preference. The participants were also asked to rank the six treatments from best to worst on their ability to catch motorists' attention and inform them to stop. Researchers computed a rank score for each treatment by assigning points for each ranking place. Similar to the rating system previously discussed, the treatment perceived to be the best would have the lowest score. Table 30 contains the mean rating and rank score for each treatment. Treatments 2, 3a, and 3b (stop paddles with lights around the border) were rated and ranked the best. The primary reason provided by participants was that these stop paddles catch a motorist's attention but do not distract from the background color, shape, and legend.

Table 30. Stop Paddle Subjective Opinion Data.

Treatment	Mean Rating[a]	Rank Score[b]	Overall Ranking
1	1.50	170	6
2	1.42	115	3
3a	1.33	104	2
3b	1.47	78	1
4	1.64	149	5
5	2.08	140	4

[a] The lowest rating (one) corresponded with the highest preference.
[b] The treatment perceived to be the best would have the lowest score.

SUMMARY AND RECOMMENDATIONS

Researchers conducted a closed-course human factors study to determine the effectiveness of five stop paddles with embedded lights compared to a standard, un-lit stop paddle. Prior to the study, researchers verified that the addition of lights improved the conspicuity of the crossing guard (i.e., could be detected farther away than the standard, un-lit stop paddle). Thus, researchers decided to evaluate the lights' impact on a motorist's ability to recognize the three critical characteristics that define a stop sign: red background color, octagon shape, and white STOP legend.

The three stop paddles with lights around the border did not significantly impact the predicted mean distance at which the participants could recognize the background color of the stop paddles compared to the standard, un-lit stop paddle. In contrast, the stop paddle with flashing red lights vertically centered above and below the STOP legend and the stop paddle with steady-burn white lights forming the STOP legend resulted in predicted mean background color recognition distances significantly shorter than the standard, un-lit stop paddle (210 to 392 ft closer to the crossing guard). Participants thought the flashing lights above the STOP legend were blinding or distracting and thus made it more difficult to discern the red background color of the stop paddle. Participants also thought the white lights forming the STOP legend made it more difficult to distinguish the red background color of the stop paddle.

None of the stop paddles with embedded lights impacted the predicted mean distance at which the participants could recognize the shape of the stop paddles compared to the standard, un-lit stop paddle. However, the three stop paddles with lights around the border did produce significantly farther predicted mean shape recognition distances (150 to 195 ft) than the stop paddle with steady-burn white lights forming the STOP legend. This is not surprising since the lights around the border highlight the shape of the stop sign.

None of the stop paddles with embedded lights impacted the predicted mean distance at which the participants could read the STOP legend compared to the standard, un-lit stop paddle. While not statistically significant, researchers did find that ambient lighting conditions affected the legibility distance of the stop paddle with steady-burn white lights forming the STOP legend. Under clear and sunny conditions, the predicted mean legibility distance for this stop paddle was 463 ft. In contrast, under pre-dawn and overcast conditions, the predicted mean legibility distance was 116 ft shorter (i.e., 347 ft). Researchers believe that when the light produced by the steady-burn white lights in the STOP legend is greater than the ambient light, over-glow of the STOP legend occurs (i.e., blending of the letters), making it more difficult for motorists to read.

Overall, researchers recommend the use of one of the following stop paddles to improve the conspicuity of crossing guards without negatively impacting a motorist's ability to recognize the three critical characteristics of a stop sign (i.e., red background color, octagon shape, and white STOP legend):

- A stop paddle containing flashing red lights arranged in an octagonal pattern at the eight corners of the paddle.
- A stop paddle containing a series of steady-burn red lights around the border arranged such that the lights clearly convey the octagonal shape of the paddle.
- A stop paddle containing a series of flashing red lights around the border arranged such that the lights clearly convey the octagonal shape of the paddle.

Since the Texas MUTCD does not currently address steady-burn lights, TxDOT should consider revising the language in the next edition of the Texas MUTCD to allow for the use of steady-burn lights in the configuration described above. Researchers do not know how the use of white lights would impact the effectiveness of the recommended stop paddles.

Based on the findings, researchers do <u>not</u> recommend using the following devices:

- A stop paddle containing flashing red lights centered vertically above and below the STOP legend.
- A stop paddle with a series of steady-burn white LED lights forming the letters of the STOP legend.

Researchers did not study the latter treatment with flashing lights, as described in the Texas MUTCD. Thus, researchers do not know whether the use of flashing lights would reduce the potential for over-glow and thus improve a motorist's ability to recognize the background color and shape, as well as read the STOP legend during darker ambient light conditions.

Researchers did not evaluate the effectiveness of a stop paddle containing flashing red lights centered horizontally on each side of the STOP legend. However, researchers believe that stop paddles containing a similar light configuration to the one tested above and below the STOP legend would also reduce the recognition distance of the background color of the stop paddle. Researchers do not know how the use of white lights would impact the effectiveness of the stop paddles with flashing lights centered horizontally on each side or vertically above and below the STOP legend.

CHAPTER 2.3:
PORTABLE IN-STREET SCHOOL CHILDREN CROSSING SIGN

INTRODUCTION

Through the initial evaluation of risks and concerns for crossing guards, researchers identified that the most hazardous time for a crossing guard is while they are in the active process of helping children to cross the roadway, and that catching the attention of motorists before entering the roadway is critical to improving safety. To address this concern, the research team evaluated a user activated sign that would improve the crossing guard's ability to catch motorists' attention and provide improved advance warning of crossing events at the school crossing. This device was a prototype that was remotely operated by the crossing guard. It consisted of an in-street school children crossing sign with flashing LEDs at the corners of each sign face to improve the visibility, and thereby safety, of the crossing area. The stabilizing legs could be folded up when stored. Two wheels were attached to the base such that when tilting the device it could be rolled. Figure 26 shows pictures of the prototype sign both close-up and deployed at the evaluation site. Texas law does not require motorists to stop for pedestrians; thus, a yield sign was used (R1-6b).

Figure 26. Prototype LED Enhanced In-Street School Crossing Sign.

At the beginning of the school zone time period, a crossing guard deployed the device on the centerline of the roadway at the crosswalk location. The crossing guard activated the LEDs on the in-street sign right before he entered the roadway to assist children in crossing the street. The LEDs remained active until the crossing guard returned to the sidewalk, at which time the crossing guard turned off the LEDs. At all other times, the LEDs remained off. The crossing guard also used a stop paddle during crossing events. At the end of the school zone time period the crossing guard removed the in-street sign from the roadway.

Researchers wanted to evaluate the impact of using the in-street sign only during the school zone time period to determine the effectiveness of this type of deployment on motorist compliance. Researchers also conducted a comprehension study for the in-street sign to determine how motorists interpreted the device.

Currently, the 2009 MUTCD (*3*) provisions for in-street pedestrian/school children crossing signs placed at unsignalized school crossings require the sign support be designed such that it can bend over and bounce back to its normal vertical position when struck by a vehicle. However, upon discussions with the FHWA, researchers determined that since the in-street sign was deployed only during a portion of the day it was considered to be a temporary traffic control device and therefore did not need to be self-righting. However, the device still had to be crashworthy. This interpretation allowed for the creation of a sign that was lighter weight and easier for a crossing guard to maneuver and deploy during the school zone times.

SITE SELECTION

Researchers did not obtain the prototype in-street sign to be evaluated until February 2011, and correspondence from FHWA allowing the use of the device was not received until late March 2011. Since the study had to be completed before school released for the summer (i.e., mid-May), researchers had limited time to conduct the study. Researchers decided to install the in-street sign at one site within a reasonable access distance of the research headquarters to allow for daily data collection and assistance with the device. Site characteristics that were needed for this task included:

- An active school crossing with crossing guard operations.
- School crossing on a TxDOT roadway.

- School crossing with no traffic signal.
- Cooperation of the applicable school/school district.

The site selected was in Bryan, Texas, at the intersection of West Villa Maria Road at Shirewood Drive near Mary Branch Elementary School. Figure 27 gives a basic layout of the field data collection site. Although this drawing is not to scale, it does provide a basic representation of where the crosswalk was in relation to other school zone signing and the school itself.

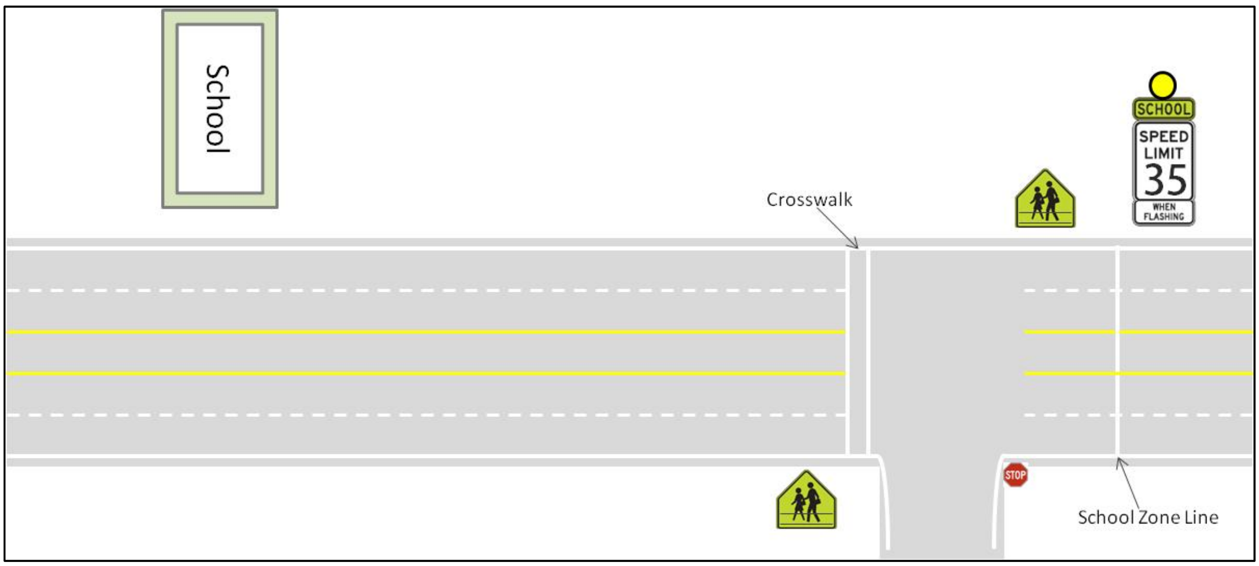


Figure 27. Portable In-Street Sign Field Observation Site Sketch.

The crosswalk that researchers observed was on an east/west road that had a cross section with two lanes traveling in each direction and a center turn lane. The speed limit during school zone times was 35 mph. Approaching the crossing area (outside of the school zone segment) the speed limit was 55 mph. The crosswalk marking at the site was comprised of two transverse solid white lines at the intersection of a cross street.

Two crossing guards were typically present at this crosswalk. The standard PPE used by the crossing guards for safety included either an orange or fluorescent yellow-green vest with CROSSING GUARD written across the back. For stopping traffic, the crossing guards used a stop paddle with engineering grade sheeting (ASTM Type I) that had a red light embedded into it below the stop legend. Additionally, there was a florescent yellow-green cone that was placed at the center of the roadway as a means of garnering extra motorist attention at the crossing. Once the crossing guards began use of the in-street sign, the cone was no longer used.

The standard crossing procedure used by the crossing guards consisted of the following steps. One guard would stop the traffic nearest the side where children wanted to cross the roadway. Once traffic was stopped in the first direction, the second crossing guard moved into the road and crossed to the opposite direction of travel to stop that traffic. In cases where only one crossing guard was available that person would begin with the same procedure of stopping the near-side traffic and then move to the center of the roadway to stop traffic in the opposite direction. These stopping procedures continued to be used after the in-street sign was deployed.

EXPERIMENTAL PLAN

Researchers conducted a before and after study to identify the impact of the in-street sign on driving behavior near a school crossing where active crossing guard operations were present. This study was the first step in determining if this type of informational device is practical for use by crossing guards and if it has safety benefits at the school crossing. Researchers collected observational, motorist understanding, and interview data to evaluate the in-street sign.

Field Observations

For the observational study, researchers collected the following data during active school zone times.

- The number of crossing events (i.e., the number of times a crossing guard escorted children across the road).
- The identification of vehicle compliance with crossing guard standard operations (i.e., use of stop paddle) and/or the new sign.
- Erratic maneuvers that occurred during crossing events.
- Traffic volumes.

Researchers also documented the site layout, including existing traffic control devices used by (or in conjunction with) the crossing guard.

Researchers collected these data for three periods as shown in Table 31. The first week, researchers collected data before installing the new device. The other two weeks of data collection were conducted after the installation of the new device; one two weeks after the installation and another four weeks after the installation. There were two after data collection efforts to determine if over time the effectiveness of the device decreased due to the novelty effect waning. Researchers did not collect data during a two week initial deployment period to avoid bias that can occur due to a novelty effect for a new device.

Table 31. Portable In-Street Sign Field Observation Data Collection.

Period Identifier	Dates	Number of Days
Before	April 4–8	5
Initial Deployment	April 11–22	10
After 1	April 25–29	5
After 2	May 9–13	5
Total Evaluation	April 11–May 13	20

Researchers collected data during morning and afternoon school crossing times. Morning data collection lasted from 7:00 a.m. until 8:00 a.m. and the afternoon period lasted from 2:30 p.m. until 3:00 p.m. Overall, researchers collected data during 29 school crossing time periods. Researchers were unable to collect data for one morning period during the second after data collection effort due to the fact that the sign was not brought to the site by the crossing guards.

Motorist Surveys

Researchers conducted motorist understanding surveys with motorists (i.e., parents of the nearby school children) who drove through the study area to obtain motorists' perceptions and understanding of the new device, as well as to garner their opinions regarding the application of the new device. These surveys began after the initial deployment period.

The administration of the survey was conducted in two formats. First, researchers went to the school to interview parents as they were picking up children at the end of the school day. These surveys were conducted in an interview format with a researcher asking the motorist questions and recording their answers. Second, the survey was made available to all school parents in an online format. Researchers created an online survey using the same questions asked during the in-person surveys. Parents were made aware of this survey through a letter that was sent home with students and could volunteer to participate by going to a specified website. This process made for a survey that was self-administered by the participant. For both of these administration methods, participants were shown a picture of the experimental in-street sign during the survey to ensure that they understood what device about which they were being questioned.

Crossing Guard Interviews

Finally, at the end of the evaluation period, researchers conducted interviews with the two crossing guards who had been using the prototype in-street sign to ascertain their thoughts as to the effectiveness of the new device during the study duration. The following specific topics were addressed during these interviews.

- Ease of use of the new in-street sign.
- The crossing guards' perceptions of motorist compliance for the new sign as compared to their standard operations.
- Changes or improvements the crossing guards would make to the new in-street sign.

RESULTS

Field Observations

Researchers observed a total of 89 crossing events (i.e., times when the crossing guard was active in assisting children across the street). As indicated in Table 32, the erratic maneuvers observed were spread fairly consistently across the three data collection periods with four occurring during the before data period, five during the first after period, and three during the second after period. These data show that the introduction of the new in-street device did not result in a significant increase in erratic behavior on the part of motorists but did not decrease these behaviors either.

In addition to simply marking a behavior as erratic, researchers also categorized the motorists' behaviors when the in-street device was used to determine if the types of erratic events occurring changed due to the new device. Table 33 categorizes the erratic maneuver events for each of the data collection periods as follows:

- Motorists not complying with device and/or crossing guard signal (no compliance).
- Motorists stopping when the device was not active and no crossing event was in progress (unnecessary stop).

- Motorists nearly missing a stop or stopping too close to the crosswalk (near miss).

Based on these data, the new in-street device did not appear to impact the types of erratic events that occurred.

Table 32. Portable In-Street Sign Field Observation Data.

Collection Period	Time of Day	Average Flow Rate (vph)	Number of Pedestrians	Number of Crossing Events	Number of Erratic Maneuvers	Total # of Erratic Maneuvers
Before	Morning	985	16	15	1	4
	Afternoon	758	58	18	3	
After 1	Morning	912	23	21	3	5
	Afternoon	716	58	13	2	
After 2	Morning	927	14	12	2	3
	Afternoon	814	52	10	1	

vph = vehicles per hour

Table 33. Portable In-Street Sign Compliance and Erratic Behavior Categorization.

Collection Period	No Compliance	Unnecessary Stop	Near Miss
Before	1	1	2
After 1	3	2	0
After 2	1	1	1

In the first after data collection period, researchers observed an increase in non-compliance at the crossing. However, this change was not observed during the second after period. Researchers believe that the increase in the first after data collection period may have been due to the newness of the device at that location, but would not reflect the long-term effectiveness of the in-street device (as shown in the second after data collection period).

Motorist Surveys

Including the two administration methods, researchers conducted a total of 31 surveys. Of these participants, 81 percent indicated that they had seen the in-street sign deployed at the study location and 19 percent had not. The questioning continued for all participants but was slightly different for participants who saw the in-street sign in the field versus those who did not see the in-street sign.

Participants That Saw the In-Street Sign

Researchers wanted to identify which feature of the sign most caught the attention of motorists as they were approaching the sign. The majority of the participants (76 percent) identified that the lights were the first thing they noticed. The other main response was the sign itself since it was in the middle of the road (12 percent).

Next, researchers evaluated the comprehension of motorists regarding what their actions should be when they saw the device. For this question, the response was divided almost evenly with 56 percent of participants stating that they needed to slow down and 44 percent indicating that they should yield to pedestrians. Although this response is split, both answers were correct in the minds of the researchers as the motorist was primarily acknowledging that the sign was alerting them to a situation that required them to use an increased amount of caution. This would give a correct comprehension rate of 100 percent of participants.

Researchers continued questioning participants by having them identify when the in-street sign should be used. The majority of the participants (88 percent) believed that the sign should be used during school zone crossing times or anytime that children are going to/from the school. These responses reinforce the idea that participants understood that this sign was being used as a warning of school children in the area who may be crossing the road as they were identifying times based around the belief that the use of the sign would be contingent on the school time schedule.

The survey addressed the motorist's interpretation of what the lights on the sign were indicating (flashing versus not illuminated) to motorists. When participants were asked if they had seen the in-street sign with the lights flashing, 72 percent said they had seen the lights flashing, 20 percent had seen the sign when the lights were not illuminated, and 8 percent were not sure if the lights were illuminated or not.

Of those who had observed the in-street sign with the lights flashing, 94 percent believed that the lights helped them to notice the sign and its message. Specifically, several participants commented that the lights helped make the sign noticeable in the environment. All of the participants who observed the in-street sign with the lights flashing believed that the lights helped them to notice the crossing guard and children. Motorists who had not seen the lights flashing believed that this addition would imply that they needed to slow down or be more attentive.

All of the participants who had seen the sign in the field were asked to identify what their action would be if they saw the in-street sign with the lights flashing. The participants gave the following responses (participants could give more than one action response).

- Slow down (68 percent).
- Look for children (28 percent).
- Stop (20 percent).
- More attentive because of flashing lights (20 percent).

These responses indicate that motorists believe that the lights are a reason to change their behavior and could improve the safety of a crossing guard and children as traffic would move slower and the motorists would be more alert to the school crossing even before a crossing guard needed to step into the road. Additionally, when questioned as to why the motorists were making the decision to slow down most indicated that this action was needed because there may be children crossing the road.

Researchers also wanted to know what the participants would have done had the lights not been flashing when they observed the sign. This question was only asked of the participants who had initially seen the sign when the lights were flashing. The responses of these participants were as follows (again, participants could give more than one response).

- Slow down (67 percent).
- Be more alert/watch for children (17 percent).
- Wouldn't notice the sign as much (11 percent).
- Yield as sign indicates (11 percent).
- Wonder why lights are off (6 percent).

Researchers saw that there was not a great difference between these responses and those of how the motorists would react if the lights were flashing. The positive difference to note, which researchers believe indicates a safety improvement, is that a greater percentage of the participants noted that they would look for or be more aware of children crossing the road when the lights were flashing. Also, 11 percent of the participants commented that without the flashing lights the sign was not as noticeable.

Overall, all of the participants who had seen the in-street sign deployed at the evaluation site believed that it improved the safety of the crossing guard and the children as they were crossing the street. The main responses as to how it could help improve safety were that the sign was more visible or attention getting (56 percent) and that the lights draw the attention of motorists (28 percent). Additionally, participants mentioned that they believed this sign would alert motorists to the fact that there are children in the area (16 percent) and that they need to pay attention to the crossing guard (8 percent). Finally, participants (8 percent) noted that they believed the sign gave them greater advance warning of the school crossing that allows them to slow down earlier as they approach.

Participants That Did Not See the In-Street Sign

The second group of participants was those who had not seen the in-street sign deployed in the field. This group consisted of six participants. Still, when asked how they would react to this sign all of the participants indicated that they needed to slow down for pedestrians if they saw this sign. Further, all participants understood that this in-street sign was specifically being used to identify that children would be crossing the street.

As these participants had only seen a still picture of the sign, researchers asked how the participant would react if the lights on the sign were flashing. The majority of the participants (83 percent) indicated that they would slow down if the lights were flashing. Other responses given by participants were that they believed motorists would pay more attention to the sign if it was flashing, that it could be seen better, and that it would indicate that motorists needed to yield or stop. Overall, these responses do not indicate a major change in the participants' interpretations of the sign if the lights were flashing or steady-burn (as shown in the picture).

Participants were then asked to identify when they believed this sign should be used at the crosswalk. The responses were split for this question as follows.

- Anytime children may be present (50 percent).
- During school zone times (33 percent).
- All day (17 percent).

Researchers believe the responses including times outside of school zone hours are indicative of the concern motorists have for children crossing the road at any time. This led participants to believe that the sign, which they viewed as a safety improvement, would be good for use in all circumstances where children are present.

Suggested Changes to the In-Street Sign

All of the survey participants were asked if they believed something should be changed on the sign to improve it. Approximately one-third of the participants believed that improvements could be made to the sign. Their suggestions were as follows.

- Make the sign larger or more visible so it can better draw the attention of motorists (26 percent).
- Make the lights bigger, make them red (instead of yellow), or always have them flashing (i.e., never turn them off) (10 percent).

Although none of the suggestions given were outside of the reasonable scope of changing the sign, researchers believe that the changes are not necessary for the sign to be understood or to gain compliance.

Crossing Guard Interview Results

Ease of Use

The crossing guards agreed that the device was easy to use. The crossing guards liked the stabilizing legs on the sign as it prevented the device from blowing over in the wind or when vehicles passed the device. They noted that other devices they had used (most particularly a cone) had issues with staying upright. One of the guards noted that on his first day deploying the new sign he walked to the middle of the road and then maneuvered the legs down and into position. He stated that when he was conducting this maneuver he was almost struck by traffic and so to alleviate that problem on subsequent days he unfolded the legs while on the sidewalk and then carried it out to the middle of the roadway. He had not encountered any problems during setup using this method.

Motorist Compliance

Overall, the crossing guards believed that the sign helped with vehicle compliance and got the motorist's attention better than their standard operations. They stated that they liked the STATE LAW wording and felt that motorist compliance increased because this text gave an impression of authority. Additionally, the crossing guards felt that traffic had slowed down in the crossing area due to the use of the in-street sign.

When asked if they had experienced any motorists not stopping at the crossing when using this device, both guards agreed that there were some but believed that these motorists had been distracted while driving and were not paying attention to anything in the roadway. The crossing guards reconfirmed that they felt the device increased the compliance rate as compared to when they were not using it. One of the guards felt that the flashing lights on the sign got motorists' attention from a farther distance and made them slow down.

Changes/Improvements

The crossing guards agreed that they liked the color of the sign and that it included flashing lights. However, they observed that the lights were harder to see in the afternoon. It was suggested that the flashing lights should be larger to make it easier to see on days with bright sunlight. They also believed that the operational procedure for using this type of sign should leave the lights flashing at all times during the school zone period to slow motorists down and not just during crossing events. In fact, one guard explained that two of the school bus drivers had stopped to tell them that the lights were not working. When they explained they were only to flash when they were crossing the street with children, these motorists concurred that the lights should be on the entire school zone period. Additional suggestions included the following points.

- Using a camera (similar to the red light running cameras) to detect non-compliance maneuvers and fine motorists.
- Adding a handle on the side or bottom of the device to make it easier for older or less physically capable users to load and unload from a vehicle. Currently, the device only has a handle on the top of the sign.
- Increasing the size of the STATE LAW text on the sign.

CONCLUSIONS AND RECOMMENDATIONS

Through the initial evaluation of risk and concerns for crossing guards, researchers identified that the most hazardous time for a crossing guard is while they are in the active process of helping children to cross the roadway safely, and that catching the attention of motorists before entering the roadway is critical to improving safety. To this end, researchers evaluated a prototype remotely operated, in-street school children crossing sign with flashing

LEDs around the border of each sign face, with the hope of improving the safety of the crossing guard and children. Three different tools were used to evaluate the effectiveness of the new in-street sign: field observations, motorist comprehension surveys, and crossing guard interviews.

Field Observations

There was no significant change in motorist behavior observed during the field study based on a comparison of erratic or non-compliance maneuvers before and after the in-street sign was used. However, the amount of data available for the field observations was limited with only five days of before data and 10 days of after data at one site. Still, researchers believe that the use of the in-street sign would not negatively impact operations at the crossing site.

Motorist Surveys

Based on the surveys conducted, there was no apparent misunderstanding of the meaning of the in-street sign. All of the participants surveyed realized that the sign was alerting them to a situation that required them to use an increased amount of caution in the area (mostly slow down or yield). Additionally, all of the participants believed that the in-street sign improved the safety of the crossing guard and the children as they were crossing the street. Finally, the majority of the participants identified that the sign should be used during school zone times as a safety measure for the children.

Crossing Guard Interviews

The crossing guards stated that they would like to use the in-street sign in the future. They believed that there was a positive impact upon motorist compliance during the time that they used the sign. They also stated that this sign was more effective than any other device that they had used in the past (cone, stop sign, etc.). Their main points in favor of the sign were that it seemed to slow motorists down near the crossing and that the sign got motorists' attention farther upstream of the crossing.

Overall Recommendations

Taking all of the gathered information into consideration, researchers believe that this prototype in-street sign could be used at school crossings to improve safety. There were no negative operational impacts at the field study site. Additionally, this sign was well understood by motorists as indicating a situation that needed them to pay additional or specific attention to the area. Although the limited observations possible in the field study did not reveal this effect, knowing that motorists understand this need at a school crossing would be expected to improve safety at the crossing. Finally, the crossing guards had a positive experience with the use of the device and believed that it improved their ability to perform their duties in assisting children to cross the road. Researchers suggest the following design and use recommendations for the in-street sign.

- The in-street sign should have identical sign faces on both sides of the device and these sign faces should meet Texas MUTCD requirements for size and content.
- The sign should be designed such that there are embedded flashing LEDs in the sign face or other appropriate lighting options as per the Texas MUTCD that can be remotely activated by the crossing guard.
- The design of the device must be such that it is easily transportable and deployable by a crossing guard.
- The design of the device must be crashworthy.
- The device should be placed at the approximate center of the road that is being crossed such that it is easily visible to both directions of traffic.
- The sign should only be placed in the street during school zone hours.
- The lights should only be activated (i.e., flashing) during active crossing events.

SUMMARY, RECOMMENDATIONS, AND GUIDELINES

AFADS

AFADs are designed to be remotely operated by a flagger positioned outside of the travel lane, thereby reducing their exposure to vehicular traffic. While AFADs may increase the safety of flaggers, there were concerns that motorists may misunderstand AFADs; thus, increasing the potential for motorists to enter the lane closure under the stop condition. Therefore, researchers administered motorist surveys to determine motorists' understanding of AFADs and the advance warning sign sequence used with AFADs. In addition, researchers conducted field studies to assess the operational and safety effectiveness of AFADs relative to the use of flaggers.

Motorist Survey Summary

To determine motorists' understanding of both types of AFADs and the advance warning sign sequence used, researchers developed and administered motorist surveys to 810 participants in Texas. The following sections summarize the motorist survey findings.

Stop/Slow AFADs

When researchers directly asked participants how they would react to a stop/slow AFAD with the supplemental sign currently required (i.e., WAIT ON STOP), approximately one-quarter stated they would stop and then proceed like at a standard stop sign. In addition, only 5 percent of participants understood that the stop sign would change to a slow sign when they were allowed to proceed. While the percentage of participants that understood the AFAD sign would change from stop to slow increased when the GO ON SLOW sign was added (28 percent), more participants stated they would stop and then proceed like at a standard stop sign (31 percent).

In contrast, only 8 percent of participants stated that they would stop and then proceed with the alternative WAIT ON STOP/GO ON SLOW symbol sign. In addition, 58 percent of the participants understood the AFAD sign would change. Overall, the alternative WAIT ON STOP/GO ON SLOW symbol sign resulted in the highest percentage of participants who understood to stop and remain stopped until the AFAD indicated that it was safe to proceed (92 percent).

The majority of participants thought the flashing and steady-burn red beacon on a stop/slow AFAD had the same meaning. In addition, researchers did not find that the beacon mode (either flashing or steady-burn) impacted motorists' understanding of the stop/slow AFAD.

Red/Yellow Lens AFADs

Participants understood that the steady red signal with the gate arm down meant stop. However, the majority of participants thought both yellow signals (flashing and steady-burn) meant proceed with caution. Even though there is evidence of a lack of understanding of the difference between the proceed and transition phases, the use of the gate arm informs motorists when to proceed and when to stop (raised when the signal changes to the flashing yellow signal and lowered when the signal changes to steady red). Also, motorists stopped at the AFAD typically do not view the steady-burn yellow signal (assuming the queue of vehicles waiting is completely discharged). In addition, more participants understood the difference between the two yellow signals when they observed the AFAD cycle from the proceed condition, to the transition condition, and then to the stop condition. This is important because motorists approaching the AFAD during the proceed condition need advance warning that the AFAD is about to change to the stop condition.

While researchers did not specifically evaluate the impact of color vision deficiencies, all of the participants understood that when the top signal indication was illuminated and the gate arm was lowered they were to stop and when the bottom signal indication was illuminated and the gate arm was raised they could proceed. Researchers felt that the use of the gate arm was the most critical component to motorist understanding of the red/yellow lens AFAD.

Advance Warning Signs

Ninety-eight percent of participants thought the advance warning signs for AFADs recommended in the MUTCD adequately informed motorists of the conditions ahead. In addition, there was a strong indication from participants that the flagger symbol sign should not be used if a person was not visibly controlling traffic at the AFAD location.

Field Study Summary

The violation rate for the stop/slow AFAD with a WAIT ON STOP sign without a gate arm was the highest and was significantly higher than the violation rate for the red/yellow lens

AFAD (which requires a gate arm). Adding a gate arm to this stop/slow AFAD decreased the violation rate such that it was not significantly different from the red/yellow lens AFAD. Once a gate arm was added to the stop/slow AFAD, the supplemental signs evaluated did not appear to impact compliance. However, the alternative WAIT ON STOP/GO ON SLOW symbol signs did increase motorist understanding that the stop sign would change when motorists were allowed to proceed. In addition, the alternative WAIT ON STOP/GO ON SLOW symbol signs increased motorist comprehension that a slow sign would be displayed when motorists were allowed to proceed.

Recommendations

While AFADs may increase the safety of flaggers by removing them from an active travel lane, the research findings show that some motorists may misunderstand the directions provided by AFADs and enter the lane closure under the stop condition, which could lead to a collision with oncoming traffic. However, AFAD violations (between 2.2 to 4.0 violations per 100 stop cycles) were less than red-light violations documented in previous literature (5.3 violations per 100 stop cycles) (*26*). In addition, for all the documented violations the flagger was able to stop the motorist before they encountered oncoming traffic. Based on these data, researchers believe that both types of AFADs (stop/slow and red/yellow lens) may be used in Texas to control traffic at lane closures on two-lane, two-way roadways.

Researchers did not make any specific recommendations regarding the red/yellow lens AFADs, since the research findings supported the current language in the MUTCD. For stop/slow AFADs, researchers made the following recommendations.

- A gate arm should be required when using stop/slow AFADs.
- The alternative WAIT ON STOP/GO ON SLOW symbol signs should be required with stop/slow AFADs (instead of the current recommended signing in the MUTCD) to improve motorist understanding of the stop/slow AFAD. Currently, TxDOT has permission from the FHWA to experiment with these alternative symbol signs.
- TxDOT should investigate the potential to combine the alternative WAIT ON STOP/GO ON SLOW symbol signs into one sign and the potential to use flexible, roll-up sign material instead of rigid sign sheeting on a rigid substrate to improve the ease of installation and removal of the AFADs and related devices.

TxDOT personnel need to be aware that violations will occur, especially when AFADs are initially deployed. Thus, TxDOT should use public outreach techniques such as news stories, the internet, and social media in areas where it will deploy AFADs to notify and educate motorists. Intrusion alarms are available with most AFADs. A flagger can manually activate these alarms when a violation occurs or the alarms can automatically activate if pneumatic hoses are connected to the AFAD. The alarm notifies other workers of the violation and can cause the motorist in violation to stop.

When used, a trained flagger must operate AFADs. A single flagger may simultaneously operate two AFADs (one at each end of the lane closure) if the flagger has an unobstructed view of both AFADs and approaching traffic in both directions. Since violations may occur, flaggers should not leave the AFADs unattended. Thus, a person operating an AFAD should not also be the person driving the pilot vehicle, since the person driving the pilot vehicle cannot always view both AFADs and approaching traffic in both directions.

Based on the motorist survey findings, researchers recommend using the following advance warning signs with both types of AFADs:

- ROAD WORK AHEAD (CW20-1D).
- ONE LANE ROAD AHEAD (CW20-4D).
- BE PREPARED TO STOP (CW20-7B).

Researchers do not recommend the use of a flagger symbol sign (CW20-7A) in advance of AFADs, unless a flagger is located near the AFAD and visible to motorists.

Based on the field studies and current TxDOT operations, researchers recommend attaching a flag to the end of the AFAD gate arm to increase the conspicuity of the arm and denote the end of the arm. Researchers also recommend the use of channelizing devices on the centerline on the approach to the AFAD. The length of the channelizing device section should be a minimum of 120 ft long and the maximum channelizing device spacing should be 20 ft.

SCHOOL CROSSING GUARDS

Similar to flaggers, there was also concern regarding the safety of crossing guards trying to stop motorists before school children enter the crosswalk. Research was needed to explore the safety issues encountered by crossing guards and to identify and assess potential portable devices for improving the safety and effectiveness of crossing guards. Based on observations of and discussions with crossing guards, researchers identified the following common threads of concern:

- The most hazardous time for a crossing guard is while they are in the active process of helping children cross the roadway.
- Catching the attention of motorists before a crossing guard is required to step into the street is critical to improving safety.
- Keeping motorists stopped throughout an active crossing event is a problem for crossing guards.

Given these concerns, researchers decided to investigate two aspects of improving the safety and effectiveness of crossing guard operations: 1) improving the conspicuity of crossing guards so they are more easily detected within the environment and 2) improving the advance warning provided to motorists before the crossing guard enters the crosswalk. To address the first aspect, researchers decided to evaluate stop paddles with embedded lights. To address the second aspect, researchers deployed and evaluated a prototype remotely operated, in-street school children crossing sign with flashing LEDs around the border of each sign face.

Stop Paddles with Embedded Lights

Summary

Researchers found that crossing guards were very interested in using stop paddles with embedded lights to improve their conspicuity before entering the crosswalk and during active operations. However, researchers were concerned that some of the embedded light configurations may negatively impact a motorist's ability to recognize the three critical characteristics that define a stop sign: red background color, octagon shape, and white STOP legend. Thus, researchers conducted a closed-course human factors study to determine the effectiveness of five stop paddles with embedded lights compared to a standard, un-lit stop paddle.

The three stop paddles with lights around the border did not significantly impact the predicted mean distance at which the participants could recognize the background color of the stop paddles compared to the standard, un-lit stop paddle. In contrast, the stop paddle with flashing red lights vertically centered above and below the STOP legend and the stop paddle with steady-burn white lights forming the STOP legend resulted in predicted mean background color recognition distances significantly shorter than the standard, un-lit stop paddle (210 to 392 ft closer to the crossing guard). Participants thought the flashing lights above the STOP legend were blinding or distracting and thus made it more difficult to discern the red background color of the stop paddle. Participants also thought the white lights forming the STOP legend made it more difficult to distinguish the red background color of the stop paddle.

None of the stop paddles with embedded lights impacted the predicted mean distance at which the participants could recognize the shape of the stop paddles compared to the standard, un-lit stop paddle. However, the three stop paddles with lights around the border did produce significantly farther predicted mean shape recognition distances (150 to 195 ft) than the stop paddle with steady-burn white lights forming the STOP legend. This is not surprising since the lights around the border highlight the shape of the stop sign.

None of the stop paddles with embedded lights impacted the predicted mean distance at which the participants could read the STOP legend compared to the standard, un-lit stop paddle. While not statistically significant, researchers did find that ambient lighting conditions affected the legibility distance of the stop paddle with steady-burn white lights forming the STOP legend. Under clear and sunny conditions, the predicted mean legibility distance for this stop paddle was 463 ft. In contrast, under pre-dawn and overcast conditions, the predicted mean legibility distance was 116 ft shorter (i.e., 347 ft). Researchers believe that when the light produced by the steady-burn white lights in the STOP legend is greater than the ambient light, over-glow of the STOP legend occurs (i.e., blending of the letters), making it more difficult for motorists to read.

Recommendations

Researchers recommend the use of one of the following stop paddles to improve the conspicuity of crossing guards without negatively impacting a motorist's ability to recognize the three critical characteristics of a stop sign (i.e., red background color, octagon shape, and white STOP legend):

- A stop paddle containing flashing red lights arranged in an octagonal pattern at the eight corners of the paddle.
- A stop paddle containing a series of steady-burn red lights around the border arranged such that the lights clearly convey the octagonal shape of the paddle.

- A stop paddle containing a series of flashing red lights around the border arranged such that the lights clearly convey the octagonal shape of the paddle.

Since the Texas MUTCD does not currently address steady-burn lights, TxDOT should consider revising the language in the next edition of the Texas MUTCD to allow for the use of steady-burn lights in the configuration described above. Researchers do not know how the use of white lights would impact the effectiveness of the recommended stop paddles.

Based on the findings, researchers do not recommend using the following devices:

- A stop paddle containing flashing red lights centered vertically above and below the STOP legend.
- A stop paddle with a series of steady-burn white LED lights forming the letters of the STOP legend.

Researchers did not study the latter treatment with flashing lights, as described in the Texas MUTCD. Thus, researchers do not know whether the use of flashing lights would reduce the potential for over-glow and thus improve a motorist's ability to recognize the background color and shape, as well as read the STOP legend during darker ambient light conditions.

Researchers did not evaluate the effectiveness of a stop paddle containing flashing red lights centered horizontally on each side of the STOP legend. However, researchers believe that stop paddles containing a similar light configuration to the one tested above and below the STOP legend would also reduce the recognition distance of the background color of the stop paddle. Researchers do not know how the use of white lights would impact the effectiveness of the stop paddles with flashing lights centered horizontally on each side or vertically above and below the STOP legend.

Portable In-Street School Children Crossing Sign

Summary

Through the initial evaluation of risks and concerns for crossing guards, researchers identified that the most hazardous time for a crossing guard is while they are in the active process of helping children to cross the roadway, and that catching the attention of motorists before entering the roadway is critical to improving safety. To this end, researchers evaluated a prototype remotely operated, in-street school children crossing sign with flashing LEDs around the border of each sign face, with the hope of improving the safety of the crossing guard and children.

Researchers conducted a before and after study to identify the impact of the in-street sign on driving behavior near a school crossing where active crossing guard operations were present. This study was the first step in determining if this type of informational device is practical for use by crossing guards and if it has safety benefits at the school crossing. Researchers collected observational, motorist understanding, and interview data to evaluate the in-street sign.

There was no significant change in motorist behavior observed during the field study based on a comparison of erratic or non-compliance maneuvers before and after the in-street sign was used. However, the amount of data available for the field observations was limited with only five days of before data and 10 days of after data at one site. Still, researchers believe that the use of the in-street sign would not negatively impact operations at the crossing site.

Based on the surveys conducted, there was no apparent misunderstanding of the meaning of the in-street sign. All of the participants surveyed realized that the sign was alerting them to a situation that required them to use an increased amount of caution in the area (mostly slow down or yield). Additionally, all of the participants believed that the in-street sign improved the safety of the crossing guard and the children as they were crossing the street. Finally, the majority of the participants identified that the sign should be used during school zone times as a safety measure for the children.

The crossing guards stated that they would like to use the in-street sign in the future. They believed that there was a positive impact upon motorist compliance during the time that they used the sign. They also stated that this sign was more effective than any other device that they had used in the past (cone, stop sign, etc.). Their main points in favor of the sign were that it seemed to slow motorists down near the crossing and that the sign got motorists' attention farther upstream of the crossing.

Recommendations

Taking all of the gathered information into consideration, researchers believe that this prototype in-street sign could be used at school crossings to improve safety. There were no negative operational impacts at the field study site. Additionally, this sign was well understood by motorists as indicating a situation that needed them to pay additional or specific attention to the area. Although the limited observations possible in the field study did not reveal this effect, knowing that motorists understand this need at a school crossing would be expected to improve safety at the crossing. Finally, the crossing guards had a positive experience with the use of the device and believed that it improved their ability to perform their duties in assisting children to cross the road. Researchers suggest the following design and use recommendations for the in-street sign.

- The in-street sign should have identical sign faces on both sides of the device and these sign faces should meet Texas MUTCD requirements for size and content.
- The sign should be designed such that there are embedded flashing LEDs in the sign face or other appropriate lighting options as per the Texas MUTCD that can be remotely activated by the crossing guard.
- The design of the device must be such that it is easily transportable and deployable by a crossing guard.
- The design of the device must be crashworthy.
- The device should be placed at the approximate center of the road that is being crossed such that it is easily visible to both directions of traffic.
- The sign should only be placed in the street during school zone hours.
- The lights should only be activated (i.e., flashing) during active crossing events.

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