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16. Abstract

The primary objectives of this research project were: (1) to develop an active advance warning device (AAWD) comprised of an actuated flashing beacon supplement to a conventional SCHOOL BUS STOP AHEAD sign (S3-1) and (2) to evaluate its effect on driver performance and safety through school bus loading and unloading zones. Secondary objectives were to summarize system components and costs, develop an activation strategy, review the liability risk, review national experience related to safety, and provide guidance regarding specifications and use in Texas. With respect to safety, 37 of 46 studies reported a positive effect resulting from AAWDs. Findings from field studies conducted in Texas also suggest favorable results with confirmed reductions in vehicle approach speeds when the flashing beacon was activated. Costs for the final AAWD are estimated to be $2,000 for the S3-1 sign and flashing beacons and $2,600 for the flashing beacon activation system, not including sign installation or ongoing maintenance and operations costs. A review of published literature and historic case law suggests minimal additional liability risk above what is already experienced by transportation departments. Unique areas of risk relate to "jurisdictional responsibility" for establishing, operating, and maintaining school bus loading and unloading zones and the hazard expectation tied to the flashing beacon activation (i.e., motorists may not exercise the same degree of caution when the bus is not present and the beacons are not flashing despite children being present at the bus stop). Given the favorable safety impacts, the low system cost, and the minimal additional liability risk incurred, the AAWD is recommended for further implementation.

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DEVELOPMENT AND EVALUATION OF AN ACTIVE WARNING DEVICE FOR SCHOOL BUS LOADING AND UNLOADING POINTS IN AREAS OF LIMITED VISIBILITY

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and the
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PROBLEM DESCRIPTION

Although school buses provide one of the safest modes of travel for students (Transportation Research Board 2002), children are at greater risk when in school bus loading or unloading zones. Students are three to four times more likely to be killed while boarding or leaving the bus than while riding the bus (Transportation Research Board 1989). Vehicles other than a school bus, typically cars or trucks that have illegally passed a stopped bus, kill one-third of these children.

Efforts to improve safety at school bus loading or unloading zones have been focused on increasing school bus conspicuity and public education and guidance. Bus-mounted devices that have been developed to inform and alert drivers of their responsibility to stop while school buses are loading or unloading include the following:

- STOP signal arms with flashing red lights that extend from the left side of the bus,
- flashing yellow lights indicating that the bus is preparing to stop,
- flashing red lights indicating that the bus has stopped and students are preparing to board or leave the bus, and
- warning lights to increase the visibility of the bus.

These devices are intended to enhance the visibility of a school bus and, in some cases, to inform drivers of their responsibility to stop during loading and unloading operations. However, none of the devices are visible from a distance if a school bus is stopped in an area of limited visibility.

Particularly in rural areas, school bus loading and unloading zones are sometimes required to be located in areas of limited visibility. *The Manual on Uniform Traffic Control Devices* (*MUTCD*) (U.S. Department of Transportation 2000) provides a warning sign that should be used in advance of locations with less than 500 feet of visibility if the bus stop cannot be moved to provide adequate visibility. The SCHOOL BUS STOP AHEAD sign (S3-1), shown in Figure 1, is intended to provide additional advance warning in those situations when the devices mounted on the school bus are not readily visible to concurrent or oncoming traffic.

One disadvantage to this added advance warning is that the sign is present 24 hours a day, 365 days a year despite its being applicable typically only twice a day during the school year. The constant display of the static warning message combined with the limited presence of the hazard (i.e., the stopped school bus and loading/unloading children) will result in rapid motorist desensitization to the risk and a subsequent degradation in safety at school bus loading/unloading zones.

Flashing beacons can be used to add conspicuity or emphasis to static warning signs and reduce the likelihood for motorist desensitization (U.S. Department of Transportation 2000) (see Figure 2). The use of these "active" warning devices is governed by the *MUTCD* and enhances the sign's ability to command attention. The *MUTCD* provides recommended applications for flashing warning beacons:

- at obstructions in or immediately adjacent to the roadway;
- as supplemental emphasis to regulatory or warning signs;
- as emphasis for mid-block crosswalks;
- on approaches to intersections where additional warning is required or where special conditions exist; and
- as supplements to regulatory signs, except STOP, YIELD, DO NOT ENTER, and SPEED LIMIT signs.

Furthermore, the *MUTCD* states that flashing warning beacons should be operated (i.e., activated) only during the times the hazardous condition or regulation exists. In the case of school buses stopped while loading or unloading children, the condition generally only occurs once in the morning and once in the afternoon with predictable schedules.

Figure 1. SCHOOL BUS STOP AHEAD Sign (S3-1).

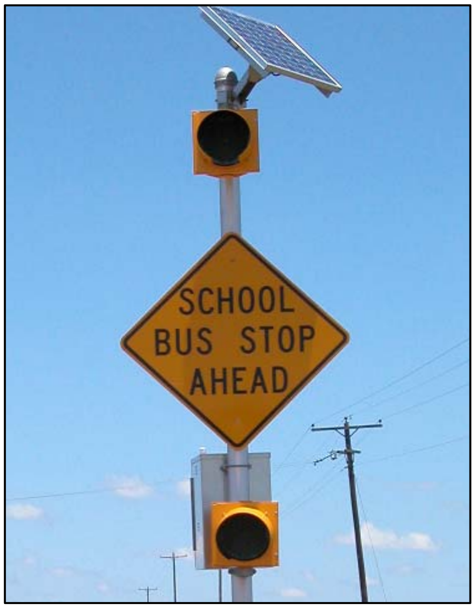

Figure 2. SCHOOL BUS STOP AHEAD Sign (S3-1) with Flashing Beacon.

PROJECT OBJECTIVES

The primary objective of this research project were: (1) to develop an active advance warning device (AAWD) comprising an actuated flashing beacon supplement to a conventional SCHOOL BUS STOP AHEAD sign (S3-1) and (2) to evaluate its effect on driver performance (i.e., reduced speeds, improved vehicle braking activity, reduced erratic maneuvers, etc.) and safety through school bus loading and unloading zones.

Secondary objectives included the following:

- summarize AAWD components and costs,
- develop an activation strategy for the flashing beacon system component,
- review the liability risk associated with AAWD (i.e. moving from passive to active warning),
- review national experience related to AAWD, and
- provide guidance regarding potential AAWD specifications and use in Texas.

The successful development and application of an active advance warning device (AAWD) that provides enhanced conspicuity to conventional SCHOOL BUS STOP AHEAD signing (S3-1) will better alert drivers to the presence of school buses in areas of limited visibility and potentially enhance the safety of both pedestrian children and vehicle occupants. If proven effective, the Texas Department of Transportation (TxDOT) can proceed with appropriate installations statewide.

PROJECT IMPLEMENTATION

Three products will be developed during this project that directly support the implementation of AAWD for school bus loading and unloading zones in areas with limited visibility. These include the following:

(1) Draft Specifications: draft specification language will allow TxDOT to specify the characteristics of the AAWD and its recommended use in the field;

(2) Draft Design and Detail Drawings: MicroStation CAD design and detail drawings will allow TxDOT to quickly incorporate the AAWD into roadway and maintenance plans; and

(3) Draft Language for the *TxDOT Operations Manual* and the *TMUTCD*: draft language regarding the AAWD specifications and use will allow TxDOT to incorporate the findings of the project directly into their operational procedures and the *Texas Manual on Uniform Traffic Control Devices (TMUTCD).*

REPORT ORGANIZATION

The findings contained in this report respond to the three-part problem described previously and summarized here:

(1) Children are at greatest risk when in school bus loading or unloading zones. Students are three to four times more likely to be killed while boarding or leaving the bus than while riding the bus (Transportation Research Board 1989).

(2) Efforts to improve safety at school bus loading or unloading zones have been focused on increasing school bus conspicuity and enhancing driver guidance. However, none of these efforts are effective (i.e., visible from a distance) if a school bus is stopped in an area of limited visibility.

(3) The constant display of the static warning message, SCHOOL BUS STOP AHEAD, combined with the limited presence of the hazard (i.e., the stopped school bus and loading/unloading children) results in rapid motorist desensitization to the risk and a subsequent degradation in safety at school bus loading/unloading zones.

This investigation considered the development an active advance warning device (AAWD) comprising an actuated flashing beacon supplement to a conventional SCHOOL BUS STOP AHEAD sign (S3-1) and evaluated its effect on driver performance (i.e., reduced speeds, improved vehicle braking activity, reduced erratic maneuvers, etc.) and safety through school bus loading and unloading zones.

Following this introductory material, Chapter 2 describes the prototype AAWD development including: (1) final system components and costs, (2) a recommended activation strategy, and (3) a review of potential liability risk associated with an active versus passive warning sign system. Chapter 3 provides a summary of national experience related to AAWD effects on driver behavior and safety and describes the results of field studies conducted locally in Texas. Specifically, the field studies considered changes in approach vehicle speeds and brake-light actuations through the school bus loading and unloading zones. This chapter also includes a description of each field study site and the evaluation methods used. Chapter 4 recommends AAWD specifications and guidelines for use. These recommendations are intended for incorporation into both the *TxDOT Operations Manual* and the *TMUTCD*. This report concludes with a summary of findings related to safety and driver behavior impacts, system costs, and liability risk in Chapter 5.

CHAPTER 2:
PROTOTYPE SYSTEM DEVELOPMENT

SYSTEM COMPONENTS AND COSTS

The system components for the prototype AAWD developed and tested as part of this project included the following:

- SCHOOL BUS STOP AHEAD advance warning sign (S3-1),
- Top- and bottom-mounted flashing beacons, and
- flashing beacon activation system.

The various system components are depicted in Figure 3. Costs for the final system are estimated to be $2,000 for the S3-1 sign and flashing beacons and $2,600 for the flashing beacon activation system; a single flashing beacon activation system can be used with multiple S3-1 sign and flashing beacon assemblies. These estimates do not include sign installation or ongoing maintenance and operations costs.

Operations and maintenance requirements for the AAWD may include the following:

- keep sign properly positioned, clean, and legible with adequate reflectivity;
- ensure that weeds or trees do not obscure the face of the sign;
- ensure that construction, maintenance, or utility activities do not obscure the face of the sign;
- clean the flashing beacon lenses and replace light sources as required;
- keep the activation system (i.e., transmitter, receiver, and system controller) in effective operation;
- provide for alternate operation or spare equipment during periods of failure; and
- provide for properly skilled maintenance personnel for the repair of all components.

SCHOOL BUS STOP AHEAD Advance Warning Sign (S3-1)

The SCHOOL BUS STOP AHEAD advance warning sign is diamond shaped, with 30-inch sides and a black legend and border on a yellow background. The design and size of this sign is compliant with *MUTCD* recommendations for conventional roadways.

Figure 3. Active Advance Warning Device Components for School Bus Loading/Unloading Zones.

Top- and Bottom-Mounted Flashing Beacons

Two vertically aligned, flashing circular yellow beacons are mounted above and below the SCHOOL BUS STOP AHEAD sign on the same assembly but outside of the border of the sign. The yellow beacons, with nominal diameters of 8 inches, flash alternately at a rate of not less than 50 nor more than 60 times per minute with an illumination period of each flash not less than one-half and not more than two-thirds of the total cycle, as recommended in the *MUTCD*. The power to operate the flashing beacons is derived from solar cells charging a storage battery.

Flashing Beacon Activation System

The activation system for the flashing beacon component of the AAWD was determined after a critical review of various mechanisms. In general, these activation systems can be categorized as: (1) on-site, school bus activation; (2) programmed time schedule activation; and (3) off-site, central location activation.

On-Site, School Bus Activation

Activation of the flashing beacons by a passing school bus could be accomplished by adapting one of five current methods used to actuate traffic signals or other devices from moving vehicles: (1) a radio frequency link between the school bus and the sign using 300 to 400 MHz radio frequencies; (2) a radio frequency link between the school bus and the sign using microwave (2500 MHz) frequencies; (3) a sign-mounted optical detector and school bus-mounted strobe; (4) a sign-mounted tag reader and passive, school bus-mounted windshield tag; or (5) a radio frequency link between the school bus and the sign using spread spectrum (902 to 928 MHz) radio frequencies. (Spread spectrum radio is free of tight FCC restrictions which limit the applications for which other bands can be used; virtually any analog or data signal can be sent without restrictions on content or duration using this frequency range.) The advantages and disadvantages of each on-site, school bus activation method are summarized in Table 1.

In general, these various on-site, school bus activation strategies were reviewed with respect to proof-of-performance, FCC licensing and certification requirements, and cost. One overriding benefit of on-site, school bus activation, regardless of the specific actuation method used, is that the flashing beacon will only be activated when the hazard (i.e., school bus) is present, enhancing driver confidence in the AAWD. Children, however, may be present and at risk prior to and following the flashing beacon activation by the bus.

Programmed Time Schedule Activation

An alternative to on-site, school bus activation, the flashing beacon component of the AAWD can be activated using a programmed time schedule, comprising a seven-day timer in the beacon control circuit to actuate the beacon during the time the school bus is expected to be passing that location. The timer could be reset once a day by using precision global positioning systems (GPS) satellite time or signals from the National Institute of Standards Technology's (NIST) radio station WWVB in Colorado. One challenge to this method would be in predicting an accurate time window when the hazard (i.e., school bus and/or children) would be present.

Table 1. On-Site, School Bus Activation Methods.

ADVANTAGES	DISADVANTAGES
RADIO FREQUENCY LINK WITH 300-400 MHz FREQUENCIES	
• Low cost • Range of 300 feet • Encoded for each bus and security	• Requires FCC certification • Continuous signals may not be permitted • Two receivers required to allow buses approaching from either direction to activate the beacons
RADIO FREQUENCY LINK USING MICROWAVE (2500 MHz) FREQUENCIES	
• System already in use on emergency vehicles • FCC license may be provided by manufacture • Encoded for each bus and security	• Possible high cost
SIGN-MOUNTED OPTICAL DETECTOR AND SCHOOL BUS-MOUNTED STROBE	
• System already in use on emergency vehicles • Does not require FCC license or certification • Encoded for each bus and security • Invisible to humans (infrared light)	• Possible high cost • Range varies with ambient light • Two receivers required to allow buses approaching from either direction to activate the beacons
SIGN-MOUNTED TAG READER AND PASSIVE SCHOOL BUS-MOUNTED WINDSHIELD TAG	
• System already in use on toll roads • Minimal hardware inside school bus (toll tag) • Encoded for each bus and security	• High cost • High power demand • Two receivers required to allow buses approaching from either direction to activate the beacons
RADIO FREQUENCY LINK USING SPREAD SPECTRUM (902 TO 928 MHz) FREQUENCIES	
• More relaxed FCC monitoring • Sends signals from the moving bus on a regular interval (i.e., every 100 feet) • Transmits a stronger signal potentially activating both the same-lane and the opposite lane roadside beacon	• Band is shared by many services (should not be a problem in rural areas)

Unpredictable events such as congestion resulting from construction activities or a school bus vehicle breakdown may result in the activation of the flashing beacon during non-hazard times or, perhaps of more concern, the inactivation of the flashing beacon when the hazard is present. A longer-duration activation period may help to prevent the latter occurrence but leads to accelerated driver desensitization to the AAWD.

Off-Site, Central Location Activation

A third alternate strategy is to use cellular technology to activate the flashing beacon component of the AAWD remotely from a central location. This activation method is commonly used to control changeable message signs remotely. Disadvantages are similar to the programmed time schedule; the remote control location may result in the activation of the flashing beacon during non-hazard times or the inactivation of the flashing beacon when the hazard is present unless regular communication with the school bus driver occurs. However, when combined with the programmed time schedule strategy, this activation method could enhance the accuracy of hazard detection by allowing for remote activation or inactivation of the flashing beacon during unexpected schedule delays.

Selected Methodology: On-Site, School Bus Activation Using Spread Spectrum (902 to 928 MHz) Radio Frequencies

After reviewing each of the various methods for activation of the flashing beacon component of the AAWD, the Encom™ Spread Spectrum Radio System that allows on-site, school bus activation was selected for use. In addition to its previously described advantages related to more relaxed monitoring and regulation by the FCC, regular interval signal transmission, and stronger signal strength allowing for activation of flashing beacons on each side of the road simultaneously, this system is currently used by TxDOT to control their traffic signal communications systems and has been found to be very reliable.

LIABILITY RISK

The use of a flashing beacon as a supplemental advance warning device is not uncommon for a variety of applications including school zones, pedestrian crosswalks, railroad grade crossings, rural and urban intersections, construction or maintenance work zones, frequent adverse weather, wildlife crossings, and areas with challenging highway geometrics. However, its use as a supplemental advance warning device in conjunction with a SCHOOL BUS STOP AHEAD sign is neither common nor well documented. The use of a flashing beacon will increase the conspicuity of the SCHOOL BUS STOP AHEAD warning sign but does not modify the meaning of the sign. Although flashing beacons have not generally been regarded as presenting an increase in tort liability risk for this reason, it is nonetheless important to review both published literature and historic case law to consider potential liability risks associated with more generally moving from a passive to an active warning sign.

Literature Review

Much of the published literature regarding liability risk was developed with the intent of assisting state departments of transportation to prevent and/or respond to tort litigation.

In 1976, Orne published a paper entitled, “Responding to Tort Litigation: A Michigan Case History” that discussed Michigan’s Act 170, reviewed the judgments issued in three cases, and developed a positive program of response to tort litigation. The paper identifies five factors that are necessary to establish liability: (1) the existence of a hazard that is the proximate cause of the accident; (2) knowledge by the responsible agency of the hazard; (3) failure to correct the hazard; (4) failure to warn of the hazard; and (5) the availability of method, time, and funds to correct the hazard. The importance of effective accident surveillance for a legally defensible safety program is emphasized. The categorization of road types, the study of concentrations of accident types, and the identification of high accident locations are equally important. As an outcome, Orne recommended an 11-step review-analysis procedure to ensure that all identified locations are subjected to critical engineering appraisal.

During the same year, the Transportation Research Board published a document describing the liability of state and local governments for snow and ice control (Transportation Research Board 1976). Generalizations on the probability of jury verdicts for plaintiffs and the relative size of jury awards where a governmental body is the defendant were noted, and the erosion of sovereign immunity was discussed. Cases hold public authorities liable in many instances where they fail to salt or sand an icy road hazard or fail to provide adequate warning of danger. In those jurisdictions having "highway defect" statutes, the courts hold that specific snow and ice hazards that are untreated or have inadequate warning may constitute a highway defect. Defenses of public agencies for negligent snow and ice removal do not appear to include immunity for governmental action, several courts holding that snow and ice removal and the use of abrasives constitute maintenance or proprietary activity. The defense that snow and ice control is a "discretionary activity" and, therefore, immune from liability also appears to be inapplicable, whether an action is brought in a common law jurisdiction or in one having a tort claims act. A snow and ice removal program, however, adopted by a public body having discretionary authority that contained an inadequate or defective feature may be immunized because of the courts' reluctance to second-guess the judgments of public authorities with legislative or quasi-legislative attributes. However, this initial immunity may be lost or fail to attach under certain circumstances.

Focusing earlier in the litigation process, Carsten and Dickinson (1979) considered ways to improve highway safety and reduce the potential liability of counties from accidents relating to alleged imperfections in highway facilities or in connection with essential highway-related activities in Iowa. The number and dollar amount of county highway-related tort claims for the years 1973 through 1978 were determined to gain a sense for the magnitude of the problem and to evaluate yearly trends. The number and dollar amounts of settlements or judgments and the number and dollar amounts of the claims pending were also determined. Data obtained from the counties were also analyzed to determine whether any significant relationships could be established between the historical tort claims experience and the locations, demographic characteristics, or highway system characteristics of the counties. Recommendations centered primarily on strictly following established specifications and guidelines such as the *Manual on Uniform Traffic Control Devices* during construction and maintenance activities.

Carsten (1981) continued this work by conducting a survey of county governments in Iowa. This survey included the use of mailed questionnaires and personal interviews with county engineers. Highway-related claims filed against counties in Iowa amounted to about $52 million during the period 1973 through 1978. More than $30 million in claims were pending at the end of 1978. Settlements of judgments were made at a cost of 12.2 percent of the amount claimed for those claims that had been disposed of, not including costs for handling claims, attorney fees, or court costs. Problems that resulted in claims for damages from counties have generally related to alleged omissions in the use of traffic control devices or defects (often temporary) that result from alleged inadequacies in highway maintenance. The absence of STOP signs or warning signs often has been the central issue in highway-related tort claims. Most frequently alleged maintenance problems have included inadequate shoulders, surface roughness, ice or snow conditions, and loose gravel.

Most recently and most comprehensively, the Transportation Research Board published a searchable CD entitled, "Tort Liability of Highway Agencies," which covers the following topic areas related to liability risk: (1) basic theories of tort liability of public transportation agencies, (2) activities that give rise to tort liability, (3) immunities and defenses, (4) trial preparation, (5) procedural considerations, and (6) shifting or sharing of tort liability (Thomas 2002). Information contained in this document provides the foundation for this liability investigation. A general discussion of tort liability, applicable transportation activities that may give rise to tort liability, and potential defenses follows.

Tort Liability

Because of sovereign immunity, transportation departments were not always subject to liability in tort. However, full sovereign immunity has generally been replaced by some form of tort claims act that permits suits against the transportation departments under certain circumstances. As such, the litigation process begins by establishing the immunity of the state department of transportation against being sued in a particular case and, if found to be eligible, establishing the state's degree of liability in the case.

For a plaintiff to establish that the transportation department was negligent, the plaintiff must show that: (1) whatever caused the plaintiff's injury was in the care or custody of the defendant, (2) that a dangerous condition of the highway existed, (3) that the department had actual or constructive knowledge of the condition, and (4) that the department had a reasonable time to correct the condition or give adequate warning. This four-part requirement stems from the state's duty and standard of care to the traveling public; the state is required to "exercise reasonable care to make and keep the roads in a reasonably safe condition for the reasonably prudent traveler" (Ufnal vs. Catteraugus County, New York Court of Appeals, 1983). Inherent in the state's duty of ordinary care is the duty to eliminate dangerous conditions, to erect suitable barriers, or to adequately warn the traveling public of hazardous conditions.

When proving causation, two aspects are considered: (1) causation in fact and (2) proximate cause. Where an alleged highway defect was the cause of the accident, it must be shown that "the defective condition was the cause of the accident or injuries resulting there from" (cause in fact) (Thomas 2002). Proximate cause is that cause "which, in a natural and continuous sequence, unbroken by any new, independent cause, produces that event and without which that event would not have occurred" (Thomas 2002). The transportation department may challenge the plaintiff's proof of causation on the length of time the alleged condition existed; how it was created or who created it; the traffic conditions at the time of the alleged condition; the need or adequacy of signs, signals, or barriers; the existence or non-existence of other causative factors; and, of course, whether the plaintiff was at fault.

Transportation Activities That May Give Rise to Tort Liability

Related most directly to this investigation, providing highway warning signs, traffic lights, or pavement markings is an important task for transportation departments in ensuring safe roads and highways. Thus, departments may be held liable for negligence in providing or in failing to provide adequate ones as required by the circumstances. Whether there is an actual duty to install warning signs, traffic lights, or pavement markings may depend on the interpretation of the local statute. There is precedent that interprets the statutes imposing liability for failure to repair roads and highways to mean that the failure to install adequate warning signs both was and was not a violation of duty under such statutes. A duty may arise, however, to install them at the location of a dangerous condition, a point of hazard, or a point of special danger.

In either case, after the decision is made to provide signs, signals, or markings, the state has a duty to place and maintain them with reasonable care. For example, after the state has provided a traffic warning, it has assumed the duty to the public, and the public reasonably has a right to rely on the warnings.

Potential Defenses for Tort Liability

The primary defense to a state's tort liability is based on the theory that certain actions taken by a government are "discretionary" in nature and, therefore, immune from suit. First, a court must determine whether the action or inaction is a matter of choice. If no options are involved, the discretionary exception does not apply. If the action involves selection among alternatives, the court must determine whether the choice was policy based; decisions at an operational level can be discretionary if based on policy (U.S. vs. Gaubert). In Trujillo vs. Utah Department of Transportation (1999), the court held that the failures to reduce speed in a construction zone as called for in a construction plan, to investigate accidents, or to consider corrective action in response to notice of a dangerous condition were all operational-level activities.

In Lee vs. Louisiana State Department of Transportation and Development (1997), it was disputed whether a STOP AHEAD sign was required to prevent an intersection accident. The trial judge determined that the sign was necessary to properly warn motorists of the need to stop at the intersection. In reversing the trial judge's decision against the state, the appellate court held that "it is well-settled that a governmental authority that undertakes actions to control traffic at an intersection must exercise a high degree of care for the safety of the motoring public" but it is not "responsible for all injuries resulting from any risk posed by the roadway or its appurtenances, only those caused by an unreasonable risk of harm to others." Although the absence of a sign may have created an unreasonable risk of harm to motorists, the intersection was guarded by two flashing red beacons, was free of obstructions, and was visible at a distance of 800 feet. The court also stated that "in all situations, the decision to erect a warning sign is discretionary on the part of DOTD." Additional cases have held that decisions concerning traffic control devices and whether extra ones are needed at a given location rest within the sound discretion of the transportation department. Thus, the general rule is that the state's decision making concerning the providing or placing of signs, signals, or warning devices is protected by the discretionary function exemption.

Instead, the strongest cases for recovery have been those in which the highway department "failed within a reasonable time to replace a traffic sign which had been removed by unauthorized persons, to re-erect or repair a sign which had fallen down or had been knocked down or bent over or to replace a burned out bulb in an electric traffic signal" (Thomas 2002).

A second area of defense for transportation departments is based on allocation of resources or priority of projects. Specifically, the issue is whether the department may defend against tort liability on the basis that it did not correct a particular hazardous location because of: (1) its need to allocate scarce resources (i.e., funds, personnel, or equipment), (2) insufficient funds, (3) the cost of a given project, or (4) the need to give other areas higher priority for repair or improvement than the one that allegedly caused an accident.

In making the defense, the department may not have to demonstrate that it considered and rejected the specific improvements alleged to have been neglected but rather may demonstrate that it consciously engaged in decision making regarding the general type of improvements alleged in the plaintiff's complaint. The state should offer proof that the challenged conduct or omission was a policy decision made by consciously balancing risks and benefits. This proof may come in the form of meeting minutes, testimony by decision makers regarding the process involved, or other documents showing that the governmental entity made an affirmative policy decision. The resource allocation defense does not always succeed; the court may believe that there were other less expensive alternatives that the public authority failed to consider that could have prevented the accident in question.

Case Law Review

Building upon the general trends related to tort liability involving state departments of transportation and related to the use of warning signs available in the published literature, this section reviews specific case law involving school bus loading and unloading zones and potential liability risks associated with more generally moving from a passive to an active warning sign. Information was derived from courts in all 50 states using the LexisNexis Legal Research database. This section considers a variety of potential hazards in addition to low-visibility school bus loading and unloading zones including school zones, pedestrian crosswalks, railroad grade crossings, rural and urban intersections, construction or maintenance work zones, frequent adverse weather, wildlife crossings, and areas with challenging highway geometrics.

School Bus Accidents

A number of historical cases were uncovered involving the injury or death of a child while accessing, waiting at, or leaving a school bus stop (see Table 2). The child was most often crossing or walking along the side of the road. In each of the cases reviewed, the injury or death was caused by a third-party vehicle and not the school bus.

The named parties at fault in these cases typically comprised: (1) the school district, (2) the school bus driver, and/or (3) the third-party driver of the vehicle that struck the child. In no instance was a transportation department named as a party at fault. In general, the school district and the school bus driver are immune from liability of this nature if the injury/fatality occurred prior to the bus arriving at the stop or after the bus had departed the stop. Instead, the most common claim was negligence on the part of the school bus driver in their "use and operation of motor-driven equipment." Specifically in question is the appropriate use of their vehicle-mounted flashing lights, the appropriateness of honking to signal a safe opportunity to cross the street, the duration of time that the bus should remain at the stop, etc.

Table 2. Summary of School Bus Accident Case Law.

Year	Court	Appellants/Appellees	Description
1950	Supreme Court of Texas	Weingarten, Inc. vs. Sanchez.	…attempted to cross the highway from behind the bus from which he had alighted and was struck by a truck which was traveling in the opposite direction.
1983	Supreme Court of Texas	Madisonville Independent School District and Polk vs. Kyle	…was exiting a school bus and was crossing the street to his home when he was struck by a car and severely injured. He died a few hours later.
1984	Court of Appeals for Ashland County, Ohio, Fifth Appellate District	Merchants Mutual Insurance Co. vs. Baker	…the victim exited the bus, went in front of the bus and across the street where she was hit and injured by the automobile driver, who, rather than stop, accelerated.
1987	Court of Appeals of Texas, Dallas	Hitchcock vs. Garvin	A student exited the bus and was crossing the street when a car hit her. The plaintiffs alleged that the bus driver did not activate his flashers to signal that students were exiting the bus.
1987	Court of Appeals of Texas, Sixth District, Texarkana	Lindburg vs. Mount Pleasant Independent School District and Gullion	…was struck and killed by a pickup truck after getting off a school bus. Witnesses testified that Misty walked away from the bus without making any effort to cross the highway.
1989	Texas	Mount Pleasant Independent School District vs. Lindburg	Two students were delivered safely to a bus stop...Once the bus was approximately 200 yards from the girl, she attempted to cross the highway; a car hit and killed her.
1991	Court of Appeals of Texas, Beaumont	Contreras vs. Lufkin Independent School District	The bus erroneously delivered her to a stop around the corner. The school bus had left the scene when the girl attempted to cross the street and was struck by a car.
1991	Court of Appeals of Texas, Thirteenth District, Corpus Christi	Luna and Sanchez vs. Harlingen Consolidated Independent School District	…waiting to be picked up by the school bus at Teege and Norma Road, in Cameron County, Texas, when suddenly and unexpectedly they were struck by a motor vehicle.
1993	Court of Appeals of Texas, First District, Houston	Goston vs. Hutchison	A bus driver allowed two students to exit the bus at an undesignated stop at their request. They got into a car driven by a friend and were involved in a collision.
1996	Court of Appeals of Texas, Second District, Fort Worth	Cortez and Hernandez vs. Weatherford Independent School District, Gerdes and Baumgartner	…as Guadalupe proceeded past the bus and onto a trail that ran along the side of the road, he was struck by Jones's motorcycle and killed.
2001	Court of Appeals of Texas, Third District, Austin	Austin Independent School District vs. Gutierrez	…was struck and killed by a passing motorist. In Gutierrez's pleadings, she argued that AISD "was negligent in the operation or use of a motor-driven vehicle."
2002	Court of Appeals of Texas, Twelfth District, Tyler	Hardin, Gilbert, and Palestine Independent School District vs. Dykes	…was hit by a minivan as she crossed the street on her way home. She had just gotten off a PISD bus driven by Gilbert.
2003	Court of Appeals of Texas, Third District, Austin	King vs. Manor Independent School District	…was struck by a passenger car as she attempted to cross the road to her home approximately one-half block from the school bus stop.
2003	Court of Appeals of Texas, Fourteenth District, Houston	Jill Miedke vs. Metropolitan Transit Authority	…ran in front of the stopped bus into an adjacent lane of traffic. Upon doing so, Tyler was hit by a truck.

In one particular case, Luna and Sanchez vs. Harlingen Consolidated Independent School District (Court of Appeals of Texas, Thirteenth District, Corpus Christi 1991), the appellant alleged that the Harlingen Consolidated Independent School District was negligent in the following particulars: (1) in failing to provide a safe place for children to stand while they waited for the school bus, (2) in failing to properly post signs to warn that the area was a school bus loading area, (3) in failing to have the bus driver stop all traffic on both sides of the street to allow the children to board safely, and (4) in allowing the children to wait for the school bus in the traffic lane.

The summary judgment conclusively showed: (1) the minor children involved in this case were struck by a private motor vehicle driven by a third party; (2) the children were waiting to be picked up by the school bus at Teege and Norma Roads; (3) the school bus had not yet arrived when the children were struck; (4) no school bus had any contact with the children since they were still waiting to be picked up at the time of the accident; (5) the school bus was not involved in the occurrence that made the basis of this suit; (6) the minor children had not boarded a school bus nor were they disembarking from a school bus when they were struck by the motor vehicle; (7) the bus stop at which the children waited had recently been moved from one side of the street to facilitate the bus driver in picking the children up on his route; (8) the new location of the bus stop required the children to wait for the bus by standing in the oncoming traffic lane of Teege Road or immediately next to that lane, since the soft shoulder of the road did not provide an area a safe distance from the road for them to stand; (9) the accident resulted in serious personal injuries to both children; and (10) the appellee is a consolidated independent school district, a political subdivision within the state of Texas.

Because these facts could not be tied to the use or operation of a motor-driven vehicle operated by an employee of the school district, it could not be proven that the school bus driver's actions were the proximate cause of the injuries to appellants' minor children. However, had the transportation department been named as a potential party at fault in this case, they may have been found liable for failure to: (1) provide SCHOOL BUS STOP AHEAD warning signs or (2) provide an adequate safe shoulder.

Regarding this first point, the issue of "jurisdictional responsibility" has been previously raised at railroad grade crossings and the approach leading up to them. Anderson (1985) described the Prescott case in which large awards and settlements came largely from the confusion of the jurisdiction at the grade crossing, the absence of pavement markings warning of the tracks, maintenance of an advance warning sign, and the failure of the governments at the state, county, and local levels to pursue the installation of active warning devices at the crossing after identifying the need for one 12 years earlier. Similar confusion over responsibility may arise with the establishment and operation of school bus loading and unloading zones, putting departments of transportation at risk.

Regarding the second point, two recent cases illustrate how agencies have been penalized for their failure to provide safe shoulders (TranSafety, Inc. 1985). In California, $8.2 million was awarded to a severely injured plaintiff who charged that the state had negligently converted a shoulder into another travel lane. The plaintiff had pulled over to the extreme right of a state freeway believing the lane was a shoulder when it was actually being used for travel to relieve traffic congestion. It was 2:00 a.m. when a drunken driver failed to heed the flashing lights on the plaintiff's car and crashed into it. An expert testifying for the plaintiff noted that the state uses shoulders as lanes only during rush hour on other parts of the highway system and that traffic traveling on the opposite side of the freeway still had a limited right-hand shoulder, as well as part of the median, for emergency refuge. He also criticized the state's failure to adequately warn motorists of the conversion or provide sufficient lighting for disabled vehicles.

In a second case, a Louisiana case involved the family of a man killed when he failed to negotiate a curve and found no shoulder for refuge. Not only had the state allowed the shoulder to deteriorate, but both the travel lane and the shoulders were narrower than the width specified in the state's own design standards.

School Zones

Only a single related case (i.e., moving from passive warning devices to active warning devices) occurring at a school zone was uncovered during this review (Sullivan vs. City of Midland, Court of Appeals of Texas, Eighth District, El Paso 2000). Note that the suit in this instance was brought against the city government rather than the school district.

The Sullivans filed suit against the City of Midland under the Texas Tort Claims Act alleging that the school zone, crosswalk, and warning signs failed to adequately warn drivers of crossing pedestrians. Their son, Adam, was struck by a motor vehicle at 7:27 a.m. as he walked through a school crosswalk near Midland High School. He suffered serious injuries to his head, legs, arms, face, and shoulders, as well as internal injuries. The Sullivans alleged that although the "zero hour" classes began at 7:30 a.m. and the city had a policy of activating all school zones 30 minutes prior to classes, this particular school zone was not in operation at the time of the accident. The Sullivans alleged that sovereign immunity had been waived because Adam's injuries were caused by a condition or use of real or tangible personal property owned and/or controlled by the city. The outcome of this case was not readily apparent.

Pedestrian Crossings

Looking more generally at tort liability cases involving pedestrian crossings, three of the four cases questioned the adequacy of the crosswalk warning devices, most often suggesting that a traffic signal was more appropriate than flashing warning beacons (see Table 3). These cases were largely dismissed citing discretionary immunity for the jurisdictional transportation department (three of the four cases named the city transportation department as the party at fault; the fourth named the county and state department of transportation).

In a fourth case (City of Edinburg vs. Garces, Court of Appeals of Texas, Thirteenth District, Corpus Christi 2002), the city's operation and maintenance of the flashing beacon warning device was alleged to be at fault (similar to the premise of Sullivan vs. City of Midland [2000] described in the previous section). Specifically, the appellees claimed that the city had set the timer on the warning sign so that the flashing beacons would not operate during nighttime hours; the lights were not flashing at the time of the accident. As with the other pedestrian crossing cases, the city asserted that: (1) they had no notice of any problems with the crosswalk or

Table 3. Summary of Pedestrian Crossing Accident Case Law.

Year	Court	Appellants/Appellees	Description
1992	Court of Appeals of Texas, Fifth District, Dallas	Zambory vs. City of Dallas	…a bicyclist was killed as he entered the intersection of the bike trail and Greenville Avenue, alleged that the present warnings – a crosswalk with "bike xing" painted on the road and warning signs with flashing lights – were not adequate to insure safety due to the amount of automobile traffic and the continuous flow of bicycle and pedestrian traffic.
1994	Court of Appeals of Texas, Fifth District, Dallas	Bookman vs. Bolt and City of Dallas	An automobile struck bicyclist Ronald W. Bookman, Jr. as he rode on a bicycle path that traversed Greenville Avenue. A warning system was in place and operating…
2002	Court of Appeals of Texas, Fifth District, Dallas	Wilkins vs. Collin County and State of Texas	…was struck by an automobile and killed while crossing FM 1138 to reach a parking lot following a program at McClendon Elementary School.
2002	Court of Appeals of Texas, Thirteenth District, Corpus Christi	City of Edinburg vs. Garces	…was struck by an automobile on East Palm Drive in front of the center… alleged that the city's negligence (1) in failing to timely repaint the crosswalk stripes and (2) in failing to properly operate and maintain a "Watch Children" sign with two flashing beacons adjacent to the crosswalk proximately caused the accident.

warning sign and (2) decisions regarding the operation and maintenance of the crosswalk and warning sign were discretionary and thus the city was immune from tort liability.

Railroad Grade Crossings

Similar to the tort liability brought forth at school zones and pedestrian crossings, the types of negligence claims occurring at railroad grade crossings relate to both: (1) the adequacy and (2) the operation and maintenance of the warning devices. The number of cases involving railroad grade crossing accidents is numerous and dates back to the 1940s. As such, only a sampling of cases is discussed here to illustrate tort liability trends and potential risks (see Table 4).

As with school bus-related accidents, transportation departments have seldom been named as the party at fault in these cases. Instead, the liability risk is carried by the various railroad companies owning and operating on the infrastructure. However, the issue of jurisdictional responsibility between transportation departments and railroad companies where their transportation networks intersect (i.e., railroad grade crossings) has been presented. As previously mentioned, Anderson (1985) described the Prescott case in which large awards and settlements came largely from the confusion of the jurisdiction at the grade crossing, the absence of pavement markings warning of the tracks, maintenance of an advance warning sign, and the failure of the governments at the state, county, and local levels to pursue the installation of active warning devices at the crossing after identifying the need for one 12 years earlier. Although the transportation department was not named in this particular suit, the issue of jurisdictional responsibility, especially if ill-defined, presents a potential liability risk for transportation departments.

Table 4. Summary of Railroad Grade Crossing Accident Case Law.

Year	Court	Appellants/Appellees	Description
1946	Supreme Court of Texas	Texas and Pacific Railway Company vs. Day	Day drove his car into the path of the approaching train in disregard of the warning of the electrical flasher device, he was seriously injured in the ensuing collision.
1967	Court of Civil Appeals of Texas, Tenth District, Waco	Western Transport Company, Inc. vs. Gulf, Colorado and Santa Fe Railway Company	…truck loaded with gasoline was struck by appellee's Santa Fe "Chief", found that the truck driver's negligence in failing to keep a proper lookout, in failing to heed the flashing signal light warning which was in operation at the crossing, in failing to properly listen to the train whistle which was blowing, and in failing to stop his truck not less than 15 feet from the track proximately caused the accident
1973	Supreme Court of Texas	Southern Pacific Company vs. Castro	The truck was stopped with its front wheels in the middle of the track at the time of the fatal collision, alleged the railroad crossing was extra-hazardous, negligent in failing to provide an automatic flashing signal
1975	Court Of Civil Appeals Of Texas, First District, Houston	Missouri Pacific Railroad Company vs. United Transports, Inc.	…collided with the train and was seriously injured, the train crew operated the train when the railroad signal light facing the plaintiff was not flashing and that such operation of the train was negligence and a proximate cause of the collision
1975	Court of Civil Appeals of Texas, Ninth District, Beaumont	State Highway Department vs. Pinner	…collided with an east bound Missouri Pacific train, State Highway Department had located its vehicles to materially obstruct Pinner's view of the approaching train and distracting his view of the signal lights and approaching train
1978	Supreme Court of Texas	Missouri Pacific Railroad Company vs. Cooper	… ran into the side of a freight train that was crossing the road, alleged that the crossing was extra hazardous, railroad was negligent in failing to have an automatic warning signal
1985	Court of Appeals of Texas, Fourth District, San Antonio	Clifton vs. Southern Pacific Transportation Co.	The van in which they were riding was struck by a freight train at a railroad crossing, the jury found that the railroad crossing at Box Canyon Road was extra hazardous and the failure to have flashing lights to warn vehicular traffic was negligence and a proximate cause of the accident
1993	Court of Appeals of Texas, Fourteenth District, Houston	Missouri Pacific Railroad Company and Johnson vs. Lemon	A freight train driven by Johnson struck and killed Sharon Elaine Lemon at the Martin Luther King (MLK) railroad crossing, crossing had no signals, flashing lights, gates, or flagmen despite numerous complaints
1997	Court of Appeals of Texas, Fourteenth District, Houston	Trevino vs. Atchison, Topeka and Santa Fe Railway Co.	… killed after their car collided with a train at the 16th Street crossing, alleged negligent failure to: (1) install adequate warning devices and (2) warn persons that the train was approaching or passing over the crossing

Despite the lack of direct involvement of transportation departments in railroad grade crossing tort liability cases, several useful observations can be made when reviewing these cases. First, regarding the adequacy of warning devices at railroad grade crossings, plaintiffs most often contended that a particular crossing was "extra hazardous" and, as such, required a higher level warning device (i.e., flashing beacons, gates, etc. in addition to static warning signs or pavement markings). As defined in Missouri Pacific Railroad Company vs. Cooper, “a railroad crossing is extra hazardous when, because of surrounding conditions, it is so dangerous that persons using ordinary care cannot pass over it in safety without some warning other than the usual cross arm sign” (Supreme Court of Texas 1978). The criteria used to define the hazard of a particular crossing may include the following conditions: the view of the crossing was obstructed, the crossing was obscured by fog, there had been prior accidents at the crossing, or the crossing had a local reputation as being especially dangerous. The outcome of these cases were largely site specific but largely dependant on the railroad agency’s systematic process for identifying the appropriate level of warning device given a set of site conditions. A similar systematic process for determining which school bus loading and unloading zones warrant a flashing beacon will be required.

With respect to the operation and maintenance of warning devices at railroad grade crossings, a unique aspect of warning device reliance was cited. Thomas (2002) stated, when generally describing a state’s duty of care to the traveling public: “after the state has provided a traffic warning, it has assumed the duty to the public and the public reasonably has a right to rely on the warnings.” In Missouri Pacific Railroad Company vs. United Transports, Inc. (Court of Civil Appeals of Texas, First District, Houston 1975), the plaintiff testified that he “knew that when the crossing was occupied by a train, a red blinking light would be flashing.” When the plaintiff was about 100 feet from the crossing, he realized that a train was across the highway; no red light was flashing. Driving a fully loaded auto transport, he collided with the train and was seriously injured. The train crew testified that they operated the train across the north half of Highway 59 at a time when the railroad signal light facing the plaintiff was not flashing. In this case, the court found such operation of the train to be negligence and a proximate cause of the collision. Had the beacon been flashing to indicate the presence of the train as was the expectation of the plaintiff, the accident might have been avoided.

Intersections

At transportation network intersections that fall under the jurisdiction of a city, county, or state transportation department, those agencies are most often named as the party at fault when an accident occurs. In rare instances, a third-party driver will be named as a singular party at fault. When a transportation department is named as the party at fault, this alleged fault most often relates to the failure to provide adequate warning of an approaching intersection (see Table 5). Typically, plaintiffs alleged that the current level of warning device was inadequate for conditions and that the transportation department was negligent in failing to upgrade to a higher level of warning device or traffic control (i.e., moving from a flashing beacon to a traffic signal). In nearly all of these cases, the transportation departments were excused from further liability risk because of discretionary immunity.

Instead, those cases that did not have favorable outcomes for the transportation departments related to a lack of responsiveness to a known malfunction of the intersection warning or traffic control devices. This observation is consistent with the general trends noted previously in the published literature.

Table 5. Summary of Intersection Accident Case Law.

Year	Court	Appellants/Appellees	Description
1977	Court of Civil Appeals of Texas, Thirteenth District, Corpus Christi	State of Texas vs. Norris	…for personal injuries which she sustained in an automobile accident which allegedly occurred because a traffic signal light at an intersection was malfunctioning, the jury found: the State Highway Department had notice of the malfunctioning condition prior to the accident; the State Highway Department failed to correct the malfunctioning condition within a reasonable time after notice of the malfunctioning condition; such failure was negligence, which was a proximate cause of the accident.
1989	Supreme Court of Virginia	Clayton vs. Critzer and Jake Alexander Wood Yards, Inc.	Critzer's truck struck the passenger side of Stewart's vehicle in the right travel lane, Clayton was killed instantly. Flashing amber lights along with warning signs are posted 1,000 feet before the intersection in the east-west direction, flashing red lights and stop signs exist north-south.
1991	Supreme Court of Iowa	Phillips vs. City of Waukee, County of Dallas and Van Ginkel	…was not provided with a "YIELD AHEAD" sign, only with a "CROSSROAD AHEAD" sign, this misled Van Ginkel concerning the nature of the intersection and plaintiff believes Van Ginkel should also have faced a flashing yellow beacon as he approached the intersection.
1995	Court of Appeals of Georgia	Department of Transportation vs. Taunton	…died from injuries he sustained in an automobile collision, alleged DOT should have installed advance warning signs, rumble strips, a crossroad sign, flashing lights, etc., none of which previously existed at the intersection.
2001	Court of Appeals of Texas, Ninth District, Beaumont	Texas Department of Transportation vs. Bederka and Berger	…were involved in a collision at the intersection of State Highway 105 and F.M. 1486, alleged the state breached its duty by failing to conduct proper traffic studies, and failing to erect additional and/or different traffic control signals and signs to remedy the dangerous condition of the intersection within a reasonable time following receipt of actual notice of the dangerous condition.
2002	Court of Appeals of Texas, Third District, Austin	Ihlo vs. State of Texas and Texas Department of Transportation	…were driving on Texas Highway 21 when a truck driving on Loop 150 proceeded through the intersection of the two roads and struck the Ihlos' vehicle, allege state was negligent by failing (1) to place a traffic or road sign, signal, or warning device at the roadway and intersection within a reasonable time after notice of a dangerous condition and (2) to exercise ordinary care in monitoring and reviewing the numerous accident reports relating to this roadway and intersection.
2003	Court of Appeals of Texas, Ninth District, Beaumont	Texas Department of Transportation vs. Garrison and Vaughn	…regarding signalization of an intersection where their four separate motor vehicle accidents occurred, TxDOT did not install the stop and go signal, but instead upgraded the flashing beacon and installed special intersection signs.

Work Zones

Only a single related case was uncovered regarding the use of active warning devices in work zones (Smith vs. the State of Texas, Court of Appeals of Texas, Eighth District, El Paso 1986). In June 1975, the State Highway Department resurfaced a part of Highway 290 in Crockett County. After the work was completed, the highway became extra slick when it was wet. The highway department was aware of the problem and placed warning signs with flasher signals and stating SLIPPERY WHEN WET at each end of the highway.

On July 16, 1975, two trucks approached each other on the wet resurfaced section of the highway. A Cartwright Van Lines truck driven by Durbin apparently started sliding and jackknifed across the center stripe into the lane of the truck driven by Smith. The resulting collision caused the death of both drivers and injuries to each of their sons, who were passengers with their fathers. In a suit filed against the Texas Highway Department, the jury found: (1) there was a dangerous condition on the roadway, (2) the state knew of the dangerous condition, (3) it was negligent in not correcting the condition, (4) such negligence was the proximate cause of the occurrence, but (5) did not find that the state failed to give an adequate warning of the dangerous condition. Hence, the state was found liable for not correcting a dangerous condition but, in fact, was found to have provided sufficient warning of the condition.

Adverse Weather

Unique to adverse weather-related accidents and resulting tort liability claims is the dynamic nature of the hazardous condition. Commonly, transportation departments have no advance notice of the dangerous condition (i.e., ice forming on a roadway) and have insufficient time to respond to the hazard. As a result, transportation departments use prior accident experience and other information to place general warnings (i.e., at bridge locations) but are typically not found liable for unsafe driving conditions resulting from natural events.

Nonetheless, plaintiffs continue to question the adequacy of the existing warning device and the responsiveness of the transportation department to remedy the hazardous condition (see Table 6). In Gapinske vs. Town of Condit (Appellate Court of Illinois, Fourth District 1993), the following allegations were made after the plaintiff's vehicle was driven into floodwater over a roadway:

- defendants failed to put the warning device far enough in advance of the flooding river to enable southbound drivers approaching the bridge from the north to stop in time to avoid driving into the river;

- defendants permitted the warning device or barricade on the northerly approach to the bridge to be moved (or removed) and to remain in the wrong location (or to remain absent) when they knew (or should have known) that the absence of such warning signs created a dangerous condition for motorists going south on the road at the bridge;

- defendants failed to properly maintain, replace, or position the warning device or barricades immediately north of the flooding river;

- defendants failed to provide a warning sign or barricade on the northerly approach to the bridge, in addition to the flashing light, to alert drivers of the flooding when flooding would not be reasonably apparent to motorists;

- defendants failed to provide barricades or warning signs on the northerly approach to the bridge far enough in advance of the flooding river when similar warnings had earlier been placed on the southerly approach to the bridge;

- defendants failed to close the road in the area of the bridge when defendants had closed the road to northbound traffic;

- defendants failed to warn southbound traffic that the road was closed when defendants had posted such warnings at the intersection for northbound motorists;

- defendants failed to post a warning device conforming to *The Manual on Uniform Traffic Control Devices* (1988) for southbound motorists;

- defendants failed to give an adequate warning of the flooded road to southbound motorists, in that the flashing light was located off the roadway, low to the ground, and was a device customarily used to mark holes in highways or lateral boundaries of roadways and was therefore ambiguous as to its intent and purpose; and

- defendants failed to give adequate warning to southbound motorists, in that the flashing light failed to conform to section 6B-3 of the *MUTCD* (warning devices should be placed in a position where they will convey their message most effectively and drivers will have adequate time for a response) and failed to accompany the light with a sign warning of the flooded roadway as required by section 2C-40 of the *MUTCD*.

The Town of Condit was cleared of these allegations because of discretionary immunity; only the flooding event was found to be the proximate cause of the accident in this case.

In the case Salvati vs. Department of State Highways (Michigan 1982), the plaintiff questioned whether the state had provided adequate warning of bridge icing by using two reflectorized signs erected 1,000 feet from the entrance to the bridge, each reading WATCH FOR ICE ON BRIDGE. The court ruled that the state's signing satisfied the technology available at the time it was installed because the technology had not advanced to such a point that the state could have installed a flashing sign that was automatically activated by ice on the bridge.

In two additional related cases, the operational use of supplemental flashing lights was called directly into question. In State Department of Highways and Public Transportation vs. Kitchen and Richards (Supreme Court of Texas 1993), Kitchen was driving his pickup across a bridge

Table 6. Summary of Adverse Weather Accident Case Law.

Year	Court	Appellants/Appellees	Description
1971	Court of Appeal of California, First Appellate District, Division Two	Briggs vs. State of California	…decedent struck another vehicle when he swerved his car into the wrong lane of traffic to avoid a mud slide on a state highway. About a week before the accident, a slide engulfed and surrounded the warning sign in the southbound lane. Occasionally, the sign was lit by a battery-operated flasher, but often no light was flashing.
1982	Michigan	Salvati vs. Department of State Highways	The issue was whether the state had provided adequate warning of bridge icing by using two reflectorized signs erected 1000 feet from the entrance to the bridge, each reading WATCH FOR ICE ON BRIDGE.
1986	Court of Appeals of Ohio, Sixth Appellate District, Erie County	Carney vs. MacAfee and City of Sandusky	…skidded on ice and crossed over a nine inch high by two feet wide concrete median, and collided with the northbound automobile, insufficient time had elapsed for the city to achieve notice and remedy the situation.
1993	Appellate Court of Illinois, Fourth District	Gapinske vs. Town of Condit	…they drove into floodwater on the roadway. The floodwater swept their car into the river, but both plaintiffs escaped from the car and grabbed onto some tree limbs to keep from being swept away. When plaintiffs drove into the floodwater, a yellow flashing light had been placed at the side of the road just ahead of the floodwater.
1993	Supreme Court of Texas	State Department of Highways and Public Transportation vs. Kitchen and Richards	…was driving his pickup across a bridge when the vehicle skidded out of control on a patch of ice and collided with an oncoming truck, a standard "Watch for Ice on Bridge" sign with a warning light was posted before the bridge. The sign had been open with the light flashing for the three days immediately prior to the accident. The day before the accident, despite the persistence of freezing, wet weather, the Highway Department folded up the sign based upon National Weather Service forecasts of warmer, drier weather for the next day.
1996	Court of Appeals of Oklahoma, Division One	Holt vs. State of Oklahoma, Oklahoma Department of Transportation	...driver of an oncoming car lost control on an icy patch, crossed the centerline, and struck the Holts' car head on. There were signs located at each end of the dam warning motorists to "Watch for Ice on Bridge." Remote-controlled amber flashing lights mounted on top of each sign were not operating at the time of the accident. None of state's employees was aware the Corps of Engineers was to release water through the dam on the day of the accident.

when the vehicle skidded out of control on a patch of ice and collided with an oncoming truck. A standard WATCH FOR ICE ON BRIDGE sign with a warning light was posted before the bridge. The sign had been open (i.e., unfolded) with the beacon flashing for the three days immediately prior to the accident. The day before the accident, despite the persistence of freezing, wet weather, the Highway Department folded up the sign based upon National Weather Service forecasts of warmer, drier weather for the next day. In this case, the state was cleared of any liability related to its operation of the active warning device because of its lack of actual knowledge related to the icing conditions the morning of the accident.

In a second case, Holt vs. State of Oklahoma, Oklahoma Department of Transportation (Court of Appeals of Oklahoma, Division One 1996), the driver of an oncoming car lost control on an icy patch, crossed the centerline, and struck the Holts' car head on. In this case, ice formed on the roadway as a result of a release of water from the dam by the U.S. Corps of Engineers. There were signs located at each end of the dam warning motorists to WATCH FOR ICE ON BRIDGE. Remote-controlled amber flashing lights mounted on top of each sign were not operating at the time of the accident since none of the state's employees was aware the Corps of Engineers was to release water through the dam on the day of the accident. The plaintiffs allege that the state was negligent in failing to adequately warn motorists of the dangerous condition.

In its defense, the state argued that "reasonable persons cannot conclude that had the amber lights been flashing the collision would not have occurred." As evidentiary material in opposition to the state's motion, Holt provided the affidavit of an expert in the field of accident reconstruction. The expert opined that had the lights been flashing, both drivers would have most probably prepared themselves to drive on ice by reducing speed, and that the reduced speed would have resulted in reduced probability of both losing control and fatal injuries. Despite this testimony, the state was not found to be liable; no evidence suggests that a negligent act of the state caused the icy condition or that the state was even aware of the icy condition.

Poor Geometrics

Despite the unique geometric site conditions in each of the reported cases, plaintiffs similarly alleged that the warning devices in place were inadequate for the given conditions (see Table 7). In nearly every case, the transportation department (defendant) was protected by discretionary immunity as long as: (1) they could demonstrate a systematic process for assessing the level of warning device needed and (2) the warning device placement and design complied with state or federal standards (i.e., *The Manual on Uniform Traffic Control Devices*).

In Reichert vs. State of Louisiana, Department of Transportation and Development (Court of Appeals of Louisiana, Second Circuit 1995), the state was able to defend against the plaintiff's claim that "in his opinion a yellow flashing beacon should have been installed at the intersection at the time of the accident" by demonstrating a logical, systematic decision process for assessing the level of warning device needed. The state testified that a flashing yellow light signal was not warranted in this case because the department of transportation guidelines provided for the installation of the flashing beacon light only when there are more than three accidents in a one-year period.

Table 7. Summary of Poor Geometrics Accident Case Law.

Year	Court	Appellants/Appellees	Description
2002	Court of Appeals of Texas, Thirteenth District, Corpus Christi	City of Mission vs. Cantu, Sifuentes and Alvarado	…the change in the width of the roadway without any road sign or warning device was a dangerous condition.
1996	Court of Appeals of Texas, Tenth District, Waco	French vs. Johnson County	…struck an I-beam protruding from the bridge, causing his car to fall into the creek below, alleged that the county's negligence in failing to…warn the public of a dangerous condition by posting warning signs or signals along the approach to the narrow bridge.
2003	Court of Appeal of California, Sixth Appellate District	Morris vs. State of California	…the transition zone from highway to city street was hazardous, signing includes an END FREEWAY, sign, two MERGING TRAFFIC symbol signs and an END FREEWAY 1/2 MILE with two yellow flashing beacons.
1995	Court of Appeal of Louisiana, Second Circuit	Reichert vs. State of Louisiana, Department of Transportation and Development	…failed to see Martin's vehicle and attempted to make an emergency stop, a hill crest is located prior to the intersection, no caution lights or turn lanes exist but both a crossroad caution sign and junction sign warn do.

Summary of Findings

After reviewing both the published literature and extensive case law to identify potential liability risks associated with the use of a flashing beacon as a supplemental advance warning device in conjunction with a SCHOOL BUS STOP AHEAD sign, the following general findings are summarized.

- Many of the tort liability cases focus on the general design, placement, adequacy, etc. of warning devices in general and do not distinguish between passive and active warning devices. Hence, the increase in liability risk with the addition of flashing beacons to the SCHOOL BUS STOP AHEAD sign is expected to be minimal.

- When the adequacy of a warning device is questioned (i.e., the use of a static SCHOOL BUS STOP AHEAD sign vs. the use of the same sign with supplemental flashing beacons), transportation departments are most often protected under discretionary immunity as long as: (1) a logical and systematic decision-making process exists for selecting warning devices and (2) the design and placement of those warning devices conform to state and/or federal standards.

- When the operation of active warning devices is questioned (i.e., appropriate activation of flashing beacons), transportation departments have also been protected under discretionary immunity again as long as a logical and systematic decision-making process exists for operation.

- A greater risk of liability exists when transportation departments fail to adequately maintain warning devices already in place. To defend against such allegations, transportation departments must prove that they had no prior knowledge of the problem and, if notified, that they did not have adequate time to respond. A program of regular inspection and maintenance for warning and traffic control devices can assist in the defense of these types of cases.

Two areas of potential concern were only cursorily mentioned in the published literature and the case law. Historic case law indicates that the school district and/or the school bus driver are primarily named as the party at fault when a child is injured or killed at a school bus loading and unloading zone. In several of these cases, however, the alleged negligence, in part, relates to the failure to post a warning sign or the failure to provide an adequate shoulder for children to wait for the bus. The issue of "jurisdictional responsibility" should be well defined with respect to a transportation department's responsibility in establishing, operating and maintaining school bus loading and unloading zones on their facilities so that they can be adequately prepared to respond to negligence claims if named in such a suit.

Also demonstrated in historic case law is the premise that "the public reasonably has a right to rely on the warnings" (Thomas 2002). Finding in favor of the plaintiff based on his testimony that he "knew that when the crossing was occupied by a train, a red blinking light would be flashing," the Missouri Pacific Railroad Company was found negligent in its operation of the train without the activation of the red flashing beacons. For this particular investigation and application of an AAWD upstream of a school bus loading and unloading zone, a potential liability risk relates to the presence of the hazard and the activation of the flashing beacon. The hazard compromises both the school bus itself and the pedestrian children entering or exiting the bus. The activation of the flashing beacons will occur upstream of the bus stop when the bus comes within range of the radio signal. Depending on how early the children arrive at the school bus stop or how long they take to depart, the hazard (i.e., pedestrian children) may still exist at the site when the flashing beacons deactivate (because of the late arrival or departure of the bus). If motorists become accustomed to only the flashing beacons as their indication of the hazard (i.e., school bus and children), they may not exercise the same degree of caution when the bus is not present and the beacons are not flashing but children are nonetheless present at the bus stop. Because the school district and/or the school bus driver are immune from tort liability if the bus has not yet arrived or has already departed from the scene, transportation departments may experience a heightened risk of tort liability under these circumstances.

With all of these findings in mind, regarding the installation of active advance warning devices at low-visibility school bus loading and unloading zones, the state should be prepared to:

- incorporate the AAWD into state standards and specifications;
- develop a logical and systematic decision-making process for selecting school bus loading and unloading zones equipped with the supplemental flashing beacons (vs. those that are unsigned or signed only with static SCHOOL BUS STOP AHEAD signs);
- develop a logical and systematic decision-making process for operating the active flashing beacon system component;

- develop a program of regular inspection and maintenance for the AAWD that includes the general condition of the sign and the functionality of the flashing beacon system component;

- define the department's "jurisdictional responsibility" with respect to establishing, operating, and maintaining school bus loading and unloading zones; and

- consider additional or modified signing to reflect the presence of children even if the flashing beacons are not activated.

Overall, the addition of flashing beacons to the SCHOOL BUS STOP AHEAD sign (S3-1) poses minimal additional liability risk above what is already experience by transportation departments. This review is based largely on historic case law experience; new trends in liability may emerge that are unforeseen at this time.

CHAPTER 3:
SAFETY IMPACT EVALUATION

Chapter 3 provides a summary of national experience related to AAWS system effects on driver behavior and safety and describes the results of field studies conducted locally in Texas. Specifically, the field studies considered changes in entering vehicle speeds and brake-light actuations through the school bus loading and unloading zones. The chapter also includes a description of each field study site and the evaluation methods used.

SUMMARY OF NATIONAL EXPERIENCE

Prior to conducting their own series of field investigations to determine the effects of active advance warning devices to improve safety at school bus loading and unloading points in areas of limited visibility, researchers examined national experience related to this application. Formal study and published literature related to safety at specifically school bus loading and unloading zones was not uncovered. However, more general safety-related impacts resulting from the introduction of active advance warning devices at sites that previously had only passive warning devices are well documented. The nature of these sites includes school zones, pedestrian crosswalks, railroad grade crossings, rural and urban intersections, construction or maintenance work zones, frequent adverse weather, wildlife crossings, and areas with challenging highway geometrics.

Literature that related specifically to school bus transportation, and the consequent levels of safety, was focused on improving the vehicle visibility through enhanced vehicle coloring, marking or lighting, and driver training and qualification. Further, much of the literature describing more general applications of active advance warning devices addressed flashing beacon specifications including color, intensity, flash rate, power source, etc. (Howard and Finch 1960, Janson 1976, Hopkins and Holstrom 1976, Ruden et al. 1977, Enterprise Program 1997) or provided only general guidelines for their use (Goldblatt 1976, Carlson and Weiss 1983, Yu 1999, International Municipal Signal Association 2000, Lalani 2001). Instead, this summary of national experience focuses on those studies that document results from actual applications and evaluation of active advance warning devices to gain an overall sense of their effectiveness in improving motorist and/or pedestrian safety.

Though significant variability was noted in experimental design, investigation duration, and performance metrics across application (i.e., school zone versus railroad grade crossing versus rural intersection) and study to study, a reduction in vehicular speed and/or vehicular-involved accidents was most commonly investigated. Table 8 summarizes, by application type, the results of this review. Of the 46 studies reviewed, 37 reported a positive effect (i.e., either a reduction in vehicular speed or a reduction in accidents) resulting from the introduction of active advance warning devices with flashing warning beacons as the, or one of the, system components. It should be noted here that the ability of researchers to isolate the effects of flashing

Table 8. Summary of National Experience Related to Flashing Beacon Active Advance Warning Devices.

			Effective at Reducing Speed?	Effective at Reducing Accidents?
SCHOOL ZONES				
1975	Rosenbaum, Young, Byington, and Basham	*Speed Control in Rural School Zones*	YES	Not Investigated
1975	Zegeer	*The Effectiveness of School Signs with Flashing Beacons in Reducing Vehicle Speeds*	YES	Not Investigated
1976	Reiss and Robertson	*Driver Perception of School Traffic Control Devices*	NO	Not Investigated
1990	Burritt, Buchanan, and Kalivoda	*School Zone Flashers – Do They Really Slow Traffic?*	NO	Not Investigated
1990	Sparks and Cynecki	*Pedestrian Warning Flashers in an Urban Environment: Do They Help?*	NO	NO
1993	Hawkins	*Modified Signs, Flashing Beacons and School Zone Speeds*	YES	Not Investigated
1993	Aggarwal and Mortensen	*Do Advance School Flashers Reduce Speed?*	YES	Not Investigated
1997	Andersen, Austin, Jones, Munro, Steed, and Tasca	*Pilot Test of an Activated School Speed Limit Sign on a Two-Lane Rural Highway in Ontario*	YES	Not Investigated
1999	Schrader	*Study of Effectiveness of Selected School Zone Traffic Control Devices*	YES[1]	Not Investigated
2000	Moore and Ram	*School Environment Safety Guidelines*	YES	Not Investigated
PEDESTRIAN CROSSINGS				
1992	Van Houten and Malenfant	*The Influence of Signs Prompting Motorists to Yield before Marked Crosswalks on Motor Vehicle-Pedestrian Conflicts at Crosswalks with Flashing Amber*	NO	NO[2]
1998	Van Houten, Healey, Malenfant, and Retting	*Use of Signs and Symbols to Increase the Efficacy of Pedestrian-Activated Flashing Beacons at Crosswalks*	Not Investigated	YES[2]
2000	Van Winkle and Neal	*Pedestrian-Actuated Crosswalk Flashers*	YES	Not Investigated
2001	Malek	*Crosswalk Enhancement Comparison Study*	YES	Not Investigated

[1] Not found to be statistically significant
[2] Considers pedestrian-vehicle conflict frequency

Table 8. Summary of National Experience Related to Flashing Beacon Active Advance Warning Devices (Continued).

			Effective at Reducing Speed?	Effective at Reducing Accidents?
RAILROAD GRADE CROSSINGS				
1967	California Division of Highways	*Evaluation of Minor Improvements*	Not Investigated	YES
1976	Schulte	*Effectiveness of Automatic Warning Devices in Reducing Accidents at Grade Crossings*	Not Investigated	YES
1976	Russell, Michael, and Butcher	*Driver Reaction to Improved Warning Devices at a Rural Grade Crossing*	YES	Not Investigated
1980	Morrissey	*The Effectiveness of Flashing Lights and Flashing Lights with Gates in Reducing Accident Frequency at Public Rail-Highway Crossings, 1975-1978*	Not Investigated	YES
1982	Ruden, Burg, and Mcguire	*Activated Advance Warning for Railroad Grade Crossings*	YES	Not Investigated
1984	Heathington, Fambro, and Rochelle	*Evaluation of Six Active Warning Devices for Use at Railroad-Highway Grade Crossings*	YES	Not Investigated
1985	Eck and Halkias	*Further Investigation of the Effectiveness of Warning Devices at Rail-Highway Grade Crossings*	Not Investigated	YES
1985	Farr and Hitz	*Effectiveness of Motorist Warning Devices at Rail-Highway Crossings*	Not Investigated	YES
1987	Bowman	*Analysis of Railroad-Highway Crossing Active Advance Warning Devices*	YES	Not Investigated
1989	Fambro, Heathington, and Richards	*Evaluation of Two Active Traffic Control Devices for use at Railroad-Highway Grade Crossings*	NO	Not Investigated
1993	Kinnan	*Grade-Crossing Safety – Safety Improvements and Awareness Help Motorists Cross Tracks with Care*	Not Investigated	YES
1998	Aeberg	*Driver Behavior at Flashing-Light, Rail-Highway Crossings*	Not Investigated	NO[3]
2000	Parham, Carroll, and Fambro	*Evaluation of Enhanced Traffic Control Devices at Highway-Railroad Grade Crossings*	YES[4]	Not Investigated

[3] Speculative based on driver head movements
[4] Statistically significant at one of five sites

Table 8. Summary of National Experience Related to Flashing Beacon Active Advance Warning Devices (Continued).

			Effective at Reducing Speed?	Effective at Reducing Accidents?
INTERSECTIONS				
1967	California Division of Highways	*Evaluation of Minor Improvements*	Not Investigated	YES
1972	Mitchell	*Identifying and Improving High Accident Locations*	Not Investigated	YES
1977	Goldblatt	*Effect of Flashing Beacons on Intersection Performance*	YES	Not Investigated
1980	Lyles	*An Evaluation of Signs for Sight-Restricted Rural Intersections*	YES	Not Investigated
1982	Styles	*Evaluation of the Flashing Red Signal Ahead Sign*	YES	YES[5]
1985	Sabra	*Driver Response in Active Advanced Warning Signs at High-Speed Signalized Intersections*	YES	Not Investigated
1985	Eck and Sabra	*Active Advance Warning Signs at High Speed Signalized Intersections: A Survey of Practice*	Not Investigated	YES
1992	Gibby, Washington, and Ferrara	*Evaluation of High-Speed Isolated Signalized Intersections in California*	YES	YES
WORK ZONES				
1981	Lyles	*Alternative Sign Sequences for Work Zones on Rural Highways*	YES	Not Investigated
1992	Benekohal and Shu	*Evaluation of Work Zone Speed Limit Signs with Strobe Lights*	YES	Not Investigated
1997	Hall and Wrage	*Controlling Vehicle Speeds in Highway Construction Zones*	NO	Not Investigated
ADVERSE WEATHER				
1972	Kobett, Glauz, and Balmer	*Driver Response to an Icy Bridge Warning Sign*	YES	Not Investigated
1976	Hanscom	*Evaluation of Signing to Warn of Wet Weather Skidding Hazard*	YES	Not Investigated
2001	Collins and Pietrzyk	*Wet and Wild: Developing and Evaluating an Automated Wet-Pavement Motorist Warning System*	YES	YES[6]

[5] Statistically significant for right-angle collisions only
[6] Anecdotal

Table 8. Summary of National Experience Related to Flashing Beacon Active Advance Warning Devices (Continued).

			Effective at Reducing Speed?	Effective at Reducing Accidents?
WILDLIFE				
2001	Gordon, Anderson, Gribble, and Johnson	*Evaluation of the Flash (Flashing Light Animal Sensing Host) System in Nugget Canyon, Wyoming*	NO	Not Investigated
POOR HIGHWAY GEOMETRICS				
1978	Koziol and Mengert	*Evaluation of Dynamic Sign Systems for Narrow Bridges*	NO	Not Investigated
1986	Janoff and Hill	*Effectiveness of Flashing Beacons in Reducing Accidents at a Hazardous Rural Curve*	Not Investigated	YES
1992	Freedman, Olson, and Zador	*Speed Actuated Rollover Advisory Signs for Trucks on Highway Exit Ramps*	YES	Not Investigated
1994	Middleton	*A Study of Selected Warning Devices for Reducing Truck Speeds*	YES	YES[6]

[6] Anecdotal

beacons when used in combination with multiple warning devices (i.e., larger-dimension static signs, automatic gates, etc.) is extremely limited; many of the results presented here may reflect the combined effects of multiple warning devices.

School Zones

As early as 1975, Rosenbaum et al. investigated the use of active advance warning devices to reduce speeds in a rural school zone located along a high-speed, two-lane highway in Maine. Data were collected in a school zone where a 15 mph speed limit is in effect during certain times of the school day. The objective was to determine the effects on drivers of *The Manual on Uniform Traffic Control Devices* mandatory and advisory school zone signs, including beacon flashers, and the effect of a new, dynamic speed violation sign. Speeds for automobiles and large vehicles were measured for one dynamic and four passive sign conditions when the 15 mph speed limit both was and was not in effect. No enforcement was used during the experiment.

Results showed that: (1) vehicle velocities at the school were less when the driver was advised by flashing beacons that the 15 mph speed limit was in effect, (2) the average vehicle velocity was relatively constant at the school when the speed limit was not in effect, and (3) the lowest average speeds at the school (34 mph) were obtained when the dynamic speed violation sign was used.

Similarly, and during the same year, Zegeer (1975) investigated the effectiveness of school signs with flashing beacons in reducing vehicle speeds for the Kentucky Department of Transportation. Non-uniform signing, inoperative flashers, hidden flashers, deteriorating signs and pavement markers, and poor sight distances challenged the accuracy of the investigation; 14 percent of the school flashers were defective or malfunctioning. Taking into account these deficiencies, speed measurements were made during flashing and non-flashing periods at 48 of the 120 flashing beacon locations.

Significant speed reductions were found to be attributed to flashing school zone signs. The average speed reduction was 3.6 mph. Supplemental crossing guards contributed to a drop of vehicle speed by 9 mph. Supplemental speed enforcement in school zones by police agencies caused an average speed reduction of 8.4 mph. As a cautionary note, signs and flashers at high-speed locations decreased speed uniformity within the traffic stream and may result in increased inter-vehicle accidents.

A year later, Reiss and Robertson (1976) investigated student and driver perceptions of school traffic control devices. Interviews were conducted with approximately 1000 students (kindergarten and third, sixth, and eighth grades) and some 400 passing motorists at school locations in New York, Maryland, and Virginia. Driver responses were evaluated based on driver recognition of existing signing and behavioral modifications as evidenced by a change in speed. Radar hand guns were employed to measure driver performance and to provide a comparison with the driver interview responses.

Although drivers were generally not observant of school advance warning and crosswalk signs, those successfully perceived were active signs with flashing lights. Unfortunately, these active signs did not necessarily modify driver behavior or reduce speed to the level indicated on the sign.

Burritt et al. (1990) later observed a more pronounced ineffectiveness of flashing beacons in reducing vehicle speeds through two existing school crossings on a state highway within the city limits of Tucson, Arizona. The evaluation was based on the analysis of speed samples collected before and after the installation of flashers. It was found that the flashing beacons at Tucson's school crossings failed to reduce vehicle speeds and/or the number of violations of the 15 mph speed limit. Instead, a significant increase in vehicle operating speeds and the number of speed limit violations was noted when flashing beacons were used.

Building upon the work of Burritt and his colleagues in nearby Tucson, Arizona, Sparks and Cynecki (1990) investigated the effectiveness of flashing beacons at four urban school zones in Phoenix, Arizona. The study considered vehicle approach speeds, red light-running occurrences, and accident experience before and following the installation of flashing beacons. The study concluded that for intermittent pedestrian crossings in urban areas, flashers offer no benefit. In addition, the longer the flasher operates, the less effective it becomes.

Contrary to Arizona's experience, Hawkins (1993) observed successful speed reductions following the installation of flashing beacons at school zones along a 35 mph multilane roadway in Des Moines, Iowa. New oversized 25 mph speed limit signs and flashing beacons were installed at four of the seven schools. The remaining three were used as control sites. Spot speed studies were conducted at all locations. Following installation of the flashing beacons, speed studies were taken at one-, six-, and twelve-month intervals.

Following the installation of the new signs and beacons, average speeds were reduced by 9.3 percent. After one year, average speeds maintained a 7 percent reduction. The city has had positive feedback from parents, school representatives, police, and the public regarding the use of flashing beacons.

Aggarwal and Mortensen (1993) observed similar speed reductions at a school zone in Vacaville, California. Because of prevailing high speeds, flashing yellow beacons were installed in addition to the existing traffic signs and pavement markings that included yellow crosswalks, SLOW SCHOOL XING pavement legends, and 25 mph speed limit signs in advance of the flashing beacons. The study results showed a considerable reduction in average speeds (from 38 mph to 31 mph) during the periods when the advance school flashers were operating.

The Ministry of Transportation of Ontario investigated a similar application and observed similar speed reductions. Andersen et al. (1997) pilot-tested an activated school speed limit sign at a school in Georgina, Ontario. Vehicle speeds were measured using hose speed traffic counters before and after sign installation. Speeds were also measured at a control site, a nearby school on a road with similar operating characteristics. Vehicle speeds were measured at both sites during the hours when students were being transported to and from the schools. The sign reduced the average vehicle speed by 9.3 mph when the flashing lights were in operation. While the average speed during sign activation was still well above the 37.3 mph speed limit, a reduction of this magnitude was viewed as positive given the road's operating characteristics.

Schrader (1999) investigated the potential of five different school zone traffic control devices for improving safety and reducing vehicle speeds. The five devices tested in the study were fiber-optic signs, span wire-mounted flashing yellow beacons, post-mounted flashing yellow beacons, transverse lavender stripes, and large painted legends. Each device was tested at a unique site. Speed data were obtained at each site before the devices were added and again one month and six months after the devices were installed. Of the five devices tested, only the site with the fiber-optic signs experienced a speed reduction significant at the 95 percent confidence level. Several of the other sites also experienced decreases in speeds; however, these decreases were not statistically significant.

More recently, Moore and Ram (2000) considered the effects of flashing lights on driver speeds in school zones as part of an effort to develop school environment safety guidelines. Six months following the implementation of the flashing beacons, 85th percentile speeds were observed to have declined by 3 to 7 mph.

In summary, the use of flashing beacons to provide active advance warning at school zones has been seemingly successful. Seven out of ten studies conducted observed a reduction in vehicle speeds through the school zone, with average speed reductions ranging typically from 3 to 9 mph depending on the roadway environment. Only one study considered a reduction in accidents attributable to the presence of active advance warning devices; no reduction in accident frequency was noted before and after implementation. The same study did not detect a reduction in vehicle speeds either. None of the studies reviewed considered effects of AAWD on accident severity although one would expect a reduction in accident severity attributable to a noted reduction in vehicle speeds.

Pedestrian Crossings

Looking more generally at pedestrian crossings, Van Houten and Malenfant (1992) investigated the effectiveness of flashing beacons in conjunction with supplemental signing to heighten pedestrian safety at crosswalks. Specifically, the purpose of this experiment was to evaluate the effects of signs reading STOP HERE FOR PEDESTRIANS alone and in conjunction with advance stop lines on pedestrian safety at multilane crosswalks with pedestrians activated amber flashing lights. Motorist and pedestrian behaviors measured throughout this experiment included: (1) the occurrence of various types of motor vehicle-pedestrian conflicts, (2) the distance that motorists stopped before the crosswalk when yielding to pedestrians, (3) and the percentage of motorists yielding to pedestrians. The introduction of the sign alone 50 feet (15.15 m) before the crosswalk increased the distance before the crosswalk that motorists yielded to pedestrians and reduced the percentage of motor vehicle-pedestrian conflicts whether the flashing light was activated or not. The addition of the advance stop line was associated with further improvements in both measures.

Van Houten et al. (1998) continued this work in a more recent study that also considered an illuminated sign with the standard pedestrian symbol next to the beacons and a sign 50 m before the crosswalk that displayed the pedestrian symbol and requested motorists to yield when the beacons were flashing. Both interventions increased yielding behavior, and the effect of both together was greater than either alone. However, only the sign requesting motorists to yield when the beacons were flashing was effective in reducing motor vehicle-pedestrian conflicts.

Van Winkle and Neal (2000) investigated the effects of installing a flashing beacon at a crosswalk located on an arterial street at a minor side street with approach volumes well below the minimum signal warrant requirements. For this crosswalk, advance and intersection flashers would be activated by the pedestrian and would flash only during the time a pedestrian was actually in the crosswalk. In order to test the effectiveness of this concept, a number of different types of studies were conducted at this and other locations in the Chattanooga, Tennessee, area. Driver behavior studies were made where the crosswalk flashers have been in place for several years to evaluate the long-term effectiveness of the devices. At one other location, an opinion survey was conducted to gauge pedestrian satisfaction with the flashers. Finally, a survey of other similar pedestrian-actuated crosswalk flasher programs in other cities across the country was conducted and summarized.

With respect to driver behavior, a before/after study conducted in 1987 indicated that the percent of vehicles either stopping or slowing at the crosswalk increased from 56 percent before installation to 90 percent following installation in the eastbound direction and 39 percent before installation to 50 percent following installation in the westbound direction at the study site. In 2000, nearly 13 years after installation, effects on driver behavior remained positive; 86 percent and 77 percent of the vehicles, respectively, either stopped or slowed down at the pedestrian crosswalk when the flashing beacons were activated. Similar findings were observed at a second study site that experienced 69 percent of the northbound and 91 percent of the southbound traffic slowing or stopping at the pedestrian crosswalk.

Differing from the common before/after installation experimental design, Malek (2001) compared the effects of flashing beacons on pedestrian safety with an alternative active warning device (i.e., embedded pavement markers). Many local agencies throughout California have been installing actuated embedded pavement lights adjacent to busy crosswalks. These lights flash only when pedestrians are present to alert approaching motorists of pedestrian activity. Most agencies, including CalTrans, continued to use the state-accepted overhead yellow flashing beacon as the standard warning device. To date, there has not been an analysis which compares the effectiveness of the two different warning systems. The purpose of this study was to examine the effectiveness of experimental embedded pavement lights with the standard overhead yellow flashing beacon, both of which are activated automatically by motion detectors that sense the movement of pedestrians into the crosswalk.

Although the embedded pavement markers proved more successful at eliciting appropriate driver response, a noted positive effect nonetheless resulted from the use of flashing beacons. The proportion of drivers yielding for pedestrians during the day increased from 1 percent before installation to 4 percent and 2 percent for one and six months after installation in the eastbound direction, respectively. Braking distance increased from 63 feet before installation to 133 and 243 feet for one and six months after installation, respectively. In the westbound direction, the proportion of drivers yielding for pedestrians during the day increased from 5 percent before installation to 14 percent and 8 percent for one and six months after installation, respectively. Braking distance increased from 87 feet before installation to 165 and 266 feet for one and six months after installation, respectively. Similar findings were observed at night. The proportion of drivers yielding for pedestrians at night increased from 0 percent before installation to 5 percent and 8 percent for one and six months after installation in the eastbound direction, respectively. Braking distance increased from 0 feet before installation to 175 and 190 feet for one and six months after installation, respectively. In the westbound direction, the proportion of drivers yielding for pedestrians at night increased from 2 percent before installation to 5 percent and 8 percent for one and six months after installation, respectively. Braking distance increased from 87 feet before installation to 200 and 228 feet for one and six months after installation, respectively.

In summary, three of the four studies reviewed found that flashing beacons used to warn drivers of a downstream pedestrian crosswalk were effective in either reducing vehicle speeds or pedestrian-vehicle accidents. In several of these studies, an additional performance metric – braking distance – was considered as a surrogate measure of safety.

Railroad Grade Crossings

The use of active advance warning devices and flashing beacons at school zones and pedestrian crosswalks is relatively new when compared to other types of applications. As early as 1967, the California Department of Transportation, then the California Division of Highways, began investigating the effectiveness of flashing lights at improving the safety of at-grade railroad crossings. A comprehensive study was conducted that considered the current effectiveness of center suspended and advance warning flashing beacons in reducing accidents. Before-and-after studies were conducted on 45 flashing beacon projects. Flashing beacons as a whole were found to be effective in reducing accidents. The accidents were reduced by 34 percent, with an 83 percent reduction at railroad crossings, 40 percent reduction at intersections, and 21 percent reduction at advance warning beacon installations.

Nearly a decade later, Schulte (1976) considered the combined effects of flashing beacons and automatic gates in reducing railroad grade crossing accidents. In the last 17 years, California has experienced over 17,000 vehicle-train accidents that have claimed over 550 lives. The California Public Utilities Commission and the California State Legislature have attempted to reduce the continuing human and economic loss by promoting the installation of flashing light signals and automatic crossing gates. This study was intended to gauge the effect of California's automatic warning device program on the frequency of vehicle-train accidents in general and to examine specific crossing locations to appraise the capabilities of automatic warning devices in reducing average vehicle-train accident and severity rates. To determine the effectiveness of automatic warning devices under varying conditions, the before-and-after accident histories of 1,552 grade crossings where automatic devices were installed between 1960 and 1970 were compared on a crossing-year basis, segregated by: (1) type of warning device before and after, (2) rural vs. urban conditions, and (3) the number of railroad tracks.

While some limitations and adverse side effects do exist, the results indicate that the installation of automatic warning devices can be expected, on the average, to reduce vehicle-train accidents by approximately 70 percent per crossing-year and related deaths and injuries per year by 89 percent and 83 percent, respectively. In addition, it would appear that automatic gates eliminate many of those accidents representing the greatest potential severity, since deaths per accident were reduced 64 percent, injuries per accident by 43 percent, and deaths per injury by 36 percent.

During that same year, Russell et al. (1976) was investigating driver reaction to enhanced flashing beacons installed at railroad grade crossings. Specifically, researchers analyzed the effect on motorists of improving the warning devices at a rural grade crossing with a high accident rate, by replacing 20.3 cm (8-inch) flashers on automatic gates with 30.5 cm (12-inch) flashers activated by a speed predictor and supplemented by additional strobe lights. The study evaluated before-and-after conditions, motorists' reaction to the system, and the data collection system itself. Most drivers were found to approach the grade crossing safely. It was found that the percentage of reduction in speed of the fastest vehicles, along with observation of individual speeding vehicles, provided a better measure of improved effectiveness than mean speeds and deceleration.

In support of the development of a resource allocation model which assists in achieving maximum safety benefits for a given level of funding, Morrissey (1980) compared the accident rates at 2,994 rail-highway crossings nationwide both before and after the installation of active warning devices to determine their effectiveness. Flashing lights and flashing lights with gates were found to be significantly effective in reducing the hazards at rail-highway crossings. Gates proved to be more effective than flashing lights in accident reduction.

Hungerford and Heathington (1981) relied on both laboratory and field environments to determine the effects of active warning devices on safety. A number of innovative active warning devices for use at railroad-highway grade crossings were conceptualized, ranked, and subjectively evaluated. Eight candidate devices were developed that were reduced to five for further laboratory testing. Specific characteristics of the eight candidate systems were incorporated into three systems, namely the four quadrant gate system, the standard highway traffic signal with active advance warning, and improvements to existing flashing light signals. The six concepts embodied in these three systems were field-tested for a one-year period.

Similarly, Ruden et al. (1982) undertook a project to design, develop, and test prototype AAWDs for use in advance of rail-highway crossings with flashing lights or flashing lights and automatic gates and associated train detection circuitry. Other objectives were to establish guidelines for using such devices and to identify the types of crossings where activated advance warning would be most effective. A literature review and survey of existing AAWD installations led to the development of four candidate devices, all consisting of a primary symbol warning sign, a supplemental message sign, and a pair of yellow flashing lights activated by the approach of a train. Indoor laboratory film tests were conducted which focused on subject understanding of the sign components of the devices. Limited outdoor tests of full-scale devices verified the indoor test results and gave further information on the effectiveness of the flashing yellow signals. Three of the four candidate AAWDs were field-tested, with day and night evaluation of vehicle speeds, braking location, and driver looking behavior. All three devices proved effective in alerting and preparing the driver for at-crossing signal activation.

Building upon the work of Hungerford and Heathington (1981) and Ruden et al. (1982), Fambro and Heathington (1984) and Heathington et al. (1984) further investigated subject understanding of the active advance warning devices and field performance in two companion studies. As part of the first effort, a short survey questionnaire was given to 32 subjects to evaluate their understandings of railroad crossings. The survey answers indicated that there are a number of motorists who neither understand nor fully comprehend the meaning of traffic control devices at railroad-highway grade crossings. The severity of train-automobile collisions is such that only a small fraction of the driving public making inaccurate decisions can lead to death and serious injury. It is therefore important to have high performance traffic control devices at railroad-highway grade crossings and to educate the motorists on the proper driving behavior at these locations.

As part of the second effort, six new active railroad-highway grade crossing warning devices were evaluated under controlled laboratory testing conditions. The six devices included two alternatives for each of three basic systems – four-quadrant gates (with and without skirts), four-quadrant flashing light signals (with and without strobes), and highway traffic signals (with one and with three white bar strobes). The evaluation involved testing the performance of each of the six devices in a near real-world environment to identify the three most desirable devices for subsequent field-testing. Thirty-two test subjects drove an instrumented vehicle repeatedly over a private two-lane highway. On each trip down the roadway, the test driver encountered three full-scale active warning devices, any one of which may or may not have been actuated as the vehicle approached. The experimental design included different actuation distances as well as day and night conditions. In addition to driver behavior data, attitudinal data on the effectiveness of the six devices were obtained from each subject. All six active warning devices tested were perceived to be superior to standard active warning devices currently in use at railroad-highway grade crossings. Generally speaking, the active warning devices comprising skirts, overhead strobes, or three white bar strobes were more effective. Four-quadrant gates with skirts tended to be a superior system in all categories of analysis. The relative effectiveness of flashing light signals and highway traffic signals tended to alternate depending on the category of analysis; there was not a consistent ordering of effectiveness for these two systems.

In 1985, Eck and Halkias analyzed the national inventory of the U.S. Department of Transportation-Association of American Railroads and the accident files of the Federal Railroad Administration to develop measures of effectiveness for the following rail-highway grade-crossing upgrade stratifications: (1) passive systems to flashing lights on single track, (2) passive systems to gates on single and multiple track, and (3) flashing lights to gates on single and multiple track. Other objectives included determining the influence of crossing angle, train speed ratio, and train speed difference on the effectiveness of warning devices. Overall results confirmed effectiveness values developed previously (but with smaller databases) for upgrades from passive systems to flashing lights and from passive systems to gates. The only marked change from previous studies occurred in the flashing-lights-to-gates category; the effectiveness value determined in this study was higher than values obtained in previous work.

During the same year and using the same accident databases (for accidents occurring from 1975 through 1980), Farr and Hitz (1985) determined the safety effectiveness of various types of motorist warning devices in reducing accidents at rail-highway crossings. Emphasis was placed on determining the effectiveness of cantilevered flashing lights, mast-mounted flashing lights, STOP signs, cross-bucks, highway signals, constant warning time devices, and crossing illumination; influences of crossing characteristics on warning device effectiveness; and refined effectiveness estimates of flashing lights and gates over those obtained in an earlier U.S. Department of Transportation study which used data for the years 1975 through 1978.

Bowman (1987) narrowed the focus of study by considering the effectiveness of three active advance warning devices for use on roadway approaches to rail-highway crossings. Each device consisted of a primary message sign, a supplementary WATCH FOR TRAINS message plate, and two 8-inch flashing beacons. The devices differed only in the configuration and message of the primary sign. The study was conducted at four sites where sight restrictions on the approach resulted in an insufficient safe stopping distance. The train activation of each warning device began 10 seconds prior to the activation of the at-grade warning system.

The results of this study indicated that the alternately flashing beacons produced a significant decrease in vehicle velocity. During the inactivated state, results revealed that there was no significant difference in vehicle velocities resulting from the use of different primary signs. These results indicate that a railroad advance warning sign with alternating flashing beacons would be effective in providing motorists with required advance warning.

Similarly, Fambro et al. (1989) considered the effectiveness of two active traffic control devices with the potential for improving safety at railroad-highway grade crossings in a detailed laboratory evaluation and in the field under normal traffic conditions at actual crossings. Two crossings with active warning devices already in place were identified as potential study sites, and train and driver behavior data were collected both before and after the experimental traffic control devices were installed. The two devices evaluated for use at railroad-highway grade crossings were four-quadrant flashing light signals with overhead strobes and standard highway traffic signals. Based on the results of the field evaluation, there were no measurable differences in driver behavior between four-quadrant flashing light signals with overhead strobes and the standard two-quadrant flashing light signals. The highway traffic signal proved to be both feasible and effective as a grade crossing traffic control device. Driver response to the highway traffic signal was excellent, with the traffic signal outperforming standard flashing light signals on several key safety and driver behavioral measures of effectiveness.

Looking specifically at driver behavior at railroad grade crossings, Richards and Heathington (1990) investigated the effects of warning time on driver behavior and safety at railroad-highway grade crossings with active traffic control (i.e., flashing light signals with and without automatic gates). The research included: (1) an evaluation of driver response data gathered at three grade crossings in the Knoxville, Tennessee, area and (2) a human factors laboratory study of drivers' warning time expectations and tolerance levels. In the field studies, the actions of over 3,500 motorists were evaluated during 445 train events. Based on the study results, warning times in excess of 30 to 40 seconds caused many more drivers to engage in risky crossing behavior. The studies also revealed that the large majority of drivers who cross the tracks during the warning period do so within 5 seconds from the time they arrive at the crossing. The human factors studies expanded the findings of the field evaluation. Specifically, the studies revealed that most drivers expect a train to arrive within 20 seconds from the moment when the traffic control devices are activated. Drivers begin to lose confidence in the traffic control system if the warning time exceeds approximately 40 seconds at crossings with flashing light signals and 60 seconds at gated crossings.

Kinnan (1993) reports, “Studies show that flashing lights reduce crossing crashes by 44 percent. Flashers in combination with gates cut the toll by 64 percent compared to crossbucks alone,” though his sources are not well cited.

Further demonstrating the benefits of physical barriers in addition to flashing lights alone, Aeberg (1998) states that “the risk of accident at flashing-light, rail-highway crossings has been found to be ten times higher than at crossings equipped with barriers,” though again sources are not well cited. The purpose of Aeberg’s investigation was to study driver behavior in rail-highway crossings and to relate measures of driver behavior to variables believed to be associated with increased risks of accident. About 2,000 drivers were observed in 16 different crossings with driver head movements as the major dependent variable. This variable exhibits wide variability among drivers as well as satisfactory inter-observer reliability. The results showed that many drivers turned their head to look for trains in rail-highway crossings although the crossings were equipped with flashing warning lights. However, fewer drivers looked when the visibility was restricted, a factor that is associated with increased risk of accident and in crossings with few trains per day. The conclusion from the present study is that flashing-light crossings should be designed in a way that redundant information about approaching trains should be easily available to the drivers.

In 2000, Parham et al. conducted a study to determine the effectiveness of two enhanced sign systems at passive highway-railroad grade crossings. The first enhanced sign system consisted of a YIELD sign with the added words TO TRAINS. The second enhanced sign system consisted of a vehicle-activated flashing yellow strobe mounted above a railroad warning sign in combination with a new yellow warning sign that reads LOOK FOR TRAIN AT CROSSING.

Before and after the sign systems were installed, on-site interviews and speed studies were conducted. The study results indicated that neither of the enhanced sign systems harmed the drivers or negatively influenced their approach speeds to railroad crossings. The YIELD TO TRAIN sign resulted in no statistical effect on the mean approach speed. The results of the LOOK FOR TRAIN sign were a decrease in mean speed on one out of five sites. No significant changes occurred at the other four sites. From the survey, 54 percent of participants stated that they believed the LOOK FOR TRAIN AT CROSSING enhanced sign was a good idea. Ninety percent of participants noticed the flashing lights at the approaches to the railroad-highway grade crossings.

Of the studies that considered safety improvements at railroad grade crossings attributable to flashing beacons (alone or in combination with other warning devices), 11 of the 13 observed positive effects, 5 observing reductions in vehicle approach speeds and 6 observing reductions in train-vehicle accidents. In one study, the noted accident reduction was speculative based on observed vehicle driver head movement, and in a second study, the noted approach speed reduction was statistically significant at just one of five study sites. Nonetheless, the findings in totality are compelling enough to suggest an overall positive effect of driver performance and safety at railroad grade crossings.

Intersections

Turning attention away from roadway-railroad track intersections, flashing beacons have two primary applications at roadway-roadway intersections: (1) when located at the intersection, flashing beacons provide an inexpensive and efficient means of traffic control at low-volume intersections and (2) when located upstream of an intersection, flashing beacons provide an opportunity for advance warning. This review focuses on the latter application.

As part of a larger comprehensive study to evaluate the effectiveness of center suspended and advance warning flashing beacons in reducing accidents, before-and-after studies by the California Division of Highways (1967) were conducted on 45 flashing beacon projects. Flashing beacons as a whole were found to be effective in reducing accidents. The accidents were reduced 40 percent at intersections and 21 percent at advance warning beacon installations. This study also suggests that flashing beacons should be considered at four-leg intersection locations that have STOP sign control and experience four or more crossing plus left-turn accidents in one year, and where STOP signs are warranted where approach speeds are high, visibility to the STOP sign is limited, or the intersection is hidden or unexpected.

Mitchell (1972) considered the effects of flashing beacons in combination with various other traffic control strategies including signalizations, striping, pavement markings, channelization, and sight distance and enforcement improvements in improving high traffic accident locations. Twenty-one major streets were analyzed by field observation, accident diagrams, and data review. A pedestrian and bicycle accident study were also completed. A fixed object study was completed which included 15 streets with narrow travel lanes and high numbers of roadside obstructions.

The results of this study included 58 locations that had been improved by enhanced traffic control (i.e., flashing beacons, signalizations, striping, pavement markings, channelization, and sight distance and enforcement improvements). Depending on the location, the number of accidents was reduced by 21 to 67 percent with an overall observed reduction of 30 percent. Estimated economic loss dropped from $3.5 million to $2.7 million in 1971. The benefit/cost ratio was in excess of three to one annually.

Specific to flashing beacons, Goldblatt (1977) investigated the operational effects of various types of continuously and vehicle-actuated flashing traffic control devices performed at the Federal Highway Administration's Maine Facility. Both electronic and manual data collection techniques were used. Five intersection and three advance warning device configurations were tested at the intersection of U.S. 2 and ME 152.

The use of continuously flashing intersection beacons along stopped approaches was found to encourage speeds consistently lower than those achieved by STOP signs or vehicle-actuated intersection beacons. Certain vehicle-actuated advisory warning devices helped to reduce speed variance on major (non-stop) approaches. A vehicle-actuated stop ahead beacon caused drivers to begin braking sooner than they would without a beacon. Reduced speed variance was also noted when the advance warning beacon was used. These effects disappeared if there was a beacon at the downstream intersection.

Lyles (1980) conducted an experiment to examine the effectiveness of six signs and sign sequences for warning motorists of a hazardous or sight-restricted intersection ahead in a rural two-lane situation. Signs examined ranged from the standard intersection symbol warning sign to vehicle-actuated signs with flashing warning lights. Data collected during the experiment included: speeds of motorists as they approached and passed through test intersections (sometimes with a vehicle stopped on the side road); vehicle classification and registration information; and, for selected sign/site combinations, survey information for some motorists regarding their recollection of and reaction to the tested signs. The principal findings were that emphatic type signs (warning sign with flashers or a regulatory sign) caused drivers to reduce their speed by about 3 mph more than standard warning signs, and increased driver awareness (as measured by sign recall and noticing of a side road vehicle) by a factor of approximately two. Familiarity with a test site, type of vehicle being driven, and sex did not have a significant effect on drivers' reactions to the various sign/site conditions.

In 1982, Styles investigated the effectiveness of the RED SIGNAL AHEAD (RSA) sign and developed guidelines for its use. The RSA sign is intended to increase motorist awareness of a traffic signal when this dynamic device is placed in advance of an unexpected signalized intersection. In brief, this study concludes that the RSA sign has the potential to be an effective device in reducing right-angle accidents at signalized intersections where certain geometric and traffic conditions exist. The results of this study followed an investigation into accident and non-accident measures of effectiveness (MOEs). Non-accident MOEs included approach speeds, through on yellow/red interval movements and initial brake application locations. The MOEs were examined for a composite of all locations and by variations in certain key elements. Those elements considered to be significant were approach geometry, sight distance, and traffic volume. Two analyses were performed with the accident data: (1) a three-year before/after accident study and (2) a one-year before/after accident study with a "control" group. Both accident analyses concurred that a significant reduction in right-angle accidents followed the installation of the RSA sign. The analyses were not conclusive regarding effects on rear-end, total, and truck accidents. There was some indication that rear-end accidents tended to increase. For total accidents as well as truck accidents, the two analyses disagree on the RSA sign's effectiveness. The non-accident MOEs revealed that the RSA sign influences approach speeds but does not appear to affect through on yellow/red interval movements. Also, the initial brake applications appeared to be a function of the geometric approach to the intersection.

Building upon this research, Sabra (1985) investigated driver response to active advance warning signs at high-speed signalized intersections. This research was conducted on the Federal Highway Administration's Highway Driving Simulator (HYSIM) using 60 test subjects. Measures of effectiveness included identification distance, reaction time, vehicle approach speed, and vehicle lateral placement measured on the HYSIM. Driver preferences were obtained from an interview following the driving test. The AAWDs examined were PREPARE TO STOP WHEN FLASHING with flashing beacons using both a diamond-shape sign and a rectangular sign mounted both on an overhead structure and ground mounted on the roadside. Also a symbolic signal ahead sign with flashing lights and a RED SIGNAL AHEAD sign with the "red" flashing lights were candidate test signs. The standard SIGNAL AHEAD and the symbolic signal ahead signs were also displayed. The results indicated the symbolic signal ahead sign with flashing beacons had the greatest identification distance among all the test signs and was preferred by most drivers. No differences could be detected between ground-mounted versus overhead signs. All the active advance warning signs were superior to the standard passive warning signs.

In a related effort, Eck and Sabra (1985) evaluated accident countermeasures at high-speed signalized intersections using a synthesis of related current traffic engineering practice. The synthesis included a review of published and unpublished literature and results of a questionnaire survey sent to practicing traffic engineers. Three types of devices were assessed: (1) flashing red SIGNAL AHEAD signs, (2) PREPARE TO STOP WHEN FLASHING signs, and (3) flashing strobe lights.

Both the survey and the literature indicated that hidden intersections and rural expressways where signals are unexpected are the problems at high-speed signalized intersections. It was found that in general, the flashing red SIGNAL AHEAD sign was the most effective of the three active devices. In general, for all dynamic devices it was concluded that activation of the flashing near the end of the green light is more effective than activation at the beginning of the yellow light.

Gibby et al. (1992) investigated safety levels at high-speed, isolated signalized intersections (HSISIs) in California. Variables investigated included advance warning signs with and without flashing beacons, signal timing and phasing, channelization, signal equipment configurations, shoulder widths and types, median widths and types, and approach speeds. Forty HSISIs out of the approximately 100 statewide were chosen for the analysis. Twenty were selected from the highest accident group and from the lowest accident group. Statistical analysis identified relationships between intersection approach speed and approach accident rates. The primary variables found to be significantly correlated to low accident rates on approaches to HSISIs were the presence of separate left-turn phase, a raised median, wide paved shoulders, and an advance warning sign with a flashing beacon.

In each of the eight studies reviewed, active advance warning devices, with flashing beacons as one component, produced a positive reduction in either vehicle approach speeds or vehicular accidents.

Work Zones

Building upon the work that he conducted regarding hazardous or sight-restricted intersections along rural two-lane roads, Lyles (1981) next considered alternative sign sequences for work zones on rural highways. Two experiments were done on U.S. 2 in Central Maine to evaluate the effectiveness of alternate signing sequences for providing warning to motorists of construction and maintenance activities that require a lane closure on the road ahead. The signs tested included a standard *MUTCD* warning sequence, the same sequence on both sides of the road augmented with continuously flashing beacons, and a sequence of symbol signs. Data were collected covertly on random motorists by using a combination of inductance loops imbedded in the roadway and piezoelectric cable. The study found that: (1) the most effective sign sequence was the *MUTCD* sequence augmented with flashing beacons, (2) the symbol sign sequence appeared to be at least as effective as the standard sequence, and (3) in no instance did the sign sequence appear to cause confusion or potentially dangerous abrupt motorists' reaction.

Based upon earlier work conducted for the Illinois Department of Transportation and Federal Highway Administration (Benekohal et al. 1992), Benekohal and Shu (1992) evaluated the effectiveness of flashing lights in reducing speeds in a rural interstate construction zone. The speed reduction effects on cars and trucks were determined at two locations within the work zone. The results indicated that the average speed of cars was reduced by 1.9 to 7.1 mph and that of trucks by 1.3 to 6.0 mph when the strobe lights were flashing. In general, the speed reduction effects were more pronounced on the cars than on the trucks and at a location past the work space than before it. The reductions at the location past the work space were two to three times more than the reductions at the location before the work space. Cars reduced their speeds, on average, by 1.9 to 4.9 mph before and by 5.9 to 7.1 mph after the work space. Similarly, the speed reduction for trucks was 1.3 to 2.9 mph before and 3.3 to 6.0 after the work space. In general, the percentages of vehicles with excessive speeds in the work zone decreased when the lights were flashing.

Most recently, Hall and Wrage (1997) evaluated the effectiveness of alternative treatments for controlling vehicle speeds in work zones. Field studies were conducted at three rural, high-speed locations, two urban freeway work zones, and five arterial locations. Three treatments were investigated in the project: (1) a radar beam that would activate motorists' radar detectors, (2) a special work zone speed limit sign with flashing beacons, and (3) a speed trailer that monitors vehicle speeds and displays this information to the driver. Vehicle speeds were collected in work zones in a "before" period, with the normal traffic control plan in operation, and in a "during" period, with the supplemental treatment in place. The study found that the radar was ineffective in reducing vehicle speeds through construction zones, perhaps because those motorists with radar detectors could see that speed regulations weren't being enforced. The work zone speed limit sign with beacons was also ineffective. In applications on urban arterials, the speed trailer was effective in reducing speeds by 4 to 5 mph; use of this treatment on an urban freeway in conjunction with enforcement also resulted in improved speed compliance. The study recommends that work zone speed limits be set realistically, that the speed trailer be used more extensively, and that other, non-engineering solutions be explored.

In two of the three studies evaluating the effect of flashing beacons on driver behavior and safety through construction zones, positive effects were observed relating to noted approach speed reductions. The third and most recent study observed no such effects. This result may be attributable to the unique environment in which the study was conducted or the experimental design methods, or it may indicate driver desensitization to flashing beacons as a result of their more prevalent use as an active advance warning device at construction zones.

Adverse Weather

Advanced detection technologies have provided the ability to warn drivers of more dynamic, short-term hazards such as adverse weather and wildlife crossings. Kobett et al. (1972) investigated the effects of active advance warning devices during adverse weather events. A field evaluation was made of driver response to a warning sign which read ICY BRIDGE AHEAD. When not in use, the sign was rotated out of the drivers' line of sight. When activated, an amber flashing light was mounted atop the sign, and another was mounted on the upstream guardrail at the bridge to increase visibility of the warning system. The types of data collected included speed measurements, traffic distribution to lane, counts of lane changes, brake-light occurrences and driver interviews. Comparative measurements were made with and without the signs. The key traffic characteristic was chosen to be the speeds of "isolated" vehicles. Data of flow rates and distribution to lane, change frequency, and brake-light activity were also recorded. A speed reduction attributable to sign/flashing beacon presence was noted.

Similarly, Hanscom (1976) investigated the effectiveness of signing to warn motorists of wet weather skidding hazards. Study objectives were to examine motorists' general awareness of the hazard and to assess the relative effectiveness of various signing treatments that warn of the hazard. Measures of signing effectiveness were motorist speeds at critical curve locations and questionnaire responses regarding motorists' observations and interpretations of the signs. Three curved highway sections were treated with five experimental signing conditions. Variations on the slippery when wet symbolic sign ranged from its use by itself to increasing levels of specificity and conspicuity to its use with flashing lights and an advisory speed limit. Experimental signing conditions incorporating flashing lights were effective at reducing highest quartile mean speeds below the critical safe wet pavement speed based on roadway geometry and surface conditions. Signs without flashing lights were not shown to be effective. Those questioned saw and properly interpreted the more conspicuous warning signs. Motorists' cues of potential hazard were observed to be roadway curvature and superelevation, behavior of other motorists, appearance of pavement surface, ambient conditions, known accident history of the site, and presence of the warning sign. About 1 percent of the interviewed motorists cited the warning sign as their cue of potential skidding hazard.

Building upon this early work, Collins and Pietrzyk (2001) investigated the effectiveness of a fully automated motorist warning system developed for wet-pavement conditions. The demonstration took place on one expressway interchange ramp where 69 percent of total recorded crashes had been classified as "run-off" crashes during wet-pavement conditions. However, less than one-half of all wet-pavement crashes occurred during rain. The potential solution was to develop an automated, dynamic motorist warning system to attract attention to the advisory speed limit signs and thus encourage motorists to reduce vehicle speed. A pavement sensor embedded in the roadway activated two flashing beacons located above the signs whenever moisture was detected. Infrared radar recorded vehicle speed at the site. Speeds and volumes were grouped into a matrix according to weather conditions and time periods, which were based on sunlight visibility and peak traffic hours. The reduction of the 85th percentile speeds served as the first measure of effectiveness, and only "like" conditions were compared for system evaluation. In total, more than 27,000 wet-pavement vehicle speeds were compared before and after system activation. The average reduction in travel speed was 10 mph during heavy rain and 5 mph during light rain; the standard deviation for vehicle speed also was reduced after system activation. No run-off crashes were reported at the site after the first week of the evaluation period.

In summary, each of the three studies reviewed that considered the effects of active advance warning devices during times of adverse weather showed a reduction in vehicle speeds at the hazardous sites. Anecdotally, one study observed a reduction of accidents following the installation of a flashing beacon.

Wildlife

Most recently, active advance warning devices have been used to warn of potential wildlife conflicts downstream. Gordon et al. (2001) evaluated the Flashing Light Animal Sensing Host (FLASH) System, which consisted of infrared detectors that sensed deer as they passed through an opening in a deer-proof fence and activated a sign with flashing lights to alert motorists to the presence of deer on or near the highway, and a second comparative geophone deer detection system. It was found that more than 50 percent of the hits registered by the FLASH system were false hits not caused by deer, though the geophone system worked well throughout the study period, with no false hits detected. Vehicles did not slow down significantly for the warning signs. When deer or a stuffed decoy was adjacent to the road and the lights activated, vehicles reduced their speed (12.32 and 6.63 mph on average for passenger vehicles and tractor trailers, respectively). This lack of speed reduction may be attributed to non-local motorists unfamiliar with the danger of deer-vehicle collisions in the area. Investigation into the application of the warning light system on stretches of road heavily used by local residents familiar with deer migratory patterns and deer-vehicle collisions is warranted. The geophone system is more reliable than the FLASH system and should be used as a model for development of similar systems in the future.

Newhouse (2003) is currently investigating a similar system, the Wildlife Protection System (WPS), which is designed to use infrared cameras to detect wildlife on or near highways. When wildlife is detected, flashing lights are triggered, warning drivers to reduce speed and anticipate wildlife on the roadway. The objectives of this project are to: (1) determine the ability of the WPS to detect wildlife and warn motorists, (2) determine the speed response of drivers to wildlife-activated warning lights, and (3) document wildlife behavior near highways using 24-hour infrared video footage in order to develop more effective wildlife collision mitigation strategies. The results of this study are not yet published.

Rousseau et al. (2003) offers a possible explanation for the findings determined by Gordon et al. (2001). The present research investigated comprehension for several types of speed management signs including animal presence warnings involving a flashing beacon, regulatory and advisory warnings, and variable speed limit signs with text and animation. The goal of this study was to determine if people make any problematic inferences from these types of signs. There were 103 participants in this research study. Participants viewed the signs, described what the signs meant, and then completed a comprehension task in which statements about each sign were presented and participants indicated whether the statement was true of the sign. Findings indicated that: (1) many participants failed to recognize that a hazard may still exist when the beacon attached to the animal presence sign is off, (2) many people thought that an advisory speed on a warning sign is an enforceable, legal speed limit, and (3) the variable speed limit sign was understood with either a text message or with animation. Further, the lack of success in achieving desired driver behavior at these locations may be attributable to the number of “false hits” indicated by the sensing system. If drivers continue to receive the active warning in the repeated absence of the hazard (i.e., wildlife in the road), they will quickly begin to disregard the warning.

Poor Highway Geometrics

Unlike the other applications of active advance warning devices described above, poor highway geometrics present a constant rather than intermittent hazard. Certain factors such as adverse weather events and nightfall can further challenge drivers at these locations, but the underlying hazard is present at all times. Use of active advance warning devices at these locations is contrary to the recommendation provided in the *MUTCD* which states that "flashing warning beacons should be operated only during the times the hazardous condition or regulation exists." In this application, flashing warning beacons would operate continuously.

As early as 1972, Dudek and Biggs developed a safety warning system for urban freeways to warn motorists approaching crest vertical curves of stoppage waves downstream of the crest that included a flashing beacon component. Several candidate systems were proposed and evaluated. The recommended design concept was a traffic-actuated safety warning device that would be located upstream of the overpass crest and that would be activated when conditions warrant. Detectors installed on each lane and located strategically on both sides of the overpass transmit traffic information to an IBM 1800 digital computer located in the control system. The computer activates and deactivates the warning device according to pre-established criteria. Manual override features would be built into the system so that all controls could be accomplished manually if desired. Three critical overpass sites were selected for a pilot installation on the Gulf Freeway. Double-loop detectors were positioned on each lane of the inbound freeway, both upstream and downstream of the three overpasses. Each warning device was located upstream of the crest adjacent to the wingwall and consisted of a 6 foot by 12 foot sign panel containing 10-inch black letters with the message CAUTION SLOW TRAFFIC displayed on a yellow non-reflectorized panel. A 12-inch flashing beacon was attached on the right and left sides of the panel. An additional 12-inch flashing beacon was mounted at the crest on a post adjacent to the right side guardrail.

Koziol and Mengert (1978) conducted a study to evaluate the effectiveness of dynamic sign systems in alerting motorists to the presence of narrow bridges on two-lane rural highways. Vehicle speed and lateral placement data were gathered for each of the dynamic sign systems tested. Before-and-after results were taken at all sites. A roadside survey was also completed to determine the public reaction to the dynamic sign systems. Four sign systems were studied under both day and night conditions, including flashing beacons, strobe lights, and two neon message signs. Two additional sign systems involving bridge lights were examined at night only. The sign systems were activated by the presence of oncoming traffic.

Results showed no substantial differences between the existing and dynamic sign systems in terms of speed and lateral placement measures. This may have been because the measures were not sensitive to the change in drivers' behavior to the new sign. The driver may not have slowed more than he or she normally would have, but he or she may have been more aware of the narrow bridge. The survey indicated that the sign systems did improve driver awareness; however, the results did not show any important improvements. It is recommended that more sites be studied to examine whether the results were site specific.

Focusing on the effect of flashing beacons on accident frequency rather than such driver behavior as speed adjustment, Janoff and Hill (1986) conducted an analysis to determine the effect of a flashing beacon on the frequency of accidents at a dangerous high-speed rural curve. A before-and-after accident analysis was conducted using two years of "before" data and two years of "after" data. The analysis revealed a 50 percent reduction in total accidents but a 91 percent reduction in accidents of the speed/lost-control/fixed-object type – the type expected to be most directly affected by the installation of a flashing beacon. Benefit-cost ratios in excess of 50:1 were demonstrated for this flashing beacon installation, and the cost of the beacon was saved within two months by the elimination of almost all the lost-control type of accidents.

Focusing exclusively on large truck traffic, Freedman et al. (1992) conducted a study of speed-actuated rollover advisory signs equipped with flashing beacons for trucks exiting high-speed roadways. A significant reduction in the number of vehicles with speeds more than 5 mph and 10 mph faster than the calculated maximum safe speed was observed with the active advance warning signs in place, although the number of trucks in strict compliance with maximum safe speeds did not significantly increase.

Also focusing on large truck traffic, Middleton (1994) investigated two roadside warning devices, one passive and one active device. The passive device consisted of a symbolic truck tipping warning sign, and the active device consisted of flashing lights mounted one above and one below a set of passive truck tipping signs on both sides of the roadway. Speed reduction, as an indicator of accident reduction, was the ultimate goal of these tests. Speed reductions due to the active system were significant downstream of the first curve on the connector, suggesting that truck drivers reduced speeds due to the lights, but beyond the desired location. Cumulative speed distributions showed that the fastest trucks decreased their speeds by approximately 2 to 3 mph during the test period. Five of the single-vehicle truck accidents recorded on the I-610/U.S. 59 connector in an 8.5-year period were speed related, resulting in rollover. None occurred after installation of warning treatments being tested, although there were other prior years before treatment with no recorded accidents.

In summary, three of the four studies that considered the application of active advance warning devices in areas of poor highway geometrics observed positive effects. Each of the two studies that considered the use of active advance warning devices to prevent large truck accidents saw successful reductions in vehicle speeds. One of these studies reported, anecdotally, a reduction in accident frequency.

TEXAS' SAFETY IMPACT EVALUATION

To investigate the effects of AAWDs on driver behavior and safety at school bus loading and unloading zones with limited visibility, several field studies were conducted locally in Texas. Specifically, the field studies considered changes in entering vehicle speeds and brake-light actuations through the school bus loading and unloading zones. This section contains a description of each field study site and the evaluation methods used.

Study Sites and Evaluation Methods

Investigations such as this are challenged by external factors (i.e., increased enforcement presence) and the novelty of the experimental device, which may exaggerate the observed effects of the traffic control device under study. To control for these potential errors, this study was designed as a before/after, case/control experiment. Changes in motorist behavior before and after the installation of the AAWD were tempered with similar observations taken at reference or control sites that did not have these devices in place. To reduce novelty effects, the “after” effects of the AAWD were not measured immediately following installation but instead were measured approximately one month following the installation to allow drivers a chance to adjust to the new signing feature. Table 9 summarizes the experimental design followed for this investigation.

Table 9. Before/After, Case/Control Experimental Design.

Site	Conditions	Activities	
Case	Experimental AAWD placed	Before:	measure motorist responses
		After:	measure motorist responses following acclimation period
Control	No AAWD placed	Before:	measure motorist responses
		After:	measure motorist responses

The number of case and control sites considered as part of this investigation was determined largely by the number of test devices available and the ability to identify suitable characteristic sites. In general, study sites for this investigation were selected with the following characteristics in mind:

- limited visibility,
- high speed,
- rural environment,
- reasonably high traffic volumes, and
- “simple” environment, without distracting stimuli (see Figure 4).

Figure 4. Typical Field Study Site Environment.

In all, four case sites and two control sites were identified for this investigation (see Table 10).

Table 10. Study Site Description.

Site	Route	District
Case	• SH 154 N. near Marshall	Atlanta
	• SH 154 S. near Marshall	Atlanta
	• SH 21 near Caldwell	Bryan
	• FM 50 near Brenham	Bryan
Control	• FM 1774 near Plantersville	Bryan
	• FM 46 near Franklin	Bryan

For each of these sites, a number of potential traffic characteristics were considered for observation, including the following:

- the average speeds or speed profile of approaching vehicles,
- erratic maneuvers of vehicles approaching a stopped bus,
- vehicle brake-light actuations,
- the stop position behind or in front of a stopped bus, and
- the number or percent of vehicles illegally passing a stopped bus.

The most promising traffic characteristics for this investigation were identified as: (1) the average speeds and speed profile of vehicles approaching the school bus loading and unloading zone both with a bus present and without and (2) vehicle brake-light actuation approaching the school bus loading and unloading zone with a bus present. While the number of vehicles illegally passing a stopped bus was of interest, it was thought to be a relatively unlikely event given the rural, low-volume nature of the study sites, and hence it was excluded from formal study.

These traffic characteristics were observed under a variety of conditions at each of the case and control sites, including: (1) active and inactive flashing beacon status, (2) same and opposite vehicle directions of travel (as compared to the school bus direction of travel), (3) morning and afternoon periods, (4) daylight conditions, and (5) immeasurable site-specific conditions reflected in site-to-site variability. Vehicle speeds were collected using automatic traffic recorders (ATRs) located at the BUS STOP AHEAD warning sign and 500 feet upstream from the site. Video, located upstream of the warning sign, was used to capture both the point of first brake activation and any erratic vehicle maneuvers. Because of the necessary acclimation period following AAWD installation and the limits of the school year, data collection time was carefully considered in the development of the experimental plan. Data were collected at each test site over a period of approximately one month prior to installation of the devices and following the acclimation period. Table 11 summarizes the resulting sample observations under each of the conditions described above.

Table 11. Summary of Total Sample Observations.

		Flashing Beacon Activated	Flashing Beacon Not Activated	Total Sample Size
Direction of Travel	Same	171	1,901	2,072
	Opposite	129	1,062	1,191
		300	2,963	3,263
Time of Day	Morning	230	2,170	2,400
	Afternoon	70	793	863
		300	2,963	3,263
Daylight	Yes	300	2,313	2,613
	No	0	650	650
		300	2,963	3,263
Site	SH 154 N.	40	351	391
	SH 154 S.	54	364	418
	SH 21	133	1,315	1,448
	FM 50	73	509	582
	FM 1774	Control Site	261	261
	FM 46	Control Site	163	163
		300	2,963	3,263

In all, 3,263 individual vehicle records comprise the data set; 2,963 vehicles were recorded when the beacon was not flashing, and 300 vehicles were recorded when the beacon was flashing. Note that 261 and 163 vehicle records were obtained at the FM 1774 and FM 46 sites, respectively, to temper the results observed at the case sites where the AAWD was installed.

In several instances, data were available in only one of the categories of interest. For example, observations at each of the sites were available only during daylight conditions when the flashing beacon was activated (yes=300, no=0). This precludes any investigation into the impact of light levels on beacon effectiveness. This limitation existed at several individual sites as well. At the SH 21 site, the vehicles' direction is always "Same," and measurements were obtained only in the morning period. At the sites along SH 154 N. and FM 50, the vehicles' direction is always "Opposite" whether the beacon is flashing or not. This limitation precludes any investigation into the interaction effects between site and direction of travel and/or between site and time of day.

A subset of the data was further analyzed to consider the effects of school bus presence on motorist behavior through loading and unloading zones. This secondary sample contained fewer observations overall and had several missing values in the dataset. Overall, there were 74 observations recorded while a school bus was present at the bus stop; 53 were recorded when the beacon was not flashing, and 21 were recorded when the beacon was flashing. Table 12 summarizes the number of sample observations recorded at each location, reflecting the missing values.

Table 12. Number of Sample Observations with Bus Present.

Observation Location	Flashing Beacon Activated	Flashing Beacon Not Activated	Total
Total	53	21	74
Vehicle Speeds 500 Feet Upstream	42	21	63
Vehicle Speeds at the Sign	47	21	68
Brake-Light Actuation	53	20	73

Approach Vehicle Speeds

Both approach speed profiles and average vehicle approach speeds were considered as part of this investigation. Speed measurements were captured at the SCHOOL BUS STOP AHEAD sign and 500 feet upstream.

Vehicle Approach Speed Profiles

Figure 5 presents the speed profiles for vehicles approaching the school bus loading and unloading zone under activated and non-activated flashing beacon conditions. These observations also include those vehicle records that coincided with the presence of a school bus at the bus stop. A skew to the left, suggesting more low-speed measurements than high-speed measurements, would indicate that the flashing beacon, if activated, was effective in reducing vehicle approach speeds. Considering Figure 5, a left skew is somewhat apparent, though difficult to definitively discern, on speeds collected 500 feet upstream of the sign with or without the flashing beacon activated and at the bus stop without the flashing beacon activated. When the flashing beacon is activated, speeds measured at the sign are skewed slightly to the right, indicating generally higher approach speeds.

Vehicle Approach Speed Changes

To better investigate the effects of the AAWD on vehicle approach speeds, a two-sample t-test was used to confirm a decrease in average vehicle approach speeds when the flashing beacon is activated. Subsequently, because the data show some skew and may not be assumed to be normally distributed, the non-parametric Wilcoxan Rank Sum Test, which is robust in its treatment of outlying data (unusually high or low data records), was also used to further confirm any results noted. In both cases, a minimum 95 percent confidence level ($\alpha = 0.05$) was desired.

Tables 13 and 14 summarize the results of the statistical analysis for speeds recorded 500 feet upstream of and at the SCHOOL BUS STOP AHEAD sign. At 500 feet upstream, the measured difference in the average vehicle approach speeds between non-flashing and flashing conditions is only 2.02 mph; however, this speed reduction under flashing conditions was proven to be statistically significant with 99.98 percent confidence (p-value=0.0002). The Wilcoxan Test

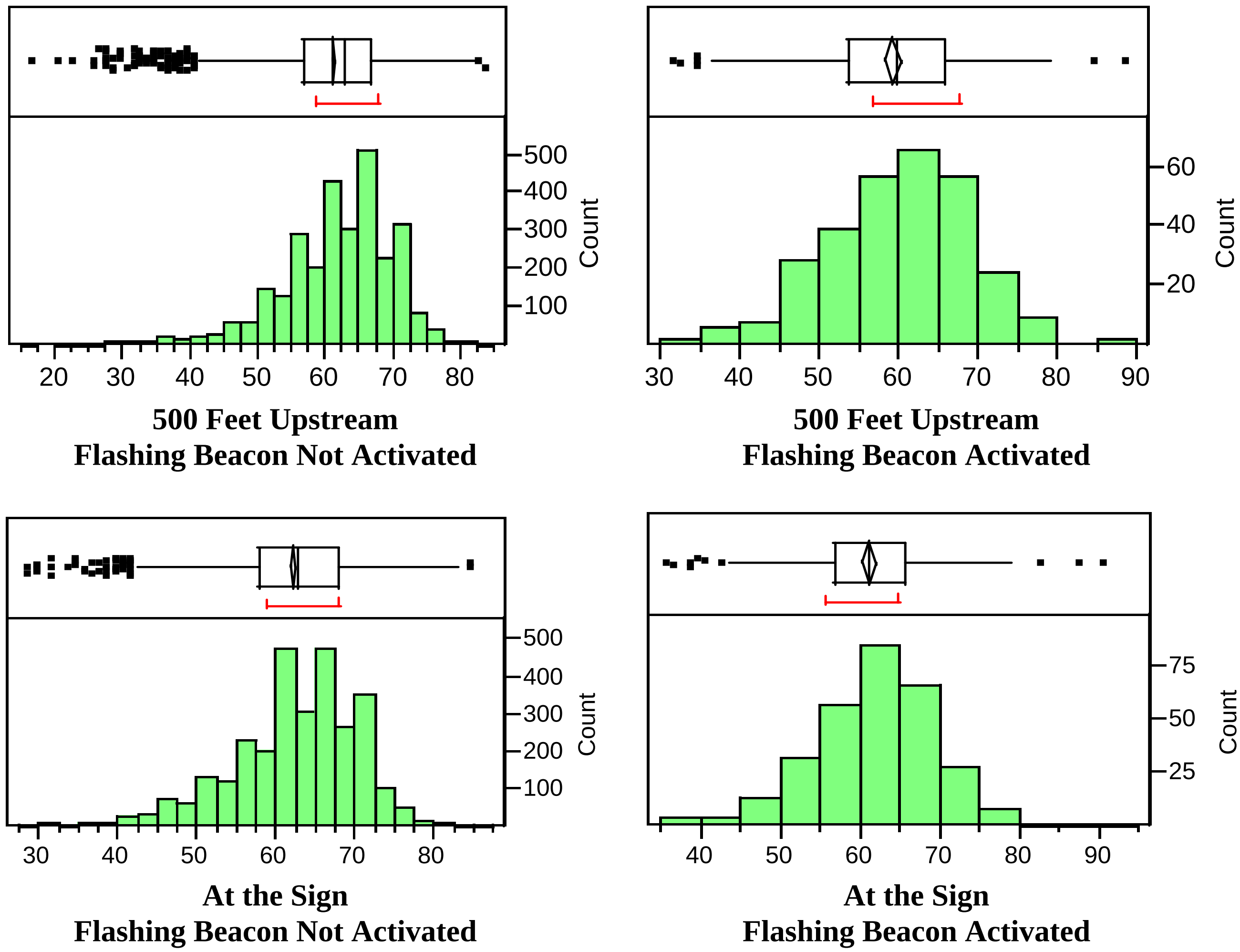

Figure 5. Approaching Vehicle Speed Profiles.

confirms these findings (p-value<0.0001/2=0.00005). Thus, it can be concluded that the average speed 500 feet upstream is lower when the beacon is flashing than when the beacon is not flashing at $\alpha = 0.05$.

Similar findings were noted for approach vehicle speeds measured at the sign. The average reduction in approach vehicle speeds was 1.00 mph when the flashing beacon was activated. This reduction was statistically significant at the 98 percent confidence level (p-value = 0.0191) using the two-sample t-test. The Wilcoxan Ranked Sum Test concurs with this finding (p-value<0.002/2=0.001) if a nonparametric distribution is assumed.

Table 13. Vehicle Approach Speed Reduction with Flashing Beacon Activation: t-test Results.

	500 Feet Upstream	At the Sign
Difference in Vehicle Speed (mph)	2.02346	0.99924
t-statistic	3.644749	2.081074
Standard Error	0.55517	0.48016
Degrees of Freedom	350.506	361.883
Upper Confidence Level	3.11535	1.94348
Lower Confidence Level	0.93158	0.05499
Desired Confidence	0.95	0.95
Probability > |t|	0.0003	0.0381
Probability > t	0.0002	0.0191
Probability < t	0.9998	0.9809

Table 14. Vehicle Approach Speed Reduction with Flashing Beacon Activation: Wilcoxan Rank Sums Results.

500 Feet Upstream				
Level	Count	Score Sum	Score Mean	$(Mean-Mean_0)/Std_0$
No	2963	4902361	1654.53	4.296
Yes	300	422855	1409.52	-4.296
At the Sign				
Level	Count	Score Sum	Score Mean	$(Mean-Mean_0)/Std_0$
No	2963	4883579	1648.19	3.088
Yes	300	441637	1472.12	-3.088

Two-Sample Test, Normal Approximation

500 Feet Upstream		
S	Z	Prob>|Z|
422855	-4.29631	<.0001
At the Sign		
S	Z	Prob>|Z|
441637	-3.08757	0.0020

Vehicle Approach Speeds by Site

To investigate whether the AAWD effects vary site to site, the two-sample t-test and Wilcoxan Rank Sum Test were conducted for individual sites. Table 15 summarizes the results. At three of the four sites, speed reductions were noted 500 feet upstream and at the SCHOOL BUS STOP AHEAD sign when the flashing beacon was activated. These speed reductions ranged from 3.18 mph observed at the SH 154 N. site to 1.18 mph observed at the SH 154 S. site. With a 95 percent confidence level, the following site-specific findings are confirmed by both the two-sample t-test and the non-parametric Wilcoxan Test:

- For sites along SH 154 N. and FM 50, the average speed of vehicles 500 feet upstream is lower when the beacon is flashing than when the beacon is not flashing. (The Wilcoxan Rank Sum Test also confirmed this effect for SH 154 S., but the two-sample t-test indicated only a 94 percent confidence level.)

- For the site along SH 154 N., the average speed of vehicles at the sign is lower when the beacon is flashing than when the beacon is not flashing. (This same effect was observed along SH 154 S. and FM 50 at the 93 percent confidence level using the two-sample t-test and at the 95 and 98 percent confidence level using the Wilcoxan Rank Sum Test.)

- For the site along SH 21, the data suggest that the average speed of vehicles is not lower when the beacon is flashing regardless of the position of speed measurements. This finding, however, is only confirmed at the 80 percent or 78 percent confidence level (using the t-test and Wilcoxan Test, respectively) for speed measurements captured 500 feet upstream and at the 98 percent and 90 percent confidence level for speed measurements captured at the sign.

The observed sample data for the site along SH 21 in fact indicate a slight increase in vehicle speeds (0.53 mph upstream of the bus stop to 1.41 mph at the bus stop) when the flashing beacon is activated as compared to when it is not.

It should be noted that the significance of the average vehicle speed difference (when the beacon is flashing and when it is not) confirmed with the two-sample t-test and the Wilcoxan Test only implies the *statistical* significance. Whether this speed reduction (or increase) is *practically* significant needs to be determined using engineering judgment.

Approach Vehicle Speeds with School Bus Present

The presence or absence of a school bus at the various field study sites has a confounding effect on the observed motorist reaction to the AAWD. If a driver observes no bus present at the loading/unloading zone, he or she may choose not to reduce his or her speed despite the active flashing beacon. On the other hand, if a bus is in fact present at the school bus stop, a driver may significantly reduce his or her speed or come to a stop. This analysis separately considers vehicle records captured when a school bus is present to further investigate these effects.

Table 15. Vehicle Approach Speed Reduction with Flashing Beacon Activation by Site.

Site	500 Feet Upstream			At the Sign		
	Vehicle Speed Difference (mph)	p-value		Vehicle Speed Difference (mph)	p-value	
	Not Flashing-Flashing	t-test	Wilcoxan Test	Not Flashing-Flashing	t-test	Wilcoxan Test
SH 154 N.	3.1759	0.0017	0.0018	2.4292	0.0070	0.0069
SH 154 S.	1.2328	0.0597	0.0485	1.1768	0.0677	0.0532
SH 21	-0.5333	0.8005	0.7755	-1.4126	0.9832	0.8991
FM 50	2.6847	0.0284	0.0034	1.8079	0.0673	0.0181

Specifically, vehicle approach speeds and brake-light actuation distances are investigated when the flashing beacon is activated and when it is not. To be deemed effective, a reduction in speed and an increase in distance should be noted when the flashing beacon is activated.

Vehicle Approach Speed Changes

A two-sample t-test was again used to confirm a decrease in average vehicle approach speeds when the flashing beacon is activated and when a school bus is present at the site. Subsequently, because the data may not be assumed to be normally distributed, the non-parametric Wilcoxan Rank Sum Test was also used to further confirm any results noted. In both cases, a minimum 95 percent confidence level (α = 0.05) was desired.

Tables 16 and 17 summarize the results of the statistical analysis for speeds recorded 500 feet upstream of and at the SCHOOL BUS STOP AHEAD sign. At 500 feet upstream, the measured difference in the average vehicle approach speeds between non-flashing and flashing conditions shows a 2.0 mph increase in speed when the flashing beacon is activated. This finding, however, is not statistically significant at the 95 percent confidence level (p-value = 0.7619). The Wilcoxan Test concurs with these findings but is again insignificant at the 95 percent confidence level (p-value=0.6145/2=0.3073). Thus, the average speed 500 feet upstream when a bus is present is not significantly lower when the beacon is flashing than when the beacon is not flashing.

Contrary findings were noted for approach vehicle speeds measured at the sign when a school bus was present. The average reduction in approach vehicle speeds was 8.62 mph when the flashing beacon was activated. This reduction was statistically significant at the 99.7 percent confidence level (p-value = 0.0033) using the two-sample t-test. The Wilcoxan Rank Sum Test concurs with this finding (p-value=0.0013/2=0.00065) if a nonparametric distribution is assumed. It can be concluded that the average speed at the school bus stop when a bus is present is lower when the flashing beacon is activated than when it is not.

Table 16. Vehicle Approach Speed Reduction with Flashing Beacon Activation and School Bus Present: t-test Results.

	500 Feet Upstream	At the Sign
Difference in Vehicle Speed (mph)	-2.0000	8.6211
t-statistic	-0.71934	2.881765
Standard Error	2.7803	2.9916
Degrees of Freedom	39.24503	35.71406
Upper Confidence Level	3.6226	14.6900
Lower Confidence Level	-7.6226	2.5522
Desired Confidence	0.95	0.95
Probability > |t|	0.4762	0.0067
Probability > t	0.7619	0.0033
Probability < t	0.2381	0.9967

Table 17. Vehicle Approach Speed Reduction with Flashing Beacon Activation and School Bus Present: Wilcoxan Rank Sum Results.

500 Feet Upstream				
Level	Count	Score Sum	Score Mean	$(Mean-Mean_0)/Std_0$
No	42	1309.5	31.1786	-0.496
Yes	21	706.5	33.6429	0.496
At the Sign				
Level	Count	Score Sum	Score Mean	$(Mean-Mean_0)/Std_0$
No	47	1864	39.6596	3.216
Yes	21	482	22.9524	-3.216

Two-Sample Test, Normal Approximation

500 Feet Upstream		
S	Z	Prob>|Z|
0.2536	1	0.6145
At the Sign		
S	Z	Prob>|Z|
482	-3.21604	0.0013

Vehicle Approach Speeds by Site

To investigate whether the AAWD effects when a school bus is present vary site to site, the two-sample t-test and Wilcoxan Rank Sum Test were again conducted for individual sites. The only significant finding worth note was observed along SH 21 (see Tables 18 and 19). The average reduction in approach vehicle speeds at the bus stop was 15.08 mph when the flashing beacon was activated and a school bus was present. This reduction was statistically significant at the 99.9 percent confidence level (p-value = 0.0000) using the two-sample t-test. The Wilcoxan Rank Sum Test concurs with this finding (p-value=0.0306/2=0.0153) if a nonparametric distribution is assumed. It can be concluded that the average speed at the school bus stop along SH 21 when a bus is present is lower when the flashing beacon is activated than when it is not.

Table 18. Vehicle Approach Speed Reduction with Flashing Beacon Activation and School Bus Present along SH 21: t-test Results.

	At the Sign
Difference in Vehicle Speed (mph)	15.0769
t-statistic	5.324266
Standard Error	2.8317
Degrees of Freedom	11.87253
Upper Confidence Level	21.2541
Lower Confidence Level	8.8997
Desired Confidence	0.95
Probability > |t|	0.0002
Probability > t	<.0001
Probability < t	0.9999

Table 19. Vehicle Approach Speed Reduction with Flashing Beacon Activation and School Bus Present along SH 21: Wilcoxan Rank Sums Results.

At the Sign				
Level	Count	Score Sum	Score Mean	$(Mean-Mean_0)/Std_0$
No	13	127	9.76923	2.162
Yes	3	9	3.00000	-2.162

Two-Sample Test, Normal Approximation

At the Sign		
S	Z	Prob>|Z|
9	-2.16211	0.0306

Vehicle Approach Speeds Considering Confounding Factors

To investigate the impact of confounding factors on the effectiveness of the AAWD, an analysis of variance (ANOVA) was conducted to determine whether observed changes in approach vehicle speeds varied across different categorical conditions, including flashing beacon activation, direction of travel, time of day, site, daytime or nighttime conditions, and the presence of a school bus requiring a vehicle to stop.

Concurrent with findings previously noted, a reduction in vehicle approach speeds measured 500 feet upstream of the AAWD could not be statistically confirmed (at a 95 percent confidence level) as attributable to the activation of the flashing beacon. Further, this insignificance of effect was noted across all of the other confounding factors; no significant change in vehicle approach speed was noted across any of the confounding factor categories (see Tables 20 and 21). Because of potential dependencies between confounding variables (i.e., time of day and daytime are not independent), further analysis considered reduced combinations of confounding effects to see how the significance of the remaining variables may change. In no case were any of the variables, including the activation state of the flashing beacon, found to be significant in affecting vehicle approach speeds 500 feet upstream of the sign.

Table 20. Analysis of Variance for Speeds 500 Feet Upstream.

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	10	1335.2091	133.521	1.3427
Error	31	3082.6957	99.442	Prob > F
C. Total	41	4417.9048		0.2523

Table 21. Effect Tests for Speeds 500 Feet Upstream.

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Beacon Flashing	1	1	207.10113	2.0826	0.1590
Direction	1	1	339.76862	3.4168	0.0741
Time	1	1	20.74981	0.2087	0.6510
Site	5	5	972.49527	1.9559	0.1133
Brightness	1	1	298.39491	3.0007	0.0932
Stopped	1	1	5.82957	0.0586	0.8103

When investigating the effects of confounding factors on vehicle approach speeds measured at the SCHOOL BUS STOP AHEAD sign, initial results indicated that direction of travel was the only significant factor in affecting vehicle approach speeds (see Tables 22 and 23). Again, because of the dependence among the variables under investigation, various reduced sets of variables were considered using a process of backward elimination; insignificant variable (p-values>0.05) were deleted one by one from the ANOVA, and the analysis was repeated. When each of the insignificant variables was removed and the interdependencies among confounding factors eliminated, findings suggest that the activation state of the flashing beacon and the time of day both have a significant effect (at the 95 percent confidence level) on vehicle approach speeds measured at the SCHOOL BUS STOP AHEAD sign (see Tables 24 and 25).

Table 22. Analysis of Variance for Speeds at the Sign – All Variables.

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	10	2086.9624	208.696	2.6880
Error	36	2795.0376	77.640	Prob > F
C. Total	46	4882.0000		0.0144

Table 23. Effect Tests for Speeds at the Sign – All Variables.

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Beacon Flashing	1	1	160.31797	2.0649	0.1594
Direction	1	1	412.11424	5.3080	0.0271
Time Period	1	1	232.44220	2.9938	0.0921
Site	5	5	639.59737	1.6476	0.1725
Brightness	1	1	38.42904	0.4950	0.4862
Stopped	1	1	183.55633	2.3642	0.1329

Table 24. Analysis of Variance for Speed at the Sign - Reduced.

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	1576.3192	788.160	6.8041
Error	65	7529.3720	115.836	Prob > F
C. Total	67	9105.6912		0.0021

Table 25. Effect Tests for Speeds at the Sign - Reduced.

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Beacon Flashing	1	1	1072.2963	9.2570	0.0034
Time	1	1	497.5439	4.2952	0.0422

Brake-Light Actuation with School Bus Present

Comparisons of the average brake-light actuation distance upstream from the AAWD were made when the flashing beacon was activated and when it was not, to determine the effects. Table 26 contains the results of the t-test, showing that the difference in the sample average brake-light actuation distances when the beacon is not flashing and when it is activated is 6.77 feet, but this difference is not statistically significant at the 95 percent confidence (p-value = 0.5246). The Wilcoxan rank-based nonparametric test agrees with the parametric t-test and shows no significant difference (p-value=0.3621/2=0.1811) in brake-light actuation distance (see Table 27). Thus, it can be concluded that the average brake-light actuation distance when a school bus is present and when the flashing beacon is activated is not significantly different (longer) than when the beacon is not activated.

Brake-Light Actuation Distance by Site

Brake-light actuation distances were also considered by individual site to determine if site-specific characteristics had any impact on the observed effectiveness of flashing beacons in increasing the brake-light actuation distance (upstream of the school bus loading and unloading zone). The only significant (p-value=0.0401) effect observed was along FM 50 where average braking distances increased by 340.56 feet when the flashing beacon was activated compared to when it was not (see Table 28).

Table 26. Brake-Light Actuation Distance with Flashing Beacon Activation and School Bus Present: t-test Results.

	At the Sign
Difference in Vehicle Speed (mph)	6.77
t-statistic	0.062479
Standard Error	108.34
Degrees of Freedom	22.94011
Upper Confidence Level	230.92
Lower Confidence Level	-217.38
Desired Confidence	0.95
Probability > |t|	0.9507
Probability > t	0.4754
Probability < t	0.5246

Table 27. Brake-Light Actuation Distance with Flashing Beacon Activation and School Bus Present: Wilcoxan Rank Sums Results.

At the Sign				
Level	Count	Score Sum	Score Mean	$(Mean-Mean_0)/Std_0$
No	53	2035	38.3962	0.911
Yes	20	666	33.3000	-0.911

Two-Sample Test, Normal Approximation

At the Sign		
S	Z	Prob>|Z|
666	-0.91139	0.3621

Table 28. Brake-Light Actuation Distance with Flashing Beacon Activation and School Bus Present by Site (Site FM 50): t-test Results.

	At the Sign
Difference in Vehicle Speed (mph)	-340.56
t-statistic	-1.9119
Standard Error	178.12
Degrees of Freedom	11.93532
Upper Confidence Level	47.78
Lower Confidence Level	-728.89
Desired Confidence	0.95
Probability > |t|	0.0802
Probability > t	0.9599
Probability < t	0.0401

For the other three sites, no significant effect on brake-light actuation distance was observed.

Brake-Light Actuation Distance Considering Confounding Factors

Concurrently while exploring the main effect or flashing beacon activation on braking distance, an analysis of variance was conducted to investigate the effects of potentially confounding factors. Specifically, this secondary analysis considered the effects of direction of travel, time of day, site, daylight, and whether a vehicle came to a complete stop in conjunction with the activation status of the flashing beacon. Considering all factors in combination, no statistically significant difference in brake-light actuation distance was observed across any of the categories, including activation of the flashing beacon. Additional ANOVAs were conducted with different two-way interaction effects, but again the results for flashing beacon activation were insignificant at the 95 percent confidence level. Hence, it can be concluded again that the average brake-light actuation distance when a bus is present and when the beacon is flashing is not significantly longer than the average brake-light actuation distance when the beacon is not flashing.

Summary of Findings

The pertinent findings from Texas' safety impact evaluation can be summarized as follows:

- Though difficult to discern graphically, vehicle approach speed profiles suggest higher speeds when the flashing beacon is activated. Measured at both the SCHOOL BUS STOP AHEAD sign and 500 feet upstream of the sign, measurements taken when the flashing beacon was activated show a slight skew to the right, suggesting more high-speed measurements. Measurements taken when the flashing beacon was inactive show a slight skew to the left, suggesting more low-speed measurements.

- When considering changes in average vehicle approach speeds measured at both the SCHOOL BUS STOP AHEAD sign and 500 feet upstream of the sign, a statistically significant reduction in average approach speeds was observed (1.0 mph and 2.02 mph, respectively) when the flashing beacon was activated.

- Three out of four sites experienced statistically significant speed reductions ranging from 1.18 mph to 3.18 mph when the flashing beacon was activated. The fourth site (SH 21) showed a statistically significant increase in average approach speed of 1.41 mph measured at the SCHOOL BUS STOP AHEAD sign when the flashing beacon was activated; no significant difference in approach speed was observed 500 feet upstream of the AAWD when the flashing beacon was activated and when it was not.

- When a school bus was present at the loading and unloading zone, a statistically significant reduction in vehicle approach speeds was observed (8.62 mph) at the SCHOOL BUS STOP AHEAD sign when the flashing beacon was activated. This increased magnitude of speed reduction suggests that motorists are responsive to vehicle-based warning devices in addition to roadside warning devices. Upstream of the SCHOOL BUS STOP AHEAD sign, no significant reduction in speed was noted with the flashing beacon activated.

- One out of four sites (SH 21) experienced a statistically significant reduction in average approach speeds (15.08 mph) measured at the SCHOOL BUS STOP AHEAD sign with a bus present at the loading and unloading zone and with the flashing beacon activated. No significant difference in approach speed was observed 500 feet upstream of the AAWD at SH 21 or at any measurement location at each of the other three sites when the flashing beacon was activated and when it was not.

- When considering all sites in combination, no significant increase in brake-light actuation distance occurred (measured at the SCHOOL BUS STOP AHEAD sign) when the flashing beacon was activated.

- At one out of four sites (FM 50), the average brake-light actuation distance was significantly longer when the beacon was flashing than when it was not.

CHAPTER 4: SYSTEM GUIDELINES AND SPECIFICATIONS

The successful development and application of an active advance warning device that provides enhanced conspicuity to conventional SCHOOL BUS STOP AHEAD signing (S3-1) will better alert drivers to the presence of school buses in areas of limited visibility and potentially enhance the safety of both pedestrian children and vehicle occupants. To facilitate implementation of such a device, three products were developed during this project that directly support the implementation of AAWD for school bus loading and unloading zones in areas with limited visibility. These include the following:

(1) Draft Specifications: draft specification language will allow TxDOT to specify the characteristics of the AAWD and its recommended use in the field;

(2) Draft Design and Detail Drawings: MicroStation CAD design and detail drawings will allow TxDOT to quickly incorporate the AAWD into roadway and maintenance plans; and

(3) Draft Language for the *TxDOT Operations Manual* and the *TMUTCD*: draft language regarding the AAWD specifications and use will allow TxDOT to incorporate the findings of the study directly into their operational procedures and the *Texas Manual on Uniform Traffic Control Devices.*

Each of these products are included within this chapter.

DRAFT SYSTEM SPECIFICATIONS

Texas Department of Transportation Departmental Materials Specification Guide

The following language is recommended for the Texas Department of Transportation *Departmental Material Specification* guide:

DMS-11XXX, Advance School Bus Stop Warning Controller Assembly

Overview

Effective Date: August 2004

This specification governs for the materials, composition, quality, sampling, and testing of a school bust stop advance warning flasher controller assembly that includes a solar generator, photovoltaic modules, batteries, signal beacons, cabinet, flasher, wireless transmitter, wireless receiver, timer, and other cabinet accessory equipment except pole and sign.

Bidders' and Suppliers' Requirements

To be accepted on bids, materials must have approved product codes or designations and be from pre-qualified producers. TxDOT's Construction Division (CST) maintains the material producers list (http://www.dot.state.tx.us/business/materialproducerlist.htm) of approved producer product codes or designations.

Procurement and Payment

Procurement by the Department

Payment for materials under this specification will be in accordance with the conditions prescribed in the Contract awarded by the Department.

Contracts

Payment for materials governed by this specification used in contract projects will be in accordance with Item 685 MOD, "Advance School Bus Stop Warning Beacon," of the TxDOT Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges.

Prequalification

For prequalification, submit 1 school bus advance warning flasher controller assembly to the Department.

Make submission to:

Texas Department of Transportation
TRF-Signal Operations Section
118 Riverside Dr.
Austin TX 78704

TRF tests samples for specification compliance and updates the list to include materials that meet specification requirements. If materials fail to meet any of the specification requirements, the producer may not resubmit for prequalification until 1 yr. from original evaluation date. TRF may waive this time limit if provided with documentation from an independent testing facility stating that materials meet all requirements. TRF will enforce the 1-yr. time limit if, after retesting, the material again fails any of the specification requirements.

All materials submitted for prequalification tests will be at no cost to TxDOT.

Sampling and Testing

Advance school bus warning controller assemblies must meet or exceed all applicable TMUTCD, *ITE Standards, and these specifications. In addition to testing of pre-shipment* *samples, complete testing of school bus advance warning flasher assemblies may be required at any time prior to acceptance.*

The Department will sample and test in accordance with Tex-1170-T.

Specific tests are normally indicated in conjunction with specific specification requirements. However, the Department reserves the right to conduct whatever tests are deemed necessary to identify component materials and verify results of specific tests indicated in conjunction with specification requirements.

Sampling and testing costs are normally borne by the Department; however, the Contractor or supplier will bear the costs for sampling and testing of failing materials. This cost will be assessed at the rate established by the Director of TRF and in effect at the time of testing. Amounts due the Department will be deducted from monthly or final estimates on contracts or from partial or final payments on direct purchases by the Department.

Warranty

All equipment must have no less than 95% of the manufacturer's standard warranty remaining on the date that the Contractor submits equipment invoices for payment. The Department will not accept any equipment with less than 95% of its warranty remaining.

Provide warranties in accordance with the following table, "Required Warranties":

Required Warranties

Item	***Warranty Type and Period***
Photovoltaic modules	*limited 12 yr.*
Signal beacons	*limited 5 yr.*
Batteries	*prorated 5 yr.*
Wireless transmitter and receiver	*3 yr.*
All other equipment	*3 yr.*

Material Requirements

Solar Generator

Size the system solar generator to provide an array-to-load ratio of 1:1 or greater. Provide a system-average state of charge 90% or greater throughout the entire year. The system-loss-of-load probability must remain 0% throughout the entire year. Design and make available the system in the following configuration: advance-warning assembly with two 12-inch signal beacons.

The specific configuration will be shown in the Contract. Provide a system-sizing report detailing the photovoltaic array, battery bank, array-to-load ratio analysis, system *availability analysis, battery state-of-charge report, battery depth of discharge (DOD), and monthly installation information for that specified region.*

Photovoltaic Modules

The photovoltaic PV module must provide 12 V DC and be capable of recharging the system to full capacity after 6 hr. of continuous operation and in 3 hr. ± 0.5 hr. during optimum sun conditions. Supply industrial-grade, polycrystalline-type solar modules. Consumer grade modules are not acceptable. Solar modules must have a power output rating of ± 5% or better. Ensure PV modules are available to the Department in a graduated product line from 40 to 120 W per module. Each solar module, regardless of wattage, must share common mounting holes for mounting so that a single mounting structure will accommodate the entire module line. Incorporate a 6-inch square polycrystalline cell and at least 2 bypass diodes installed at the factory into each solar module. Construct PV module with a low-iron tempered glass surface and an industrial grade anodized aluminum frame that completely surrounds and seals the module laminate. Ensure construction is consistent with the demands of installation near humid salt air environments. Provide an ultraviolet (UV) resistant, weatherproof junction box providing wire termination for up to No. 8 AWG wiring with the PV module.

Design and construct the photovoltaic module mounting assembly of galvanized steel (ASTM A-153 Class A) or aluminum. The mounting assembly must provide a means of securely attaching the PV module frame to a pole ranging from a minimum 4-1/2 inch outside diameter steel or aluminum pole to a wood pole at a permanent angle of 45° to 50°. Provide at least four 3/4-inch stainless steel bolts, lock washers, and hex head nuts with the mounting assembly to secure the PV module to the frame. Provide a mounting assembly capable of 360° horizontal orientation with a means of locking the bracket at an inscribed angular position about the pole.

The photovoltaic harness must not exceed 2% total voltage drop between the solar module and the charge control circuit.

Battery

Provide group-27 gel batteries specified in the system sizing report. Use valve-regulated, gelled-electrolyte batteries rated for a minimum of 2000 cycles with 10% capacity withdraw. Provide 12 V DC batteries. Use lead-calcium for the plate alloy. Use a T881-type terminal element post designed for 1/4-inch bolt termination. Use a polypropylene container or cover. The gelled electrolyte must contain sulfuric acid, fumed silica, pure demineralized and deionized water, and a phosphoric-acid additive. Provide a spill-proof gel cell battery to allow installation in any position. Size the batteries to allow 12 days autonomy. Depth of discharge (DOD) for the system must not exceed 80%.

Signal Beacons

Supply 12-inch light-emitting-diode (LED) signal beacons (signal heads and LED unit) and mounting hardware. Use TxDOT pre-qualified LED lamps. The color of the indications will be shown in the Contract.

The solid-state amber 12-inch LED signal lamp must be easily retrofitted into standard polycarbonate signal closures using the existing lens gasket. Use AllnGap technology LEDs in the LED unit. Use LEDs that conform to the chromaticity limits outlined in the Vehicle Traffic Control Signal Heads - Part 2: Light Emitting Diode (LED) Vehicle Traffic Control Signal Modules, Section 4.2, Photometric Requirements, Chromaticity. The power rating of any beacon must not exceed 35 W maximum. Provide a self-regulating beacon with input voltages of 10.5 to 35 V DC. Supply either a clear or a tinted UV-stabilized acrylic in the lamp lens. Indicate the "top" mount position on the lamp. Provide a 24-inch, color-coded wiring harness (red for positive and black for negative) in the beacon. Provide strain relief on the wiring harness.

Supply signal beacons in an optical system that conforms to the ITE Standards for Flashing Beacons, Section 4-E-5, "General Design and Operations of Beacons," and to the TMUTCD *for all operating voltages above the manufacturers designed cut-off voltage.*

Cabinet

Provide a cast-aluminum alloy or aluminum cabinet with a minimum thickness of 1/8 inch. Size the cabinet to provide adequate space for the control electronics, required number of batteries, or both. Install rubber mats in the bottom of the cabinet.

Provide a gasket between the door and cabinet. Supply a stainless-steel, aluminum, or other non-rusting alloy door hinge with a stainless-steel hinge pin. Spot weld the hinge pin at the top of the hinge.

Weatherproof the cabinet to prevent the entry of water. Seal unwelded seams with a clear or aluminum-colored weather-seal compound.

Provide vent openings in the cabinet to allow adequate convection cooling of the electronic components and prevention of accumulation of gasses. Design and locate vents to prevent the entry of water. Screen the vents to minimize the infiltration of dust and insects. Screen material must have openings no larger than 0.0125 sq. inch.

Provide a police lock with a metal keyhole cover as an integral part of each door. Provide 1 brass key with each cabinet.

Provide tamper-resistant exposed hardware including screws, bolts, rivets, hubs, etc.

Provide two ¾-inch stainless steel brackets for strap-type mounting on a wood or metal pole. Ship cabinets with the brackets mounted to the back of the cabinet.

Cabinet Accessory Equipment

Mount a back panel on the inside of the cabinet. Mount wiring and accessory equipment, including a flasher, on the back panel.

Equip the cabinet with an 8-section-barrier terminal block with double 8-32 by 5/16 inch binder head screw terminals or larger. Wire and label the terminals as follows:

- *Solar Power +*
- *Solar Power - / Battery -*
- *Battery +*
- *Switch Common*
- *Switch N/O*
- *Output Circuit 1*
- *Output Circuit 2*
- *Output Common*

Provide an on-board, solid-state charge-control circuit to ensure proper charging on the system battery bank. Incorporate a blocking diode for reverse-current protection of the charging circuit. Incorporate thermal compensation in the charge-control circuit to adjust the battery charge rate to variances in temperature with an adjustable voltage swing above and below the ambient set point as defined by the battery manufacturer. Use a battery float voltage calibration as defined by the battery manufacturer for voltages at 25°C. Provide an LED or LCD to indicate solar-panel charging.

The back panel must provide for mounting of a solid-state time clock with maximum overall outside housing dimensions of 10.25 inches high by 6.25 inches wide by 7.5 inches deep. Configure the mounting holes as an inverted "T." Place the top hole 3 inches ± 0.05 inch from the top of the cabinet and 5.75 inches ± 0.05 inch above a horizontal line connecting the centers of the 2 bottom holes. Place the bottom 2 holes 2.3125 inches ± 0.05 inch apart from center to center. Position the top hole so that a vertical line through its center bisects the horizontal line. Drill and tap each screw hole for an 8-32 screw.

Provide a user-adjustable low-voltage-disconnect (LVD) circuit in the controller. This circuit must disconnect the battery bank when the battery voltage reaches a voltage deemed critical by the manufacturer of the battery. Provide an LED indication for the LVD circuit. Illuminate the LED when the LVD circuit is active.

The controller must incorporate automatic night dimming. Calibrate the night-dim level to reduce the power of the LED lamp by a maximum of 75% where ambient light levels are 5 foot-candles or less.

Supply a color-coded harness. Use stranded No. 16 AWG wire as a minimum. Use connectors to terminate the harness wiring to components mounted to the pedestal pole, photovoltaic module, and signal beacons. Supply male connectors with each harness. Terminate female connectors for ease of installation. Use 3/8-inch diameter, round-crimp battery terminals. Use spade terminals for flasher termination and regulator-charger terminations. Use chassis tie-downs on the harness and rivet them to the harness bracket. Protect the wires in the harness with spiral tubing. Provide a total voltage drop no greater than 5% of any branch of the harness.

Initiate and terminate the flashing operation of the unit by toggle switch.

Supply a 2-circuit, solid-state flasher. Use a solid-state design with no electro-mechanical devices for the 2-circuit flasher. Construct the flasher for easy replacement of each component.

The 2-circuit, solid-state flasher must operate at 12 V DC. The 2-circuit, solid-state flasher must provide a flash rate in accordance with TMUTCD *standards.*

Wireless Receiver and Transmitter

Supply a wireless spread spectrum transmitter and receiver pair that have the minimum operating characteristics given in the following table, "Transmitter and Receiver Specifications."

Transmitter and Receiver Specifications

Specifications	
Frequency range	*902-928 MHz*
Output power	*1mW, 10mW, 100mW, 1000mW*
Input power	*6-30 VDC*
Power consumption	*<100mA standby* *<125mA at 100mW transmission*
Operating environment	*-40º C to +80º C (-40ºF to 176ºF)*
Humidity	*95% non-condensing*
Enclosure type	*Milled aluminum, BK powder coat*
FCC approval	*No license requirements, acceptance under FCC 15.247*
Interface	
Programming port	*RJ12*
Open collector outputs	*Max 30 volts, 500mA per output*
I/O connector type	*Quick release terminal block*
Indicators	
I/O activity	*Yes*

Timer

Supply a pin-type 12 volt DC timer operating in control signal mode specifications given in the following table, "Timer General Specifications."

Timer General Specifications

Specifications		
Operating system	*Solid-state CMOS circuit*	
Operation type	*Multi-mode*	
Time range	*0.1 sec. to 600 hr.*	
Input off voltage	*Rate voltage x 10% minimum*	
Rated operational voltage	*12V DC*	
Voltage tolerance	*10.8-13.2V DC*	
Ambient operating temperature	*-20º C to +65º C (-4ºF to 149ºF) (without freezing)*	
Relative humidity	*35 to 85% RH (without condensation)*	
Reset time	*100 msec maximum*	
Repeat error	*±0.2%, ±20msec**	
Voltage error	*±0.2%, ±20msec**	
Temperature error	*±0.2%, ±20msec**	
Setting error	*±10%, maximum*	
Insulation resistance	*100M Ohm minimum (500V DC)*	
Dielectric strength	*Between power and output terminals*	*2000V AC, 1 minute*
	Between contacts of different poles	*2000V AC, 1 minute*
	Between contacts of same pole	*1000V AC, 1 minute*
Vibration resistance	*10 to 55 Hz amplitude 0.5mm* *2 hours in each of 3 axes*	
Shock resistance	*Operating extremes: 98m/sec^2 (10G)* *Damage limits: 490m/sec^2 (50G)* *3 times in each of 3 axes*	
Power consumption	*1.6 W*	

** For the value of the error against a preset time, whichever the largest applies*

Documentation Requirements

Supply 2 copies of the following documentation with each school bus stop advance warning flasher assembly:

- *complete and accurate schematic diagram*
- *complete parts list, including names of vendors for parts not identified by universal part numbers such as JEDEC, RETMA, or EIA*
- *full report on system analysis, including all manufacturer's supporting documentation*
- *complete users' manual for the system*

Texas Department of Transportation Standard Specifications

The following language is recommended for the Texas Department of Transportation *Standard Specification* guide related to roadside flashing beacon assemblies:

STANDARD SPECIFICATIONS: ITEM 685 Mod
Advance School Bus Stop Warning Flashing Beacon

685.1. Description*. This specification governs the installation, relocation, and removal of an advance school bus warning flashing beacon system.*

685.2. Materials*. Furnish new materials in accordance with the following Items and with details as show on the plans:*

- *Item 441, "Steel Structures"*
- *Item 442, "Metal for Structures"*
- *Item 445, "Galvanizing"*
- *Item 449, "Anchor Bolts"*
- *Item 656, "Foundations for Traffic Control Devices"*

685.3. Equipment*. Provide solar-powered flasher controller assemblies in accordance with DMS-11XXX, "Advance School Bus Stop Warning Controller Assembly."*

Provide flasher assemblies from manufacturers prequalified by the Department. The Traffic Operations Division maintains a list of prequalified flasher assembly manufacturers.

Provide pedestal pole bases in accordance with FMS-11140, "Pedestal Pole Base."

Provide pedestal pole bases from manufacturers prequalified by the Department. The Traffic Operations Division maintains a list of prequalified pedestal pole base manufacturers.

Provide pedestal pole bases in accordance with FMS-11140, "Pedestal Pole Base."

Provide pedestal pole bases from manufacturers prequalified by the Department. The Traffic Operations Division maintains a list of prequalified pedestal pole base manufacturers.

Provide shop drawings for the complete assembly. Refer to the appropriate ASTM or Aluminum Association designation for all materials shown in submittals. Use the fabricator's model number to identify the base in all tests, drawings, documentation, and other references.

685.4. Construction

***A. Fabrication**. Provide poles and bases in accordance with Item 687, "Pedestal Pole Assemblies." Provide mild steel anchor bolts in accordance with Item 449, "Anchor Bolts." Use galvanized bolts, nuts, and washers.*

***B. Galvanizing**. Galvanize all fabricated parts in accordance with Item 445, "Galvanizing." Repair galvanizing for any steel part or member damaged in assembly, transit, or erection, or for any steel part or member welded after galvanizing, in accordance with Item 445.3.D, "Repairs."*

***C. Installation**. Install roadside flashing beacon assemblies at the locations show on the plans or as directed. Unless otherwise shown on the plans, stake the assembly locations for verification by the Engineer.*

Install pole, breakaway base, connectors, wiring, signal beacons, signs, and foundation as shown on the plans or as directed. Install the flasher controller assembly on the electrical service pole. Install watertight breakaway electrical fuse holders in all line and neutral conductors at the breakaway base.

Use established industry and utility safety practices to erect assemblies near overhead or underground utilities. Consult with the appropriate utility company prior to beginning such work

***D. Relocation**. Disconnect and isolate the electrical power supply prior to removal of the assembly. Remove existing assembly as directed. Unless otherwise directed, salvage existing components such as sign, beacons, pole, and base. Repair or replace lost or damaged components as directed.*

Relocate existing assembly to the location shown on the plans or as directed. Install existing assembly at new foundation in accordance with Section 685.3.C, "Installation." Remove existing foundations in accordance with Section 685.3.E, "Removal." Accept ownership of unsalvageable materials and dispose of in accordance with federal, state, and local regulations.

***E. Removal**. Disconnect and isolate existing electrical power supplies prior to removal of the assembly. Remove existing sign panel, beacons, pole, and base from existing assembly. Store items to be reused or salvaged without damaging. Store sign panels above the ground in vertical position at locations shown on the plans or as directed. Accept ownership of unsalvageable materials and dispose of in accordance with federal, state, and local regulations.*

Unless otherwise shown on plans, remove abandoned foundation, including steel, to 2 ft. below the finished grade. Backfill with material equal in composition and density to the *surrounding area, and replace any surfacing, such as asphalt pavement or concrete riprap, with like material to equivalent condition.*

***F. Upgrade**. Remove existing sign panel, pole, and base from existing assembly. Store items to be reused or salvaged without damaging. Store sign panels above the ground in a vertical position at locations shown on the plans or as directed. Accept ownership of unsalvageable materials and dispose of in accordance with federal, state, and local regulations.*

Unless otherwise shown on plans, remove abandoned foundations in accordance with Section 685.3.E, "Removal." Install new or salvaged pole, breakaway base, connectors, wiring, signal beacons, signs, and foundation in accordance with Section 685.3.C, "Installation."

***685.5. Measurement** This Item will be measured by each installed, relocated, or removed advance warning flashing beacon assembly.*

***685.6. Payment**. The work performed and the materials furnished in accordance with the Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Install Advance School Bus Stop Warning Flashing Beacon Assemblies," "Relocate Advance School Bus Stop Warning Flashing Beacon Assemblies," "Remove Advance School Bus Stop Warning Flashing Beacon Assemblies," or "Upgrade School Bus Stop Ahead Sign."*

***A. Installation**. This price is full compensation for furnishing, fabricating, galvanizing, assembling, and erecting the advance warning flashing beacon assemblies; foundations; furnishing and placing anchor bolts, nuts, washers, and templates; controller; and equipment, materials, labor, tools, and incidentals.*

***B. Relocation.** This price is full compensation for removing the advance warning flashing beacon assemblies; removing existing foundations; installing new foundations; furnishing, fabricating, and installing any new components as required and replacing the assembly on its new foundations with all manipulations and electrical work; controller; salvaging; disposal of unsalvageable material; loading and hauling; and equipment, material, labor, tools, and incidentals.*

***C. Removal**. This price is full compensation for removing the various advance warning flashing beacon assemblies components; removing the foundations; storing the components to be reused or salvaged; disposal of unsalvageable material; backfilling and surface placement; loading and hauling; and equipment, materials, tools, labor, and incidentals.*

***D. Upgrade**. This price is full compensation for removing existing foundations; installing new foundations; furnishing, fabricating, and installing any new components as required and placing the assembly on its new foundations with all manipulations and electrical work; controller; salvaging; disposal of unsalvageable material; loading and hauling; and equipment, material, labor, tools, and incidentals.*

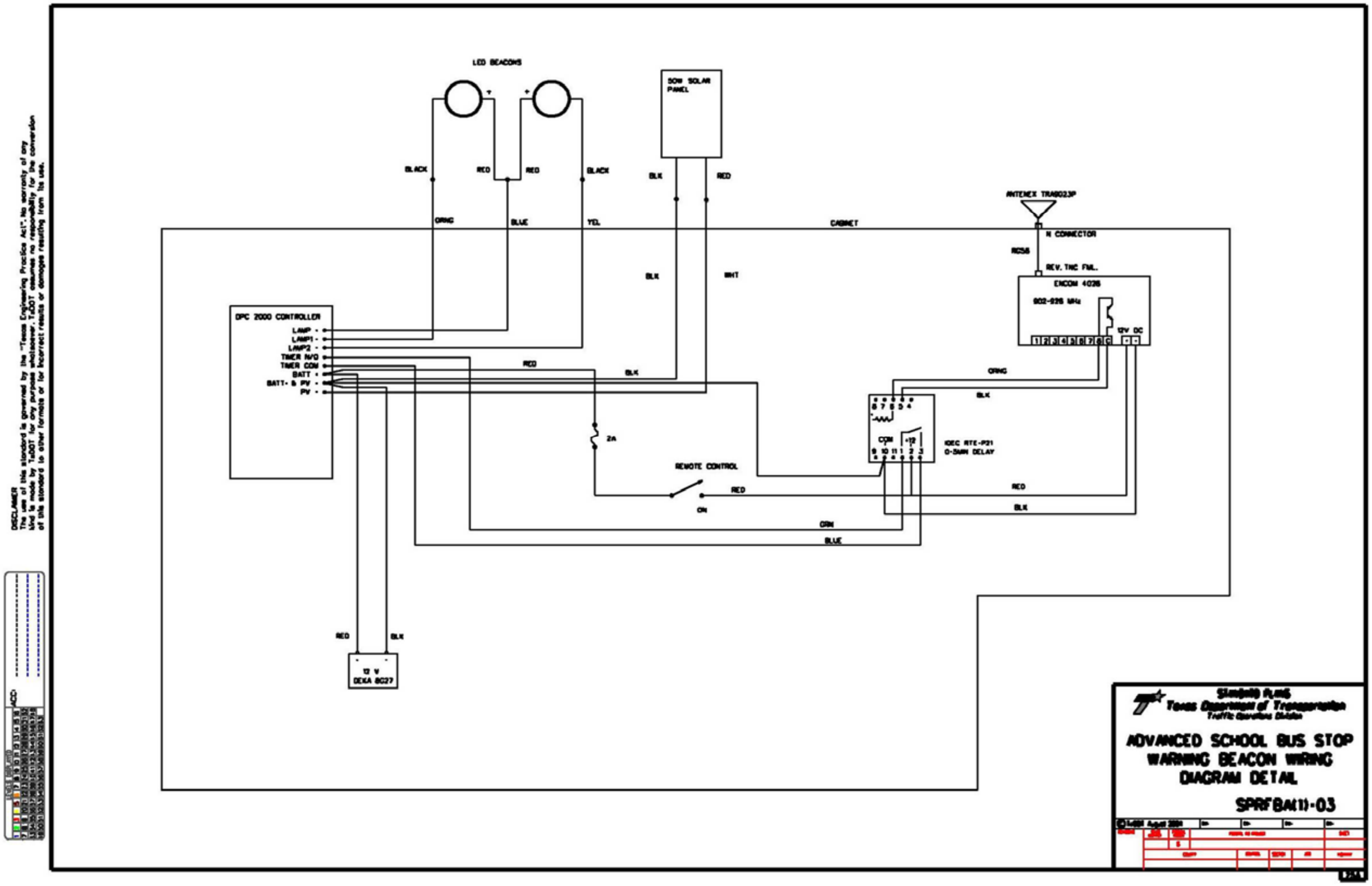

Figure 6. Active Advance Warning Device Wiring Diagram Detail – System Overview.

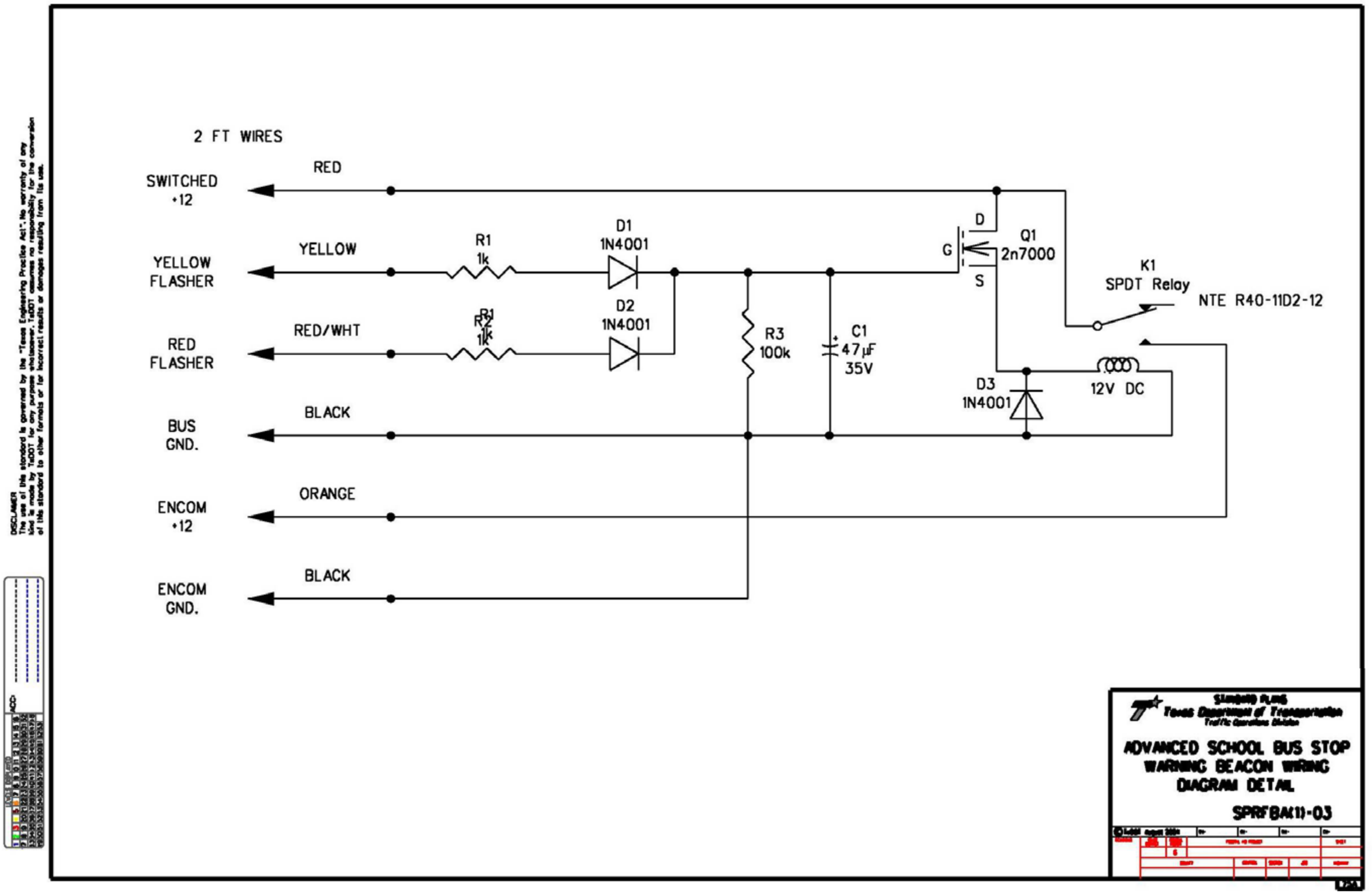

Figure 7. Active Advance Warning Device Wiring Diagram Detail – Wire Connections.

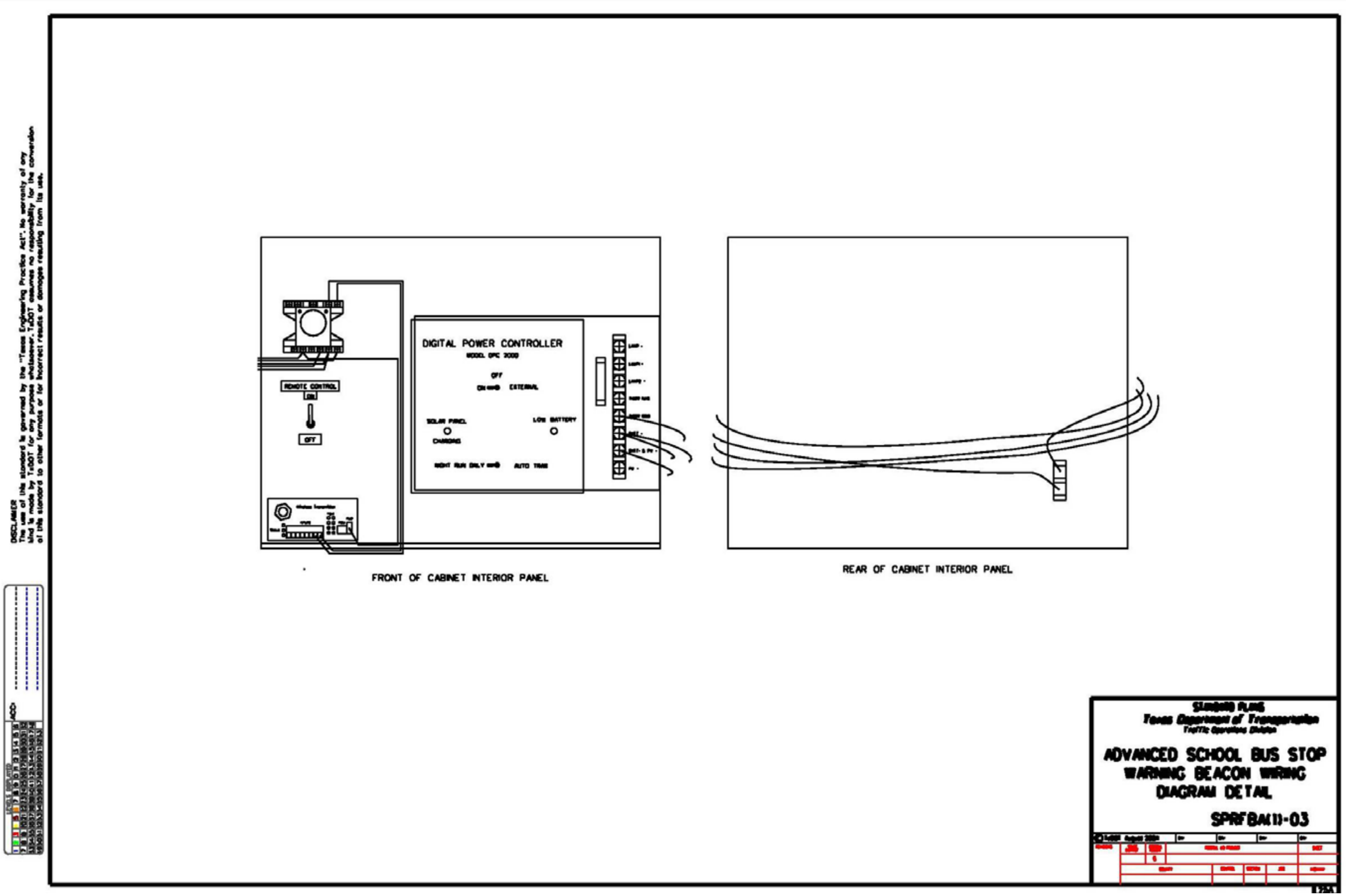

Figure 8. Active Advance Warning Device Wiring Diagram Detail –Interior Cabinet Panel.

DRAFT MANUAL MODIFICATIONS

Texas Manual on Uniform Traffic Control Devices (TMUTCD)

The existing language contained in the *Texas Manual on Uniform Traffic Control Devices* pertaining to the SCHOOL BUS STOP AHEAD sign (S3-1) reads as follows:

TMUTCD

Section 7B.10 (Current text)

> *School Bus Stop Ahead Sign (S3-1)*
>
> *Guidance:*
>
> *The School Bus Stop Ahead (S3-1) sign should be installed in advance of locations where a school bus, when stopped to pick up or discharge passengers, is not visible for a distance of 150m (500 ft.) in advance and where there is no opportunity to relocate the bus stop to provide 150m (500 ft.) of visibility.*
>
> *(Additional text)*

The following language is recommended for inclusion:

> *Option:*
>
> *The School Bus Stop Ahead sign (S3-1) may be supplemented with Advance School Bus Stop warning beacons.*
>
> *Guidance:*
>
> *When the School Bus Stop Ahead sign (S3-1) is supplemented with beacons, the beacons shall follow Sections 4K.01 and 4K.03 (or proposed 4K.06).*

Proposed Section 4K.06 Advance School Bus Stop Warning Beacons

> *Standard:*
>
> *An Advance School Bus Stop warning beacon shall consist of two signal sections of a standard traffic control signal face, with a flashing CIRCULAR YELLOW signal indication in each signal section. The signal lenses shall have a nominal diameter of not less than 300mm (12 inches) and shall be vertically aligned. The lenses shall be alternately flashed.*
>
> *The beacons shall only be active during the presence of a school bus when stopped to pick up or discharge passengers.*

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The findings contained in this report respond to the three-part problem described below:

(1) Children are at greatest risk when in school bus loading or unloading zones. Students are three to four times more likely to be killed while boarding or leaving the bus than while riding the bus (Transportation Research Board 1989).

(2) Efforts to improve safety at school bus loading or unloading zones have been focused on increasing school bus conspicuity and enhancing driver guidance. However, none of these efforts are effective (i.e., visible from a distance) if a school bus is stopped in an area of limited visibility.

(3) The constant display of the static warning message, SCHOOL BUS STOP AHEAD, combined with the limited presence of the hazard (i.e., the stopped school bus and loading/unloading children), results in rapid motorist desensitization to the risk and a subsequent degradation in safety at school bus loading/unloading zones.

The primary objectives of this research project were: (1) to develop an active advance warning device comprised of an actuated flashing beacon supplement to a conventional SCHOOL BUS STOP AHEAD sign (S3-1) and (2) to evaluate its effect on driver performance (i.e., reduced speeds, improved vehicle braking activity, reduced erratic maneuvers, etc.) and safety through school bus loading and unloading zones.

Secondary objectives were to summarize AAWD components and costs, develop an activation strategy for the flashing beacon system component, review the liability risk associated with AAWD (i.e., moving from passive to active warning), review national experience related to AAWD, and provide guidance regarding potential AAWD specifications and use in Texas.

CONCLUSIONS

Provided below is a summary of findings related to safety and driver behavior impacts, system costs, and liability risk related to the use of an active advance warning device comprised of an actuated flashing beacon supplement to a conventional SCHOOL BUS STOP AHEAD sign (S3-1) to improve safety at low visibility school bus loading and unloading zones.

Safety Impacts

Of the 46 published studies reviewed, 37 reported a positive effect (i.e., either a reduction in vehicular speed or a reduction in accidents) resulting from the introduction of AAWDs with flashing warning beacons as the, or one of the, system components.

Findings from local field studies conducted in Texas also suggest generally favorable results:

- When considering changes in average vehicle approach speeds measured at both the SCHOOL BUS STOP AHEAD sign and 500 feet upstream of the sign, a statistically significant reduction in average approach speeds was observed (1.0 mph and 2.02 mph, respectively) when the flashing beacon was activated.

- Three out of four sites experienced statistically significant speed reductions ranging from 1.18 mph to 3.18 mph when the flashing beacon was activated.

- When a school bus was present at the loading and unloading zone, a statistically significant reduction in vehicle approach speeds was observed (8.62 mph) across all sites at the SCHOOL BUS STOP AHEAD sign when the flashing beacon was activated.

- One out of four sites (SH 21) experienced a statistically significant reduction in average approach speeds (15.08 mph) measured at the SCHOOL BUS STOP AHEAD sign with a bus present at the loading and unloading zone and with the flashing beacon activated.

Further statistically significant favorable results are likely precluded by the small sample sizes, particularly when looking at AAWD performance at individual sites. Brake-light actuation distances were largely unaffected by the activation of the flashing beacon.

System Components and Costs

The system components for the prototype AAWD developed and tested as part of this project included a SCHOOL BUS STOP AHEAD advance warning sign (S3-1), top- and bottom-mounted flashing beacons, and a flashing beacon activation system. Costs for the final system are estimated to be $2,000 for the S3-1 sign and flashing beacons and $2,600 for the flashing beacon activation system; a single flashing beacon activation system can be used with multiple S3-1 sign and flashing beacon assemblies. These estimates do not include sign installation or ongoing maintenance and operations costs.

Liability Risk

After a review of published literature and a review of historic case law, overall, the addition of flashing beacons to the SCHOOL BUS STOP AHEAD sign (S3-1) appears to pose minimal additional liability risk above what is already experienced by transportation departments. With respect to general warning sign use, transportation departments are largely protected from tort liability through discretionary immunity and are further protected by the following: (1) state or federal standards and specifications for installation and operations, (2) a logical and systematic decision-making process for selecting appropriate warning devices, (3) a logical and systematic decision-making process for operating active warning devices, and (4) a program of regular inspection and maintenance for warning devices.

Areas of potential liability risk, though not prevalent in the historic case law to date, relate to a transportation department's "jurisdictional responsibility" with respect to establishing, operating, and maintaining school bus loading and unloading zones and the expectation or lack of expectation of a hazard tied to the activation of the flashing beacon; i.e., motorists may rely solely on the flashing beacons as their indication of the hazard (i.e., school bus and children) and may not exercise the same degree of caution when the bus is not present and the beacons are not flashing but children are nonetheless present at the bus stop.

RECOMMENDATIONS

Given the generally favorable safety-related impacts (both nationally and locally), the low system cost, and the minimal additional liability risk incurred beyond that of a general warning sign, the active advance warning device system comprised of a SCHOOL BUS STOP AHEAD sign (S3-1), flashing beacons, and a flashing beacon activation system is recommended for implementation. Prior to or in conjunction with this implementation, the following activities are recommended to ensure that the safety of children and the motoring public is maximized and the Texas Department of Transportation is protected from tort liability:

- incorporate the AAWD into state standards and specification;
- develop a logical and systematic decision-making process for selecting school bus loading and unloading zones equipped with the supplemental flashing beacons (vs. those that are unsigned or signed only with static SCHOOL BUS STOP AHEAD signs);
- develop a logical and systematic decision-making process for operating the active flashing beacon system component;
- develop a program of regular inspection and maintenance for the AAWD that includes the general condition of the sign and the functionality of the flashing beacon system component;
- define the department's "jurisdictional responsibility" with respect to establishing, operating, and maintaining school bus loading and unloading zones;
- investigate additional or modified signing (i.e., a supplemental plaque) to reflect the presence of children even if the flashing beacons are not activated; and
- periodically evaluate driver behavior at the AAWD sites to ensure that driver desensitization to the warning has not compromised the safety of the site.

If proven to be successful in Texas, this type of AAWD would be easily transferable for application in other states.

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