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16. Abstract  This report describes the research conducted within a two-year study that developed an effective advance warning for end-of-green phase at high-speed traffic signals in Texas. High-speed signals are defined as having approach speeds of 45 mph or more. The Advance Warning for End-of-Green Signal (AWECS) was developed in this research by the Texas Transportation Institute for the Texas Department of Transportation (TxDOT). Two AWECS were designed and the field tests showed a 40-45 percent reduction in red-light running can be expected with well designed, constructed, and maintained systems.  This report provides a manual that traffic engineers can use to design and install an AWECS in the field to improve the safety experience with problematic traffic-actuated signalized intersections. Advance detector design and layout guidelines are provided together with sign design and deployment guidance. A set of uniformly spaced dilemma zone detectors is presumed to be in place on each high-speed approach at the existing traffic actuated signalized intersection to which the AWECS is envisioned to be added as a safety treatment.  A Microsoft™ Excel-based software, named AWECS Designer, which can be used to design and layout an AWECS is available online at <a href="http://tti.tamu.edu/documents/0-4260-2-awecs.xls">http://tti.tamu.edu/documents/0-4260-2-awecs.xls</a> .			
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# **DESIGN AND INSTALLATION GUIDELINES FOR ADVANCE WARNING SYSTEMS FOR END-OF-GREEN PHASE AT HIGH SPEED TRAFFIC SIGNALS**

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# CHAPTER 1. INTRODUCTION

## BACKGROUND

Research sponsored by the Texas Department of Transportation has developed an Advanced Warning for End-of-Green System (AWEGS) for applications to high-speed signalized intersections in isolated (non-coordinated) locations. This report contains the guidelines developed by the research team at Texas Transportation Institute to assist traffic engineers in the design and installation of AWEGS. This manual emphasizes deployment along rural Texas highways having traffic-actuated signals, although AWEGS could be readily installed anywhere similar conditions exist. A companion report provides a manual for traffic signal technicians to use as a guide for installation and maintenance of AWEGS (1). The research project's final report provides the complete research, theory of operation, and field evaluation of AWEGS (2).

## AWEGS

What does AWEGS look like in the field? Advance warning to approaching motorists of the forthcoming end-of-green is provided by a warning sign and activation of its warning beacons by the local AWEGS computer control logic. Types of AWEGS advance warning signs that may be used include: (1) a single W3-4 sign (advance traffic control sign) shown in Figure 1a for two-lane, two-way, undivided roadways; (2) dual W3-4 signs for divided highways as shown in Figure 1b, and (3) possibly an overhead mounted sign where conditions are deemed warranted. Overhead options include the W3-4 sign with flashing beacons mounted on span-wires or on a rigid steel mast arm. Where complex roadway and environmental conditions exist and more communication power and flexibility are desired, an electronic matrix warning sign mounted on a cantilevered sign support as shown in Figure 2 could be used. No overhead signs were field tested in this research, but they have been widely deployed in Canada (2).

What does an AWEGS do that current advance traffic control signs (i.e., W3-3) don't already do to warn motorists about a signalized intersection ahead? Traffic engineers sometimes install passive W3-3 signs when visibility or traffic conditions warrant, and they may also add two flashing warning beacons to provide additional attention-getting value to the sign message. These beacons flash continuously regardless of the state of the downstream traffic signal. However, this constantly "barking" operation may tend to lose its effectiveness with widespread usage over time. Moreover, flashers are distracting when the signal ahead is green and may provide little useful or timely information that the approaching motorist can and will use.

AWEGS does not flash unless it thinks the downstream thru phase, now green, is about to end. When it flashes, it means business!



a. Pole-mounted AWECS Advance Traffic Control Sign (W3-4) near Waco.



b. Two Pole-mounted AWECS Advance Traffic Control Signs (W3-4) in Brenham.

**Figure 1. Examples of AWECS Advance Warning Signs in Waco and Brenham.**



**Figure 2. Example of Cantilevered Electronic Matrix Advance Warning Sign Located in Marshall.**

If the downstream traffic signal is traffic-actuated, how can AWECS know when the signal is about to change, especially without always adding a fixed-time trailing overlap to the phase? Through extensive monitoring of the existing detector inputs, by slightly modifying some of these critical inputs, and by adding two advance detectors per approach lane, AWECS can see “what’s coming down the road” farther into the future than can the existing traffic-actuated controller. Using these data, AWECS can reliably estimate when the signal controller will gap-out a phase about 5 seconds before the controller does it. In those rare phase termination cases missed by the AWECS prediction model, adaptive trailing overlaps will be provided, but only when needed. If no traffic is detected in the AWECS approach zone, then AWECS will not override the signal’s operation (no phase hold is placed) and signal operation will proceed normally.

## **NADER’S DETECTOR GUIDE**

AWECS has been developed with the assumption that the existing traffic-actuated signal controller has been provided with uniformly-spaced, high-speed dilemma zone detectors that the controller uses to extend the green signal phase for the thru traffic. TxDOT traffic engineers often use Nader’s design guidelines when laying out these dilemma zone detectors. “Nader’s Guide” provides uniformly-spaced inductive loops along the approach roadway to provide safe stopping distance for the given design-speed, as presented in [Table 1](#) below (3). We have assumed herein that design speed is equivalent to the 85<sup>th</sup> percentile approach speed of the arriving free-flow traffic, as used to determine the length of the yellow change interval following the end-of-green.

**Table 1. Nader’s Guide on Detector Installation for High-Speed Approaches. (3)**

Approach Speed, mph	Distance from Head of Detector to Stopline at Intersection, feet			Stopline Area Detector <sup>a</sup>	Passage Gap, Sec	TTI Rec. Min. Passage Gap, sec <sup>b</sup>
	CDA 1	CDA 2	CDA 3			
45	330	210	---	6' x 40'	2.0	2.8
50	350	220	---	6' x 40'	2.0	2.8
55	415	320	225	6' x 40'	1.2	1.6
60	475	375	275	6' x 40'	1.4	1.5
65	540	430	320	6' x 40'	1.2	1.6
70	600	475	350	6' x 40'	1.2	1.7

<sup>a</sup> Presence on red; then delayed (off) call on green following first (queue) gap-out.

<sup>b</sup> Minimum recommended passage gap in Nader’s Guide (3) detector layout by TTI (2).

Table 1 also provides the passage gaps that Nader’s Guide recommends for the respective signal phases. However, research in this project has shown that passage gaps longer than those given in Table 1 have been and should be used in the field in most cases to minimize the number of slower vehicles unexpectedly gapping out between the detectors. The right-hand column of Table 1 provides recommended minimum passage gaps for these design conditions based on this research (2).

## NEED FOR AWEGS

As AWEGS is a very new system, Texas has no formal warranting procedure for its installation. Some installation authorization is provided in Section C of the 2000 Manual on Uniform Traffic Control Devices (MUTCD, 4) covering advance traffic control sign applications, particularly the new W3-4 BE PREPARED TO STOP sign (with When Flashing plaque). Many Advance Warning Flashers (AWF) are installed around the country, but it is unclear whether any of these systems have the operational efficiency provided by the prediction features of AWEGS. In any case, the best application guidance that can be gleaned from the current literature and research is summarized in a recent Minnesota Dept. of Transportation (MnDOT) technical memorandum on the subject dated August 2000 (5). MnDOT has conducted several research projects on applications of advance warning flashers during the past decade, and their implementation guidelines reflect this expertise.

## Minnesota Application Guide

The Minnesota DOT guidelines (5) state that “AWF should only be installed in response to a specifically correctable problem, not in anticipation of a future problem. Generally, AWF implementation is appropriate only at high-speed locations. Before an AWF is installed, other remedial actions should be considered.”

The MnDOT guide continues with a taxonomy of potential problem categories for which application criteria and comment were provided: “The following guidelines for Advance Warning Flashers which include guidelines from American Association of State Highway Transportation Officials (AASHTO) and Institute of Transportation Engineers (ITE) generally apply only where the posted speed is 55 mph or higher by category and [criteria]:

1. isolated or unexpected signalized intersection [ $>10$  miles to next signal];
2. limited sight distance of 2 signals [ $<$ AASHTO stop dist, truck decel - 20 percent];
3. dilemma zone [ITE stopping distance, truck decel. reduced 20 percent];
4. accidents [and problem type 2 or 3 above exists];
5. heavy truck volume [ grade  $>3$  percent with  $> 15$  percent trucks]; and
6. engineering judgment.”

This MnDOT advance warning flasher guide (5) is generally consistent with other prior published research and traffic engineering practice on advance warning flashers (2).

### **Operational Objective**

The basic operational goal of AWECS is to get targeted motorists approaching a signalized (traffic actuated) intersection at high speed to immediately slow down to a speed from which they can safely stop when the signal turns yellow and then red shortly thereafter. Yellow lights are not generally timed for these high speeds (i.e., usually illegal speeds above the speed limit). A flashing warning (e.g., beacon) is activated to warn approaching motorists when AWECS detects that the traffic signal phase is about to end, usually in about 5 seconds.

An additional function provided by AWECS is to minimize dilemma zone exposure to trucks and high-speed cars when the signal is operating in the “green rest” state. Thus, it is essential to know the distribution of approach speeds expected to be served by AWECS.





## CHAPTER 2. DATA FOR DESIGN

AWEGS should be designed with the best traffic and roadway data that can be obtained. In addition, an accurate inventory of the existing traffic detector layouts (e.g., from Nader's Guide) must be provided. Even the type of existing signal controller, cabinet features, and signal timings must be determined. As current AWEGS design requires the installation of a hardened industrial-grade computer, space availability in the cabinet and the quality of cooling system are important factors that should be determined. Construction and installation of inductive loop detectors to the designated spacing and sizes are also paramount.

### SPOT-SPEED DATA

Important inputs to the design of AWEGS include the characteristics of traffic flow, including traffic speed, traffic mix, and degree of interruption by adjacent traffic signals. AWEGS design assumes that the arrival traffic is located in Texas, is isolated from adjacent traffic signals, has mixed traffic of cars (and pickups) and trucks, and has free-flowing speeds that are normally distributed.

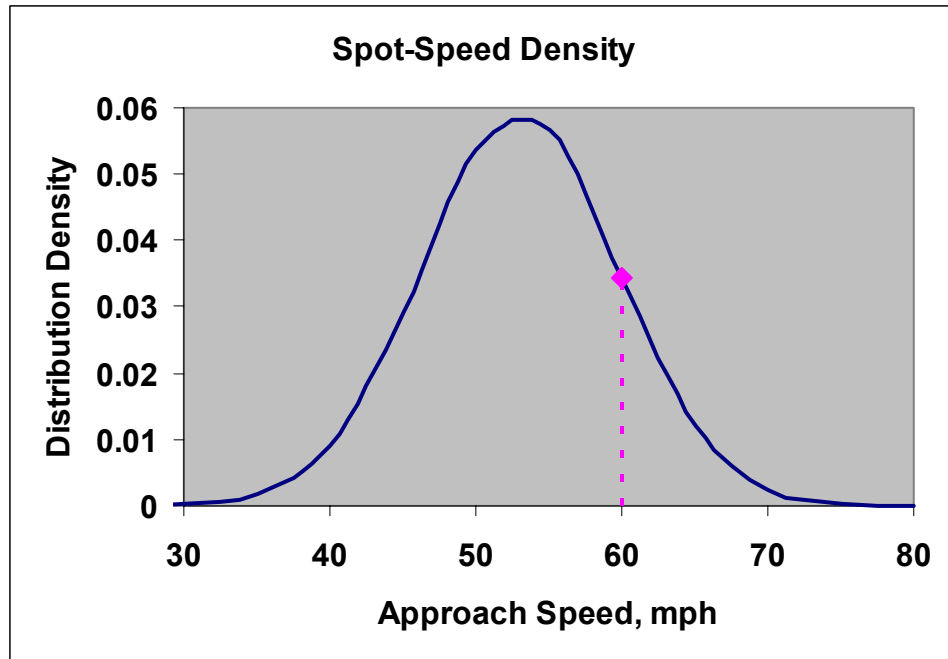
Spot-speed studies for each high-speed approach conducted in Texas should use TxDOT's Procedures for Establishing Speed Zones (6). Additionally, spot speeds should be recorded only during the green signal display, and the sample station should be located approximately 1000 feet in advance of the signalized intersection. Two basic spot-speed parameters are needed for each high-speed approach: the mean (50<sup>th</sup> percentile) speed (mph), and the 85<sup>th</sup> percentile speed (mph), as used for speed zoning. The term "approach speed" used herein is synonymous with the 85<sup>th</sup> percentile speed of a spot-speed study.

An example distribution of spot speeds for a high-speed rural highway is shown in Figure 3 for a mean (50<sup>th</sup> percentile) speed of 53 mph and an 85<sup>th</sup> percentile speed of 60 mph. Note that 15 percent of the traffic will be traveling at speeds exceeding the 85<sup>th</sup> percentile speed. Thus some higher speed drivers may find stopping on red difficult unless warned in advance. Spot speed data should provide the following speed results for each approach:

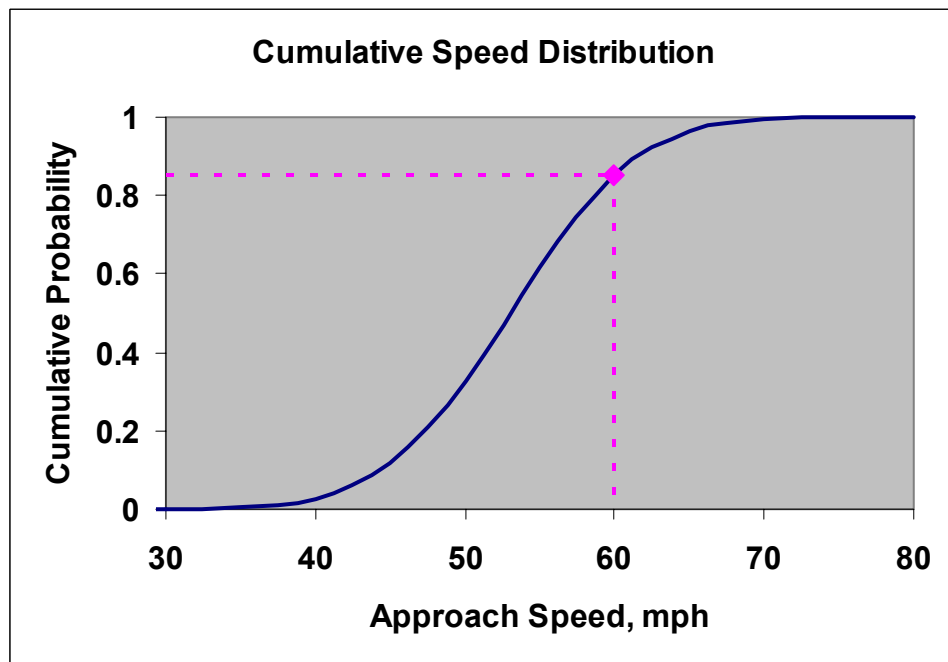
EASTBOUND TX 16 @ FM 475:

1. 85<sup>th</sup> percentile speed:  $V_{85\%} = \underline{60 \text{ mph}}$
2. 50<sup>th</sup> percentile speed:  $V_{50\%} = \underline{53 \text{ mph}}$
3. std. dev. of speed:  $\sigma = \underline{7 \text{ mph}}$

A standard deviation of speeds (  $\sigma = V_{85\%} - V_{50\%}$  ) exceeding 9 mph should be examined for probable cause and design implications. High driveway, side road, turning and platooning traffic are likely and may need special consideration.



a. Distribution Density of Approach Spot Speeds.



b. Cumulative Distribution of Approach Spot Speeds.

**Figure 3. Example of Spot-Speed Data and Resulting High-Speed Traffic Not Covered by Typical (85<sup>th</sup> percentile) Dilemma Zone Detection Layouts.**

## EXISTING DILEMMA ZONE DETECTION LAYOUT

The existing detector layout for each high-speed approach should be accurately measured. Record all detector locations in feet from the leading edge of the loop to the stopline. Multiple-loop designs may include as many as three to five advance detectors. Nader's Guide identifies only two or three dilemma zone detectors with uniform spacing between them, as noted in [Table 1](#). Stopline queue detection may also be provided.

The existing detector layout and related phase timings need to be assessed ([Figure 4](#)):

1. Record and evaluate the existing dilemma zone detectors for each approach:

TxDOT Dilemma Zone Detector	Distance to Stopline, feet	Head-to-Head Spacing, feet
CDA 1	475	---
CDA 2	375	100
CDA 3	275	100

### Example

2. Are the detectors uniformly spaced? (Nader's Guide are.) Yes
3. Is this a Nader's Guide detector layout? (See [Table 1](#).) Yes
4. If so, for what design speed? 60 mph
5. Record the passage gap recommended by Nader's Guide. 1.4 sec
6. Record the min. pass. gap rec. in [Table 1](#) for Nader's Guide. 1.5 sec
7. Record the passage gap set in the controller for this phase. 2.0 sec
8. If Nader's Guide, is passage gap set OK? Yes = #7  $\geq$  #6 Yes

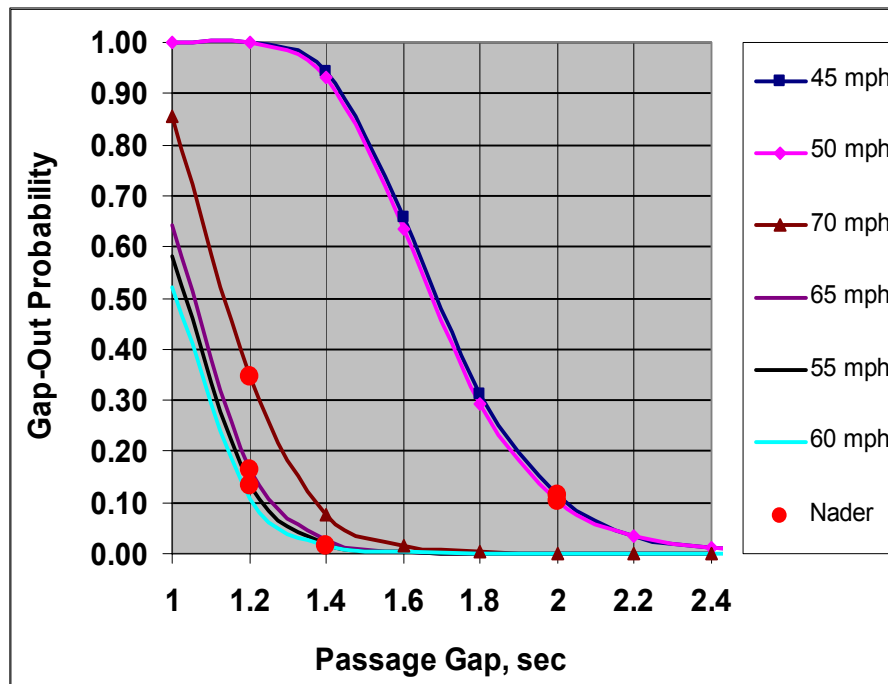


Figure 4. Probability of First Detector Gap-out by Design Speed for Nader's Guide.

If the existing multiple loop detector design is not from Nader's Guide, but it is uniformly spaced, then calculate the critical gap-out time from:

$$CritPassGap, sec = \frac{(CDA1 - CDA2 - 22)}{1.467 * (V_{85\%} - 3 * \sigma)} = \frac{(475 - 375 - 22)}{1.467 * (60 - 3 * 7)} = 1.36 sec$$

where

$$\begin{aligned} CritPassGap &= \text{minimum passage gap that will hold the 15}^{th} \text{ percentile approach} \\ &\text{speed across TxDOT's first two detectors (CDA 1 and CDA 2),} \\ &\text{sec;} \\ V_{85\%} &= 85^{th} \text{ percentile approach speed, mph; and} \\ \sigma &= \text{standard deviation of approach speeds, } \cong 7 \text{ mph.} \end{aligned}$$

or assess the probability of unexpected gap-out over the spacing, knowing the mean and standard deviation of approach speeds, and now the critical speed, *CritSpeed*, from:

$$CritSpeed, mph = \frac{0.682 * (CDA1 - CDA2 - 22)}{PassGap_{\phi}} = \frac{0.682 * 78}{2.0} = 26.6 mph$$

Microsoft™ Excel spreadsheets provide convenient assessment of the probability of any approach vehicle, chosen at random from a normal distribution, not exceeding the critical speed. Here, Excel shows that the probability ( $V < 26.6, 53, 7$ ) = 0.000. Clearly, no vehicle should gap out between these detectors when a 2.0 second passage gap is used for controlling the related signal phase. Passage gaps set in the controller for uniformly spaced detector plans should not produce gap-out probabilities exceeding 0.01, but they also should not be extra long. For a 78-foot clear space between presence detections, a 1 percent gap-out rate would be produced by a speed of 36.7 mph which will just hold a phase against a passage gap of 1.45 seconds. This could be determined using Excel from:

$$CritSpeed, mph \Rightarrow Prob = 0.01 \approx N(\mu = 53, \sigma = 7) \Rightarrow 36.7 mph$$

$$CritGap, sec = \frac{CDA1 - CDA2 - 22}{1.467 * 36.7} = \frac{78 ft}{53.8 fps} = 1.45 sec \Rightarrow 1.5 sec$$

If the multiple-loop detector layout has variable spacing (e.g., a legacy Bierle [7] layout in Texas) then check the first spacing (it will be the largest) against the critical speed and probability distribution, as shown above, to assess the likelihood of vehicles gapping out between the CDA1 and CDA 2 detectors.

## APPROACH ROADWAY GEOMETRY

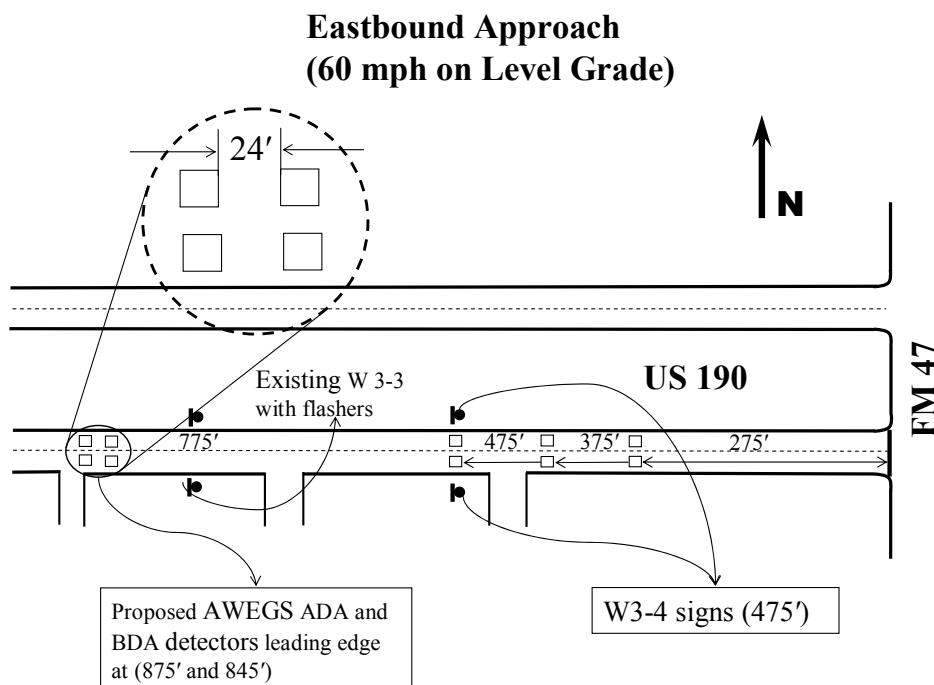
Basic features of the approach roadway geometry are needed, and these data should be verified by site investigations. It is assumed that as-built roadway design plans

for the highway are available. Locate the existing detectors on a copy of the plan sheet. The following specific roadway geometry data per approach are needed, as a minimum:

- number of approach lanes, and type of roadway (divided, undivided);
- average approach grade for the last 1000 feet to the intersection;
- design speed of highway; and
- proposed pavement rehabilitation over the next 5 years.

### APPROACH ROADWAY SUMMARY

The data collected for the proposed AWEGS design should be summarized into a plan view for each approach. [Figure 5](#) depicts an example for the eastbound direction of a hypothetical 60 mph four-lane divided highway on level grade. Also shown in [Figure 5](#) are two pairs of AWEGS speed-trap detectors (known as ADA and BDA) and two W3-4 advance warning signs, later designed and located, for reference.



**Figure 5. Summary of Existing Conditions of High-Speed Approach and Proposed Layout of AWEGS Detectors and Signs.**



## CHAPTER 3. DESIGN OF AWEGS

### DESIGN PROBLEM

A system for providing advance warning for end-of-green must be designed to reliably perform its mission. AWEGS must first detect distant (800-1100 feet away) arriving traffic just as a traffic-actuated signal does. It also must monitor within the local signal cabinet almost all traffic detections and signal status inputs that the existing controller sees. It must provide timely advance warning outputs to the distant (300-600 feet) AWEGS signs. And finally, it should provide a reliable backup flasher assembly in case of control system failure. Other features, such as performance surveillance of red-light-running and remote monitoring capabilities by PC Anywhere telephone dial-up, were provided in recent AWEGS research systems (2), but they are not considered minimum AWEGS design requirements.

An overview of the general features and flow of the first AWEGS is presented in Figure 6. The form and function of the computer and related electrical wiring interface terminals shown in Figure 6 and located in the signal cabinet are expected to change over time into a smaller and more simplified design. In the future, the entire AWEGS control system could be fully integrated within an attached programmable computer card (8).

### SIGN DESIGN

Passive W3-4 Advance Traffic Control signs (see Section 2C.26 of the 2000 MUTCD, 4) supplemented by warning beacons were used by TTI researchers (2) at two sites to provide approaching motorists advance warning for end-of-green. TxDOT's Sign Crew Field Book (9) and the relevant sections in the state (10) and national MUTCD (4) should always be consulted for official design requirements and guidance. All aspects of the signs noted in this section are in compliance with the 2003 Texas MUTCD (10). A relevant Standard of the 2003 Texas MUTCD (10) regarding this design should be noted here:

“Standard: When a BE PREPARED TO STOP sign (W3-4) is used in advance of traffic signals, it shall be used in addition to a Signal Ahead sign. (W3-3)

In both field trials of AWEGS, W3-3 signs were already in place near the AWEGS ADA/BDA detectors. The W3-3 signs are not specifically identified as being a part of AWEGS. In Waco, TxDOT had not attached flashing beacons to the existing W3-3 signs; whereas, at the four-lane divided Brenham site, two W3-3 signs per approach were already in place, with two vertically-mounted beacons per sign constantly flashing in an alternating mode of display. These existing advance warning beacons mounted with the W3-3 signs were recommended by TTI to be turned off during all AWEGS studies. Nighttime viewing suggests that this was the correct decision, given that the AWEGS beacons located with its W 3-4 signs remain off until activated for warning.





## Features

At the site near Waco, a single ground-mounted W3-4 sign was provided for each approach. Design features of this W3-4 sign were shown in [Figure 1a](#) and included:

- screw-in pole foundation;
- vertically-mounted 12-inch LED flashing beacon; assembly (RFBA-98);
- 50/50 flashing (on/off) cycle (0.50 second/0.50 second), and computer driven;
- 7-inch series D black lettering on 48-inch x 48-inch high-intensity yellow sheeting. Layout is equivalent to CW 21-8 construction warning sign; and
- When Flashing 36-inch x 24-inch plaque with 6-inch Series D legend.

At the four-lane divided highway study site in Brenham, as shown in [Figure 1b](#), a ground-mounted W3-4 sign was located on each side of the approach roadway. Dual flashing W3-3 Signal Ahead signs preceded these signs in time and space. Design features of the AWECS W3-4 sign shown in [Figure 1b](#) included:

- cast-in-place pole foundations (Type 24-A);
- two horizontally-mounted 12-inch LED flashing beacons assembly (RFBA-98). Due to local vertical curves, beacons mounted at 10 and 2 o'clock positions horizontally above the sign;
- 41/59 flashing (0.45/0.65) cycle, all beacons flash together, computer driven;
- 7-inch series D black lettering on 48-inch x 48-inch high-intensity yellow sheeting. Layout is equivalent to CW 21-8 construction warning sign; and
- When Flashing 36-inch x 24-inch plaque with 6-inch Series D legend.

More visually attractive advance warning signs could readily be used in AWECS using basic on/off switch control. An example could include overhead cantilevered electronic matrix signs, similar to the one installed in Marshall, as shown in [Figure 2](#). This type of sign support structure would appear justified for high-speed, multilane roads having two-way left-turn lanes, or no (adequate) median divider. This large high target value sign, mounted over the running lanes, would appear to be equivalent to two ground-mounted signs posted on either side of the running lanes, as depicted in [Figure 1b](#) in Brenham. Less costly overhead designs using rigid mast-arm mounting or dual-span wire designs for mounting W3-4 signs with warning beacons have also been used around the country.

Draft materials for the federal Series 2000 Standard Alphabet indicate that 6C, 8C, and 9C legends (3-line BE PREPARED TO STOP) will be recommended for similar 36-, 48- and 60-inch square construction warning signs.

## Location

Two AWECS-related sign location problems need to be addressed. One is the station along the highway where the W3-4 sign is to be positioned. The second identifies the target location along the approach roadway where the flashing beacons should be targeted. The AWECS W3-4 sign should be located along the roadway where the ITE-

based stopping distance to the onset of the yellow signal exists, based on serving the 85 percentile approach speed, from:

$$X_{W3-4} = 1.467 * V_{85} * T + \frac{2.151 * V_{85}^2}{2(d \pm gG)}$$

where:

$X_{W3-4}$	=	ITE-based stopping distance, feet;
$V_{85}$	=	85 <sup>th</sup> percentile approach (design) speed, mph;
$T$	=	perception-reaction to yellow onset, 1.0 sec;
$d$	=	maximum usual (ITE) stopping deceleration rate, 10 fps <sup>2</sup> ;
$g$	=	gravity, 32.2 fps <sup>2</sup> ; and
$G$	=	roadway grade, decimal equivalent.

Since the above stopping distance is about the same as that recommended for the leading detector (CDA1) in Nader's Guide, the practical location of the W3-4 sign is near the location of the first dilemma zone detector given in Nader's Guide. This similarity assumes that the approach speed now existing (as determined from a spot-speed survey) is similar to the design speed used to select the detector layout from Nader's Guide. Local site adjustments of  $\pm 50$  feet to avoid driveways, etc are considered acceptable in locating the W3-4 sign. An Excel spreadsheet is provided, as will be illustrated later, that conveniently calculates these design requirements.

The focal point of all flashing beacons for an approach is the same. The target location shall be (the drivers' eyes) the centerline of the approach roadway at the location of the ADA advance detector described later in this chapter. Field experience suggests that correctly targeting these beacons must be given high priority, and subsequent field inspection of their targeting during and after construction is imperative.

Field observations indicate that several problems may arise during installation. The beacons may be misaligned during initial setup, perhaps due to the approach road vertical curvature. They may later become misaligned due to temperature changes and wind-induced vibrations, if their mountings are not secure. LED beacons tend to have a relatively narrow angle of focus, and their apparent brightness will not be high or uniform unless they are always targeted at the same point on the approach roadway. This is especially true if two signs are used per approach, one on each side of four-lane divided roadways.

## Electrical

The assembly of AWECS W3-4 signs shown in [Figure 1](#) is relatively simple. Power is required to drive only the LED flashing beacons and is provided from the signal cabinet by the AWECS computer/terminal switches. Thus, 120 VAC electrical power and control of the sign beacons are combined using a 3-conductor #12 AWG IMSA 20-1 signal cable, or equivalent. Since the sign is strategically located close to the existing dilemma zone detectors, electrical ground boxes and conduit should already be in place

which may expedite the cable run to the signal cabinet. Wireless communications to these signs would not appear cost-effective for existing systems at this time.

## **ADVANCE WARNING DETECTORS**

Two advance warning detectors are added to existing signal control systems per approach to serve three functions in AWECS. They provide a more distant look into the future regarding the nature of arriving traffic than is typically provided (or needed) by dilemma zone detectors (Nader's Guide). They also form a well-defined speed trap to better estimate the arrival time of each and every vehicle to the first downstream dilemma zone detector. Lastly, they are used to classify the type of vehicle into car or truck categories. Knowing the type of vehicle and its speed, AWECS estimates its arrival in real time (2).

The design, location, and construction of the advance speed-trap detectors are critical to the successful operation of AWECS. Inductive-loop detectors (ILD) are currently recommended for AWECS applications based on field experience with their operational measurement precision, dependability, and technology requirements. Wireline communication is also recommended due to its dependability, although wireless technology is advancing rapidly. Long home-runs (some over 1000 feet long) to the signal cabinet offer design challenges, but modern ILDs seem to have little problem working as specified when the ILD system is well designed and constructed.

In AWECS design, the two ILD speed-trap detectors are called the ADA and BDA detectors. As noted in Figure 5, ADA is the leading detector and BDA is the trailing detector of the speed trap. Both detectors operate in the presence mode of detection. Both ILD detectors shall be 6-foot x 6-foot inductive loop detectors.

### **Location**

The leading edge of the ADA detector provides AWECS with the first indication of the arrival of a vehicle. AWECS begins a process of responding to this vehicle as it travels across the ADA detector and then arrives at the BDA detector. A typical travel time between these two arrival events is on the order of 0.3 second or so. The activation presence of the ADA detector is also monitored by AWECS as the vehicle travels over the ADA detector. By strategically placing the leading edge of the BDA detector 30 feet downstream from the leading edge of the ADA detector, providing a 24-foot gap between them, a car will leave the ADA detector (lose its presence) before reaching the BDA detector, but a truck will still have its presence noted on the ADA detector. Thus, AWECS can distinguish a car (ADA off, BDA on) from a truck (ADA on, BDA on) as the vehicle arrives on the BDA detector and can also easily determine its speed. Research indicates that trucks have more difficulty stopping than cars. The literature suggests that the maximum acceptable deceleration rate for a typical truck to stop is 70 to 80 percent of that for a car (2, 5).

How much advance warning distance and time are needed? AWEGS design specification provides a car with enough distance (and time) to permit the 99<sup>th</sup> percentile approach speed car (probably going at an illegal high speed) to slow down to the design speed of the downstream dilemma zone detectors (CDA) at the leading edge of the first dilemma zone detector (CDA1). Another way of saying this is that AWEGS provides the 99<sup>th</sup> percentile approach speed vehicle (car) with enough warning that it could safely stop if and when the downstream red signal is displayed, assuming ITE's base deceleration rate. An equation to calculate this location for the ADA detector is:

$$ADA = 1.467 * V_{99\%} * T_{W3-4} + \frac{2.151 * (V_{99\%}^2 - V_{85\%}^2)}{2(d \pm Gg)} + X_{W3-4}$$

where the new terms are:

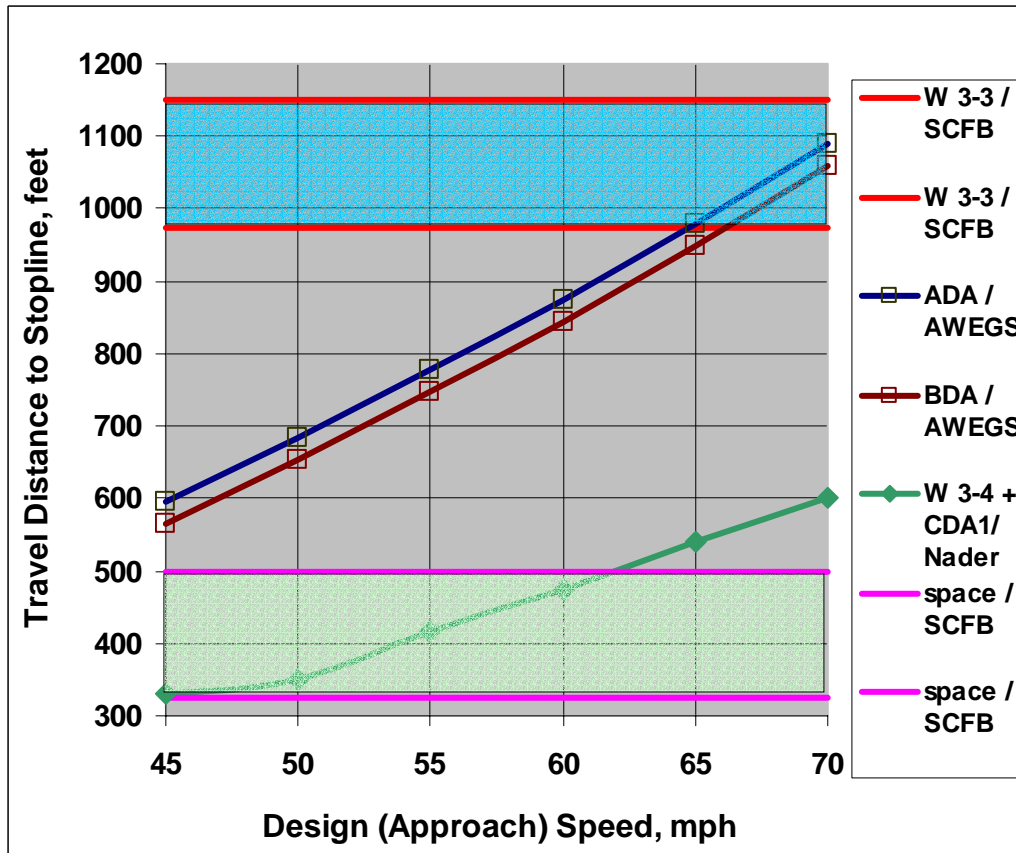
$$\begin{aligned} ADA &= \text{leading edge of the ADA advance warning detector, feet;} \\ V_{99\%} &= 99^{\text{th}} \text{ percentile speed } V_{99\%} = V_{85\%} + 1.3 * \sigma \cong V_{85} + 9, \text{ mph; and} \\ T_{W3-4} &= \text{input-perception-read-reaction to W3-4 flasher and decision to} \\ &\quad \text{slow. Time is } = 2.7 \text{ sec} = 0.2 \text{ sec} + 2.5 \text{ sec.} \end{aligned}$$

Several factors increase the distance the ADA detector should be from the stopline. Increasing speed increases the stopping distance. Increasing downgrade to the intersection ( $-G$ ) increases the stopping distance. An AWEGS requirement is that the flasher must always display a full-on period within 0.2 seconds of the time a vehicle is detected arriving at the ADA detector. Surprisingly, the detection-response time of 0.2 seconds is not the real challenge. The real challenge is to always get the “full on” flash time. No off-the-shelf flasher could be found in the signal industry that could reliably provide this desired feature. Only expensive microprocessor-based programmable timers could. Thus, the AWEGS computer is routinely used to drive the flashers to get the desired initial full-on flash.

As noted above, the BDA detector is located 30 feet downstream of the ADA detector. Thus, the relative location of the leading edge of the BDA detector is:

$$BDA = ADA - 30 \text{ feet}$$

A graphical summary of the above results is presented in [Figure 7](#) for level grades. Also shown in [Figure 7](#) are the windows for locating various signs, as defined by TxDOT's Sign Crew Field Book (9). The Texas MUTCD required W3-3 Signal Ahead Sign is indicated to be placed some 975 to 1150 feet from the intersection for approach speeds of 45 mph or more. A space window of opportunity is provided by the Sign Crew Field Book (SCFB) for future signs, such as the new W3-4 sign used by AWEGS, in the range of 325 to 500 feet from the intersection for speeds of 45 mph or more. The new AWEGS sign will conveniently fit into this “space” until the approach speeds reach 65 mph, where some readjustment of signage may be needed. [Table 2](#) provides a tabular summary of the sign and detector location results shown in [Figure 7](#).



**Figure 7. Distance to the Stopline for ADA, BDA and CDA1 Detectors (from Nader's Guide) as Related to Design (85<sup>th</sup> percentile) Speed for Level Grades.**

**Table 2. Locations of AWEGS Advance Speed-Trap Detectors and W3-4 Sign for Level Grade Using Nader's Guide for Dilemma Zone Detection.**

Design or Approach Speed, mph	AWEGS ADA Detector, feet	AWEGS BDA Detector, feet	Sign W3-4 @ CDA 1 Detector of Nader's Guide, feet
45	595	565	330
50	683	653	350
55	776	746	415
60	875	845	475
65	979	949	540
70	1089	1059	600

## Spreadsheet

An Excel spreadsheet, named AWECS Designer, has been prepared to help users solve this design problem for a given data set. Users can readily examine several design options and assess the effects of roadway grade, requirements for handling of high-speed trucks, impacts of high variance in traffic speeds, and existing detector design speed not being the same as the measured approach speed. Moreover, the designer may or may not wish to set the W3-4 sign at the CDA1 detector for various reasons. Guidance is also provided on desirable sign letter size, which varies with critical advance detection zone location and where the W3-4 sign is to be placed. In addition, graphic plots of the effects of changes in passage gaps in the controller are shown. Printouts can be made to provide engineering file documentation. The AWECS Designer Excel program can be obtained on the internet at <http://tti.tamu.edu/documents/0-4260-2/>. An example of an AWECS Designer application is shown in Figure 8 below for 60 and 65 mph (Nader's Guide) design speeds. The appendix provides more details of AWECS Designer, including descriptions and recommendations for values of characteristic input data.

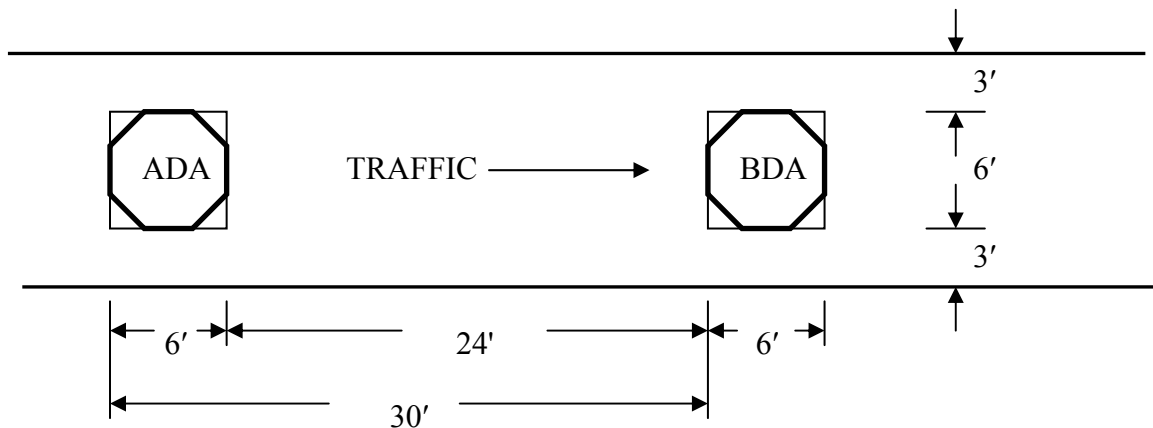
AWECS DESIGNER		
Approach Data		
District =	17 - Bryan	17 - Bryan
Main Highway =	US 190	US 190
Intersection =	TX 47	TX 47
Direction =	Westbound	Eastbound
Grade (%) =	3%	-3%
V 85 % (mph) =	58	64
DS of DZ Det (mph) =	60	65
Dil. Zone Det. Type =	1	1
Design Results		
Speed Trap Detectors:		
ADA (feet) =	888	1079
BDA (feet) =	858	1049
AWECS Sign:		
Location (feet) =	475	540
Series D Height (in.) =	8.3	10.8
Dilemma Zone Detectors		
CDA1 (feet) =	475	540
CDA2 (feet) =	375	430
CDA3 (feet) =	275	320

Figure 8. Example of Sheet 1 from AWECS Designer.

## Loop Layout and Wiring

Inductive loop detectors are recommended for constructing the two AWECS advance speed-trap detectors, ADA and BDA, because of their demonstrated repeatability and accuracy of speed and headway measurement. The recommended layout of the two ILD speed-trap advance detectors used in AWECS is depicted in [Figure 9](#). Both detectors should be 6-foot x 6-foot loops, with a minimum of four turns of #12 XHHW stranded copper wire per loop. Five or six turns may be needed on very high-speed roads having very long home-runs to the cabinet. As mentioned earlier, the distance from the leading edge of ADA to the leading edge of BDA detector should be 30 feet, providing a 24-foot space gap between the detectors so that AWECS can readily distinguish cars from trucks. This 30-foot spacing, providing a 24-foot space-gap specification, must be accurately provided without exception.

The initial location of the leading edge of the ADA detector can be adjusted  $\pm 50$  feet to avoid driveways and pavement problems, but the distance between the pair cannot be adjusted. Since the cable home-run feed to the signal cabinet may be over 1000 feet, high-quality digital amplifiers should be used together with #12 detector shielded lead-in detector cable (e.g., a #12 AWG IMSA 50-2 detector feeder cable → Belden 8718).



**Figure 9. Design Layout of AWECS Speed-Trap Advance Detectors.**

## **SYSTEM**

The AWECS computer system is located in the local intersection signal cabinet. AWECS detects and classifies approaching vehicles as either cars or trucks using the upstream speed-trap detectors, monitors the actuations within the local signal cabinet, including stop-bar detectors, phase status, and dilemma zone detectors, and provides timely advanced warning outputs to the AWECS signs. The AWECS consists of an environmentally hardened industrial-grade computer, a backup flasher panel with watchdog maximum flash timers, two timer relays to disconnect the phase holds, and interface terminals/connections. [Figure 6](#) illustrates the components of the system, whose further description and applications follow.

### **Cabinet**

Since the AWECS computer system is located in an existing signal cabinet, a large TS-2 compatible base-mounted cabinet is desired. Special ventilation may be required to provide maximum acceptable cabinet temperature during the summer. Two ventilation fans with separate 95 °F and 105 °F thermostats may be required to minimize maximum temperatures in the cabinet.

### **Computer**

An environmentally hardened industrial-grade PC is currently used to run the AWECS. The industrial PC used is manufactured by Kontron America and includes an Intel 850 MHz single board computer, 40 gigabyte hard disk, and two National Instrument's digital I/O cards (NIDAQ 6527) with 24 inputs and 24 outputs each. The NIDAQ cards are used to monitor the actuations of the advance speed-trap detectors. The NIDAQ cards are also used to monitor the status of the main-street phases, stop-bar detectors, dilemma zone detectors, and the controller ring status bits (3 bits: A, B, and C per ring) through contact closure connections on the signal cabinet's back-panel. The large hard disk was necessary to store log files collected to evaluate and analyze the system performance during research and development. Future system data storage requirements should be much lower and electrical interfaces simpler.

Future AWECS designs should not need the power available in the currently used industrial PC. The final system could run on a much smaller industrial microcontroller. TTI researchers have also identified another alternative for getting the inputs needed by the AWECS from the signal cabinet, especially for TS-2 cabinets. Instead of using the NIDAQ cards to get the contact-closure actuations from the signal cabinet's back-panel, serial Bus Interface Units (BIUs) could be used to replace the existing BIU's 1, 2, 3, and 4 in the TS-2 signal cabinet, and the AWECS would get its needed inputs by communicating with the serial BIUs over a serial connection. That is, the two NIDAQ cards and complex interface wiring would be replaced with four serial cables.



## **Software Flasher System**

The software flasher system uses four solid-state relays whose on/off input signal is controlled by the AWECS. When AWECS turns on one of the four outputs, an output signal of 24 VDC is supplied by the computer to the designated optically isolated input of a solid-state relay, causing the output of that interface relay to supply 120 VAC to the selected approach warning beacon(s) (but not necessarily all). By precisely switching the relays alternately on and off, AWECS creates a software flasher with the desired 50-percent duty cycle. The design output should be 0.50 seconds on and 0.50 seconds off, providing a cycle time of 1.00 seconds. Note that the first and immediate response of the flasher shall be the onset of the full 0.50 second “on” phase for the primary (top or inside) beacons of the sets of two. When two W3-4 signs are placed on opposite sides of a four-lane divided road, it is recommended that all four beacons (two for each sign, horizontally mounted) flash simultaneously.

Current signal flashers operate continuously and cannot provide the desired immediate and full-on phase because the on command from AWECS comes randomly and, thus, partial on/off flashes would result using off-the-shelf flashers. Advance warning time is critical in AWECS and should not be compromised. This desired flasher function is not easy to provide and may require using microprocessor-based technology.

## **Backup/Watchdog Flasher**

When AWECS is running, its computer changes an output on the digital output interface from high to low voltage every 2 seconds. The (digital output) heartbeat is connected to the reset terminal of the timer relay that is set to countdown to 3 seconds. The heartbeat signal causes the timer relay to reset its countdown time back to zero whenever the voltage state changes to low. Whenever the heartbeat is not present for 3 seconds, the timer relay’s normally open contacts, which are currently closed, switch open. This action disconnects the software flasher system and connects the backup flasher system. At the same time, another set of normally open contacts in the timer relay switch closed, disconnecting the logic common for the software flashers.

When the backup flasher system activates due to loss of heartbeat signal, phases having the approach beacons continue flashing independently whenever those phases are either red or yellow. The optically isolated inputs of the four 120 VAC input solid-state relays constantly monitor the status of the load switches for the phases yellow or red signal lights. When the backup system is activated, the timer relay’s normally closed contact powers the 120 VAC output supply voltage of the solid-state relays monitoring the load switches. When any one of the four solid-state relay’s inputs is supplied with 120 VAC from a load switch, the relay supplies 120 VAC to the appropriate solid-state double-pole flasher connected to the flasher beacon associated with that particular phase. If and when the heartbeat is restored, the timer relay disconnects the backup flasher system power supply and reconnects the AWECS software flashers 120 VAC power supply and logic common connection.

The backup system will also flash the beacons when the cabinet is in cabinet flash, when the malfunction management unit (MMU) detects a malfunction or if the power to the flash transfer relay's input is not present for any reason, for example a loss of power to the rest of the cabinet. The mechanical relay's 120 VAC input is supplied from the same source as the flash transfer relay's input source. When 120 VAC input is not present on the relay's input, due to a fault condition or loss of power, the normally closed contacts in the mechanical relay power both solid-state, two-pole flashers. The backup flasher system's control logic was created by combining the inputs and outputs of four solid-state relays with one mechanical relay and one timer relay.

### **Timer Relay for Phase Holds**

Two IDEC GT3D-4AD24 electronic timer relays are used to disconnect the phase hold signal from the AWECS in case of a malfunction in the system. The timer relay is set to mode 3C on the operation mode selector and 8 seconds of delay on the time-setting digital switch. In this mode, the relay starts counting down when a phase hold signal is applied. The phase hold signal passes through closed contacts in the timer relay. If the phase hold signal continues longer than 8 seconds, the timer relay times down from 8 to 0 seconds and then opens the contacts, dropping the phase hold. If the phase hold signal does not last for more than 8 seconds, then nothing happens. The relay resets back to 8 seconds whenever the AWECS drops the phase hold signal. Two timer relays work independently, one for each phase hold.

### **Resistor Input Interface Circuit for NIDAQ 6527**

The interface circuit consists of a double-layer IDEC terminal strip with 24 individual terminals. A bus connecting all 24 bottom level terminals supplies all 24 16K-ohm resistors with 24 VDC. The supply to the bus is fused by a 1/5 amp fuse to protect the output of the traffic signal controller. The current flowing (leaking) through each resistor is approximately 1mA when the output from the traffic signal controller is active low on a particular output. Each input for the DAQ card requires 1mA for the DAQ card's optical isolator's LED to work reliably. The path the current flows is from the 24 VDC supply through the fuse then to the resistor and into the DAQ optical isolator then out of the DAQ and into the output of the traffic signal controller. Current sinks into the output only when the output of the traffic signal controller is active low.

## REFERENCES

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## **APPENDIX**

### **EXAMPLE SPREADSHEET OF AWECS DESIGNER**



Advance Warning for End-of-Green System (AWEGS) Detector Layout Designer				Aug-03												
<b>Approach Data</b>			*Distances in feet to Stopline for AWEGS Speed-Trap Detectors (ADA,BDA) and Advance Warning Sign (W 3-4).*													
District =	17 - Bryan	17 - Bryan	<<--- Approach Input Data Shown in Red.													
Main Highway =	US 190	US 190														
Intersection =	TX 47	TX 47														
Direction =	Westbound	Eastbound														
Grade (%) =	3%	-3%	<<--- Roadway grade toward signalized intersection. Uphill (+%); downhill (-%).													
V 85 % (mph) =	58	64	<<--- 85 %-tile Approach Speed (mph). Use same sample procedures as for Speed Zoning.													
DS of DZ Det (mph)	60	65	<<--- Design Speed (mph) of Dilemma Zone Approach Detectors.													
Dil. Zone Det. Type	1	1	<<--- Type of "Dilemma Zone" Detection Design: 1= Nader's multiple loop Guide, 2 = VIVDS or Other*.													
<b>Design Results</b>																
Speed Trap Detectors:			<table border="1"> <thead> <tr> <th colspan="4">* VIVDS or Other ILD uniformly-spaced design (feet)</th> </tr> <tr> <th>CDA1</th> <th>CDA2</th> <th>CDA3</th> <th>CU Gap (sec)</th> </tr> </thead> <tbody> <tr> <td>481</td> <td>356</td> <td>231</td> <td>2.0</td> </tr> </tbody> </table>		* VIVDS or Other ILD uniformly-spaced design (feet)				CDA1	CDA2	CDA3	CU Gap (sec)	481	356	231	2.0
* VIVDS or Other ILD uniformly-spaced design (feet)																
CDA1	CDA2	CDA3	CU Gap (sec)													
481	356	231	2.0													
ADA (feet) =	888	1079	*All detector distances from head of detector to stopline, feet. If only two ILD detectors, set CDA3=CDA2.													
BDA (feet) =	858	1049	*If VIVDS, code upstream start of Advance Detection Zone as CDA1; code downstream end as CDA2=CDA3.													
AWEGS Sign:			*CU is the thru phase passage gap set in signal controller unit (CU), or timer.													
Location (feet) =	475	540	<< --- Distance of Advance Warning Sign (W 3-4) to Stopline (feet).													
Series D Height (in.)	8.3	10.8	<< --- Desirable Letter Height of W 3-4 "Be Prepared to Stop" advance warning message on W 3-4 other sign (matrix) type. Recommended Minimum Letter Size = 6"D													
<b>Dilemma Zone Detectors</b>																
CDA1 (feet) =	475	540	<<--- Distance from upstream head of detector to downstream stopline, in feet.													

AWEGS Database for Design		Revise "Typical" Database to Local Conditions, as needed.	
"Typical"			
High Speed Coverage (%) =	99%	99%	AWEGS Percentile Coverage Standard for High Speeds (95%, 99%). Recommend 99%.
Set AWEGS W 3-4 at CDA1 =	TRUE	TRUE	Locate AWEGS W 3-4 Sign at CDA 1 (dilemma zone) detector station? True/False? (Yes/No?)
Minimum AWS Letter Height =	6.0	6.0	Minimum Advance Warning Sign Series D Letter Height, inches.
W 3-4 Sign Legibility Rate (ft/in)	50	50	Legibility Rate for W 3-4 Sign (feet/inch). Letter Series: D = 50 ft/in & C = 43 ft/in for good viewing conditions.
Offset to AWEGS W 3-4 (feet)	18.0	18.0	Offset from right travel lane (RTL) to center of W 3-4 Advance Traffic Control Sign, feet.
Advance Warning Time (sec)	2.5	2.5	Minimum Advance Warning Time to be Provided by AWEGS to approaching motorists.
Compute Time (sec) =	0.2	0.2	Maximum AWEGS Flash delay plus computer computational time, seconds.
TPRT (sec) =	1.0	1.0	AWEGS design Perception-Reaction Time to Yellow Onset for "No Go" decision.
Deceleration (f/ps) =	10.0	10.0	AWEGS design Auto deceleration rate for "No Go" decision to Yellow Onset.
Cover 85%-tile Speed Truck?	TRUE	TRUE	Locate AWEGS ADA detector to guarantee coverage of Trucks traveling at 85%-tile speed? True/False (Yes/No)
Truck Reduction (%) =	30%	30%	Percent reduction of Truck's Stopping deceleration rate w.r.t. cars. MnDOT recommends 20% reduction.
Speed Standard Deviation (m)	7.0	7.0	Standard Deviation of Approach Speeds, mph. = (V85-V50)/1.04
Speed-Trap Distance (feet) =	30.0	30.0	AWEGS ADA to BDA head-to-head speed-trap detector spacing, feet. Recommend 30' = ILD of 6' + 24' space gap. 24' is needed to separate trucks from cowboy crew-cab pickups.

Nader's Guide for Dilemma Zone Detectors						
Speed	Dilemma Zone Detector Locations			TxDOT CU Passage Gaps (sec)		
mph	head-to-stopline, feet			Nader	Rec. Min.*	Used**
45	330	210		2.0	2.8	3.0
50	350	220		2.0	2.8	3.0
55	415	320	225	1.2	1.6	2.0
60	475	375	275	1.4	1.5	2.0
65	540	430	320	1.2	1.6	2.0
70	600	475	350	1.2	1.7	2.0

\* Recommended Minimum for less than 1% gap out potential with no speed error.

\*\* Based on Field Observations.

