Chapter P2 Advance Warning Systems

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NOTE: *This document remains marked as "DRAFT" pending the addition of graphics, details, and additional ICWS guidance. Placeholders for these items are highlighted in yellow. PTSWF guidance is considered complete.*

P2.1 General

An Advanced Warning System (AWS) is and actuated system that provides advance warning of a condition which may require a vehicle to stop, but the condition is not always present. These systems consist of an actuation system, signs, and beacons. There are two primary types of AWS:

1. Prepare to Stop When Flashing (PTSWF). This type of system is installed on a signalized approach and activates when phase termination (the change from green to yellow) is about to occur. The goal of this type of system is to provide additional warning and decision time to drivers so that they can make a more controlled stop at the intersection, ideally resulting in reductions of hard stops, red light running, and rear-end collisions – particularly by large vehicles. Although normally used for traffic signals, this type of system can be modified to address any location where a temporary stop condition may be expected.

2. Intersection Conflict Warning System (ICWS). This type of system is installed on an approach where cross traffic may be entering the roadway, but may not be sufficiently visible for adequate stopping sight distance. Minor street warning signs may also be included.

P2.2 Warrants

An AWS may only be considered on intersection approaches with a posted speed of 45 MPH or greater for travel towards the intersection. Additionally, at least one of the following warrants must be met before an AWS may be considered (not all warrants apply to both system types):

Warrant 1: Isolated or Unexpected Signal (PTSWF Only)

The signalized intersection is located 10 miles or more from the last signalized intersection, is located at the end of a freeway/expressway, or in a similar location where a signal would not normally be expected. Document the condition that makes the signal unexpected for drivers on that approach. It should be noted that PTSWF systems are less effective in urban areas, where

there are a larger number of potential conflicts that may require a sudden stop and approach speeds are generally lower.

Warrant 2: Limited Sight Distance

The intersection is not visible within design stopping sight distance for that approach. Visibility for this situation depends on the type of intersection control:

1. For signalized intersections, visibility is the ability to see at least two signal displays (in case one display fails).

2. For non-signalized intersections, visibility is the ability to see a stopped vehicle on the cross road. This may be on one or more approaches, depending on conditions.

Limited Sight Distance is determined by Equation P2-1:

$$D \leq 1.47Vt + \frac{V_{85}^2}{0.93\left[a + 32.2\left(\frac{G}{100}\right)\right]} \qquad \textit{Equation (P2-1)}$$

Where:

- D =
  - For PTSWF: Distance to the stop line, in feet; Measured from where the second signal display for that approach becomes visible (such that if one display fails, the other is still visible).
  - For ICWS: Distance to the nearest crossroad lane edge (before the radius return starts), in feet; measured from where a stopped vehicle becomes visible.
- V_{85} = 85th Percentile Speed, in mph;

  If 85th percentile speed is not known, use posted speed plus 7 mph. (See Reference 7)
- t = 2.5; Perception-Reaction time, in seconds.
- a = deceleration rate, in feet / seconds^2;

  Use a = 8, unless trucks are prohibited on the approach. If trucks are prohibited on the approach, use a = 10. (See Reference 4)
- G = grade, in percent;

  Uphill approach is positive (+), downhill approach is negative (-).

Warrant 3: Truck Downhill Dilemma Zone (PTSWF Only)

On a downhill approach, the upstream end of the signal dilemma zone detection (UDZ_{90}) is closer to the stop line than the safe stopping sight distance for trucks (SSD_T), as determined by Equations P2-2, P2-3, and P2-4:

$$UDZ_{90} < SSD_T \qquad \textit{Equation (P2-2)}$$

$$UDZ_{90} = \frac{V_{90}^2}{2\left[a + 32.2\left(\frac{G}{100}\right)\right]} \qquad \textit{Equation (P2-3)}$$

$$SSD_T = 1.47Vt + \frac{V_{85}^2}{0.93\left[a + 32.2\left(\frac{G}{100}\right)\right]} \qquad \textit{Equation (P2-4)}$$

Where:

- V_{90} = 90th Percentile Speed, in mph;

  If 90th percentile speed is not known, use posted speed plus 12 mph. (See Reference 7 for 85th Percentile Speed; Estimated V_{90} is V_{85} + 5 MPH)
- a = 8; deceleration rate, in feet / seconds^2. (See Reference 4)
- G = grade, in percent; G is always negative (-).
- V_{85} = 85th Percentile Speed, in mph;

  If 85th percentile speed is not known, use posted speed plus 7 mph. (See Reference 7)
- t = 2.5; Perception-Reaction time, in seconds.

Warrant 3 may not be used if trucks are prohibited on the approach.

Warrant 4: General Truck Downgrade

The approach has a downgrade of 3% or greater and greater than 15% truck volume.

Warrant 5: Collision History

There is a documented history of collisions on the approach, which have not been correctable through other means.

Warrant 6: Engineering Judgement

An Engineering Study or documented evidence of issues such as verified complaints, field observations of red light running, field observations of hard braking or skid marks (particularly from large trailers), or similar may be determined to justify an AWS. Requires approval from the Region Traffic Engineer.

P2.3 Preliminary Countermeasures

The following countermeasures must be attempted, and shown to be insufficient, in the order shown below, before implementing an AWS:

1. Installation or Revision of Dilemma Zone Detection, as applicable (PTSWF only).
2. Improving sight distance, including obstruction removal or adding supplemental signal displays.
3. Speed limit revisions, if possible.
4. Revision of signal timing – Yellow Clearance Interval, in particular (PTSWF only).
5. Installation of a single 48" x 48" Signal Ahead (W3-3) sign or applicable W Series Intersection Warning (W2-1 Cross Road Symbol, W2-2 Side Road Symbol, etc.) sign.
6. Installation of dual (gated) 48" x 48" Signal Ahead (W3-3) signs or applicable W Series Intersection Warning signs, for two lane, three lane, and divided (median or barrier with sufficient shoulder width) highways.
7. Installation of a single 48" x 48" Signal Ahead (W3-3) sign or applicable W Series Intersection Warning sign with continuous or actuated (actuated preferred), alternating flashing beacons.

For traffic signal systems, evaluation of countermeasures should be done as part of signal operations preventative maintenance/routine evaluation (at a minimum – more frequently is acceptable), and documentation should be included in the SIMMS Database.

P2.4 Design

P2.4(1) Placement

P2.3(1)(a) Major Roadway Signs

AWS signs shall be installed on the major roadway (typically the mainline highway) at a location determined by Equation P2-5:

$$D_S = \left\{ 1.47Vt + \frac{V_{85}^2}{30\left[\frac{a}{32.2} + \left(\frac{G}{100}\right)\right]} \right\} - 50 \qquad \textit{Equation (P2-5)}$$

Where:

- D_S =
  - For PTSWF: Distance to the stop line, in feet.
  - For ICWS: Distance to the nearest crossroad lane edge (before the radius return starts), in feet.
- V_{85} = 85th Percentile Speed, in mph;

  if 85th percentile speed is not known, use posted speed plus 7 mph (See Reference 7)

- t = 2.5; Perception-Reaction time, in seconds
- a = 8 or 10; deceleration rate, in feet / seconds^2;

  Use a = 8 unless trucks are prohibited on the approach. (See Reference 4)
- G = grade, in percent; uphill approach is positive (+), downhill approach is negative (-)

Note: The sign position is 50 feet closer to the intersection (-50 at end of Equation P2-5) than the actual calculated stopping sight distance in an effort to allow for a response to beacon actuation right up to the calculated stopping sight distance (a sign at the calculated stopping sight distance cannot be seen from the calculated stopping sight distance).

The AWS sign location on the major roadway is dependent on the number of through lanes on the approach:

- For a single lane approach, one AWS sign shall be installed on the right shoulder of the roadway.
- For a multilane approach with a median or barrier with sufficient shoulder width, two AWS signs shall be installed – one on each side of the approach.
- For a multilane approach without a median, one overhead sign shall be installed. As an alternative, two modified overhead signs may be shoulder mounted if there is sufficient visibility of the left sign across the oncoming traffic lanes. Ground mounting should not be considered for highways with high average daily traffic (ADT).

For convenience, typical major roadway sign placement locations are shown in the table in Section P2.6. Exhibit P2-1 shows the basic concept of major roadway sign placement.

- Placeholder, Exhibit P2-1

P2.3(1)(b) Minor Roadway Signs (ICWS Only)

For ICWS, it may be appropriate to include warning signs for the minor roadway, such as if there are issues with minor roadway gap acceptance. When used, minor roadway signs are placed on the far right corner of the intersection from the minor roadway approach (or equivalent location if a T intersection). Exhibit P2-2 shows the basic concept of minor roadway sign placement.

- Placeholder, Exhibit P2-2

P2.3(1)(c) ICWS Sensors

Placeholder for ICWS System Sensor Placement. To be provided in future version of this document.

P2.4(2) Construction

Standard ground mounted AWS signs shall be installed on a Type FB Signal Standard with Alternating Beacons as shown in the *Standard Plans*. The beacons shall be increased in size to 12-inch diameter displays and include backplates (no reflective tape). Overhead mounted signs must be installed on a cantilever sign structure, due to their size. Overhead signs shall include two 12-inch diameter yellow displays, one in each upper corner.

P2.4(2)(a) PTSWF Signs

Signs shall be a standard 48" x 48" W3-3 (Signal Ahead Symbol) with a W11-101 (MOD.) sign reading "BE PREPARED TO STOP WHEN FLASHING". The standard arrangement is shown in Exhibit P2-3. A construction plan sheet is available from the Plan Sheet Library as part of Detail IS-##.

- Placeholder, Exhibit P2-3

Overhead mounted signs shall be 108" wide by 78" high, and includes a 30" x 30" W3-3 (Signal Ahead Symbol) on a black background, with the text "PREPARE TO STOP WHEN FLASHING" beneath it. The standard arrangement is shown in Exhibit P2-4. The modified ground version is shown in Exhibit P2-5. Both versions are available from the Plan Sheet Library as part of Detail IS-##.

- Placeholder, Exhibit P2-4

- Placeholder, Exhibit P2-5

P2.4(2)(b) ICWS Signs

Placeholder for ICWS System Construction Information. To be provided in future version of this document.

P2.5 Operation

The operation of an AWS system depends on the type of AWS System.

P2.5(1) PTSWF Operation

PTSWF systems are designed to start flashing before the start of the Yellow Change Interval and remain flashing until the start of the next green phase. The amount of time the system flashes before the Yellow Change Interval starts is determined by Equation P2-6:

$$AWT = \frac{D + D_P}{1.47V_{85}} \qquad \textit{Equation (P2-6)}$$

Where:

- AWT = Advance Warning Time, in seconds.
- D = Distance to the stop line, in feet;

  Measured from where the PTSWF sign is located.
- D_P = 70; PTSWF sign perception distance, in feet.
- V_{85} = 85th Percentile Speed, in mph;

  If 85th percentile speed is not known, use posted speed plus 7 mph. (See Reference 4)

The system shall also flash if the associated traffic signal system goes into flash. The PTSWF beacons shall always flash alternately.

For convenience, typical Advance Warning Times are shown in the table in Section P2.6

P2.5(2) ICWS Operation

Placeholder for ICWS Operational Guidance. To be provided in future version of this document.

P2.6 Quick Reference Table

The following table is provided as a quick reference guide for AWS sign placements and Advance Warning Times for basic grades and posted speeds **where the 85th percentile speed is not known**. Where the 85th percentile speed is known, the sign placement distance and Advance Warning Time must be calculated as described in Sections P2.4 and P2.5.

		Trucks Allowed (deceleration rate = 8 ft/s^2)								Trucks Prohibited (deceleration rate = 10 ft/s^2)							
Speed (mph) ➡		45		50		55		60		45		50		55		60	
Grade ⬇		D	AWT	D	AWT	D	AWT	D	AWT	D	AWT	D	AWT	D	AWT	D	AWT
Downhill	-8%	676	9.8	802	10.4	939	11.1	1085	11.7	532	7.9	629	8.3	734	8.8	845	9.3
	-7%	646	9.4	766	10.0	896	10.6	1035	11.2	516	7.7	610	8.1	710	8.6	818	9.0
	-6%	619	9.0	734	9.6	858	10.2	990	10.8	501	7.5	592	7.9	689	8.3	793	8.8
	-5%	595	8.7	705	9.3	824	9.8	950	10.4	487	7.3	575	7.7	670	8.1	771	8.5
	-4%	574	8.4	679	8.9	793	9.5	914	10.0	474	7.1	560	7.5	651	7.9	749	8.3
	-3%	554	8.2	655	8.7	764	9.2	881	9.7	462	7.0	545	7.3	635	7.7	730	8.1
	-2%	536	7.9	634	8.4	739	8.9	851	9.4	451	6.8	532	7.2	619	7.6	711	7.9
	-1%	519	7.7	614	8.2	715	8.6	824	9.1	441	6.7	520	7.0	604	7.4	694	7.8
	0%	504	7.5	595	7.9	694	8.4	798	8.8	431	6.6	508	6.9	590	7.2	678	7.6
Uphill	1%	490	7.3	579	7.7	674	8.2	775	8.6	422	6.4	497	6.8	578	7.1	663	7.4
	2%	477	7.2	563	7.6	655	8.0	754	8.4	414	6.3	487	6.6	565	7.0	649	7.3
	3%	465	7.0	548	7.4	638	7.8	734	8.2	406	6.2	477	6.5	554	6.8	636	7.2
	4%	454	6.8	535	7.2	622	7.6	715	8.0	398	6.1	468	6.4	543	6.7	623	7.0
	5%	443	6.7	522	7.1	607	7.4	698	7.8	391	6.0	460	6.3	533	6.6	611	6.9
	6%	433	6.6	511	6.9	593	7.3	681	7.6	384	5.9	452	6.2	524	6.5	600	6.8
	7%	424	6.5	500	6.8	580	7.1	666	7.5	378	5.9	444	6.1	515	6.4	589	6.7
	8%	416	6.4	489	6.7	568	7.0	652	7.3	372	5.8	437	6.0	506	6.3	579	6.6

P2.7 References

The following references are used in the development of this chapter:

1. B.A. Farraher, R. Weinholzer and M.P. Kowski, "The Effect of Advanced Warning Flashers on red-light Running-A Study Using Motion Imaging Recording System Technology at Trunk Highway 169 and Pioneer Trail in Bloomington, Minnesota."
2. British Columbia Ministry of Transportation and Infrastructure, Electrical and Traffic Engineering Manual (2013), Section 402.6.9 (http://www.th.gov.bc.ca/publications/eng_publications/electrical/electrical_and_traffic_eng/Electrical_Signing_Design_Manual/tableofcontents.htm)
3. Donnell, ET, ML Adolini, DJ Torbic, JM Mason, & Lily Elefteriadou. "Truck Safety Considerations for Geometric Design and Traffic Operations." Proceedings of the ITE 2001 Annual Meeting and Exhibit, Chicago, IL: 2001. (https://nacto.org/docs/usdg/truck_safety_considerations_for_geometric_design_and_traffic_operations_donnell.pdf)
4. Minnesota DOT (MnDOT) Traffic Signal Timing and Coordination Manual, 2017, Section 4.14: Guidelines for Consideration and Timing of Advanced Warning Flashers; http://www.dot.state.mn.us/trafficeng/signals/manual.html
5. Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD) (2018), Chapter 4O, Advance Warning Flashers (http://www.dot.state.mn.us/trafficeng/publ/mutcd/)
6. NCHRP Report 505 – Review of Truck Characteristics as Factors in Roadway Design, Transportation Research Board, Washington, DC, 2003 (http://www.trb.org/Publications/Blurbs/153579.aspx)
7. NCHRP Report 731 – Guidelines for Timing Yellow and All Red Intervals at Signalized Intersections, Transportation Research Board, Washington, DC, 2013 (http://www.trb.org/Publications/Blurbs/168017.aspx)
8. Ohio Department of Transportation (ODOT) Traffic Engineering Manual (2018), Section 407-2 Prepare to Stop When Flashing Signs (W3-H4a) (http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/traffic/TEM/Pages/default.aspx)
9. P. D. Pant, X. H. Huang. "Active Advance Warning Signs at High-Speed Signalized Intersections: Results of a Study in Ohio," Transportation Research Record, no. 1368 (1992): 18-26. (http://onlinepubs.trb.org/Onlinepubs/trr/1992/1368/1368-003.pdf)
10. T. Sayed, H. Vahidi, and F. Rodriguez, "Advanced Warning Flashers: Do They Improve Safety?" Transportation Research Record 1692, (Washington, DC: Transportation Research Board, 1999). (https://trrjournalonline.trb.org/doi/abs/10.3141/1692-05)

11. TTI Report FHWA/TX-04/0-4260-2, Design and Installation Guidelines for Advance Warning Systems for End-of-Green Phase at High Speed Traffic Signals (2003) (https://tti.tamu.edu/publications/catalog/record/?id=9128)

12. TTI Report FHWA/TX-04/0-4260-4, Development of Advance Warning Systems for End-of-Green Phase at High Speed Traffic Signals (2004) (https://tti.tamu.edu/publications/catalog/record/?id=9130)

13. Virginia DOT Traffic Engineering Instructional and Informational Memorandum TE-348, Traffic Signal Controller Actuated Warning Beacons, May 2007 (http://www.virginiadot.org/business/traffic_engineering_memoranda.asp)