

1. Report No. FHWA/TX-05/0-4084-P1		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle GUIDELINES FOR THE USE OF COUNTERMEASURES TO REDUCE CRASHES ON APPROACHES TO SIGNALIZED INTERSECTIONS NEAR VERTICAL CURVES				5. Report Date September 2004	
				6. Performing Organization Code	
7. Author(s) Paul A. Barricklow and Marc S. Jacobson				8. Performing Organization Report No. Product 0-4084-P1	
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. Project 0-4084	
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin, Texas 78763-5080				13. Type of Report and Period Covered Product	
				14. Sponsoring Agency Code	
15. Supplementary Notes Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration. Project Title: Countermeasures to Reduce Crashes at Signalized Intersections near Vertical Curves URL: http://tti.tamu.edu/documents/0-4084-P1.pdf					
16. Abstract The research described herein documents an investigation into countermeasures that can be used to provide motorists with advance notification of traffic signals or queues from those signals that are located beyond the motorists' line of sight due to a vertical curve. A "reduced decision zone" (RDZ) was identified in the research as the location along a roadway with a vertical curve and a traffic signal beyond the curve where stopping sight distance (SSD) is provided but decision sight distance (DSD) is not. Essentially, motorists within the RDZ are provided with SSD for unexpected stopping but are not provided with the added decision-making and response time that DSD might otherwise provide as they approach the vertical curve and the downstream traffic signal. Contained within this report are techniques for determining whether an RDZ exists along an existing roadway. In cases where a traffic signal or queue from a signal is located within the RDZ, guidance is provided on both the type and location of countermeasures that can be used.					
17. Key Words Signal, Vertical Curve, Sight Distance				18. Distribution Statement	
19. Security Classif.(of this report)		20. Security Classif.(of this page)		21. No. of Pages 20	22. Price

**GUIDELINES FOR THE USE OF COUNTERMEASURES TO REDUCE
CRASHES ON APPROACHES TO SIGNALIZED INTERSECTIONS NEAR
VERTICAL CURVES**

by

Paul A. Barricklow
Assistant Transportation Researcher
Texas Transportation Institute

and

Marc S. Jacobson, P.E.
Assistant Research Engineer
Texas Transportation Institute

Product 0-4084-P1

Project 0-4084

Project Title: Countermeasures to Reduce Crashes at Signalized
Intersections near Vertical Curves

Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

September 2004

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

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

ACKNOWLEDGMENTS

This research was conducted during a two-year project under a cooperative research program between the Texas Transportation Institute (TTI), TxDOT, and FHWA. Imelda Barrett of the TxDOT Austin District was the project director (PD). Other TxDOT members of the Project Monitoring Committee included Brian Van De Walle, David Mitchell, Chuck Ansley, Arnold Ramirez (retired), Bill Tucker (retired), and Peter Eng. Ali Mozdbar of the City of Austin, Texas, also served on the Project Monitoring Committee. Tom Beeman of the Traffic Operations Division was the program coordinator, and Wade Odell of TxDOT's Research and Technology Implementation Office was an active participant in project management meetings. Angelia Parham, Michael Martello, Gary Barricklow, Mark Wooldridge, and Hassan Charara of TTI also contributed to the materials used in this report. Angelia Parham and Mike Martello helped with literature and site reviews, Mark Wooldridge provided guidance on data collection techniques, Hassan Charara assisted with field implementation, and Gary Barricklow conducted field studies.

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GUIDELINES FOR THE USE OF COUNTERMEASURES TO REDUCE CRASHES ON APPROACHES TO SIGNALIZED INTERSECTIONS NEAR VERTICAL CURVES

INTRODUCTION

Signalized intersections located at or near the bottom of a crest vertical curve have the potential to experience higher crash rates than other similar signalized intersections. Two common effects that occur when signals are located near vertical curves are a reduction in the sight distance to the signal heads and a reduction in the sight distance to the back of the queue waiting at a signal. If the traffic signal heads and/or the end of the queue are not visible due to the crest of the curve, drivers may not have sufficient time to react in order to avoid a crash. [Figure 1](#) demonstrates these issues from the driver's perspective. In part a of the figure, the driver cannot see the signal heads for the approaching intersection. In part b, the driver can see the signal heads but not the back of queue. The waiting vehicles are illustrated in part c.

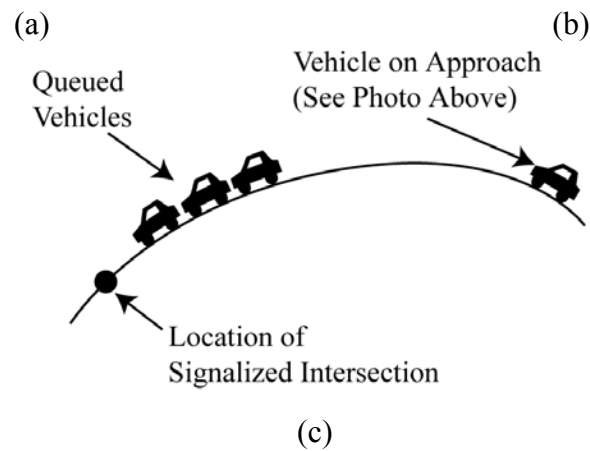


Figure 1. Reduced Sight Distance on the Approach to Signalized Intersections near Vertical Curves.

When the geometry of the roadway prevents a driver from seeing the signal heads or the back of the queue with enough time to appropriately react and, if necessary, stop, increased accidents, red-light running, or other erratic maneuvers (such as hard deceleration) may result. These intersections present complex situations to the driver that require more time to perceive and react appropriately to the situation. Thus they are candidates for the provision of decision sight distance (DSD) rather than stopping sight distance (SSD).

Since reconstruction of the approach to provide DSD is usually not feasible, countermeasures can be used to communicate to the driver the situation ahead that is beyond the available sight distance. The countermeasures could be passive devices that constantly display the same message, or they could be active devices that offer a varying message depending on the state of the traffic signal or presence of a queue.

This document provides some information on available countermeasures and presents some guidelines for their use at signalized intersections near vertical curves.

TMUTCD STANDARDS AND GUIDANCE

The *Texas Manual on Uniform Traffic Control Devices* (TMUTCD) provides some guidance on the use and placement of advance warning signs prior to signalized intersections (1). The TMUTCD states that the SIGNAL AHEAD warning sign shall be used on approaches to signalized intersections that are “not visible for a sufficient distance to permit the road user to respond to the device.” Furthermore, the TMUTCD states that two signal heads must be visible for the distance listed in Table 1 in order to be considered “visible.”

Table 1. Guidelines for the Location of Advance Warning Signs and Required Visibility Distance (1).

85th Percentile Speed (mph)	Sign Placement (ft) ¹ [MUTCD Table 2C-4]	Visibility Distance (ft) [MUTCD Table 4D-1]
30	100	270
35	150	325
40	225	390
45	300	460
50	375	540
55	450	625
60	550	715

¹Typical condition is the warning of a potential stop situation. Typical signs are STOP AHEAD, YIELD AHEAD, or SIGNAL AHEAD. The distances are based on the 1990 AASHTO policy for stopping sight distance (page 120) providing a PIEV time of 2.5 seconds, friction factor of 0.30 to 0.40, minus the sign legibility distance of 50 m (175 ft).

The TMUTCD also provides for the use of a BE PREPARED TO STOP sign in situations where the driver needs additional warning about stopped or queued traffic near traffic signals where queues occur regularly. If this sign is used, it must be accompanied by the SIGNAL AHEAD sign. Flashing beacons may be used to supplement the warning sign. The

TMUTCD encourages the use of the WHEN FLASHING plaque when flashing beacons that are connected with the traffic signal are used although it is not required.

AVAILABLE COUNTERMEASURES

In many cases the signalized intersection will not be clearly visible at the appropriate DSD due to the crest of the preceding vertical curve. In this situation another type of warning device should be installed at the appropriate distance to provide adequate warning time. These devices could range from a simple SIGNAL AHEAD sign to an active warning sign that provides information on the current indication of the traffic signal.

Symbolic SIGNAL AHEAD Warning Signs

The use of the SIGNAL AHEAD warning sign (TMUTCD designation W3-3) is thoroughly covered in the TMUTCD. This sign may be used by itself (Figure 2a), with continuously flashing or actuated beacons (Figure 2b), or with actuated flashing beacons and a supplemental plaque warning motorists to be prepared to stop (Figure 2c).

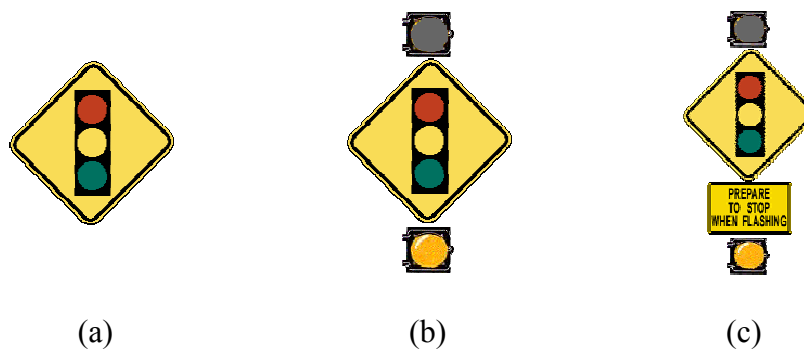


Figure 2. Uses of the Symbolic SIGNAL AHEAD Warning Sign.

Several studies compared drivers' reaction to the several configurations of SIGNAL AHEAD signs. The results found that the sign with the continuously flashing beacons produced results similar to the standard sign (without beacons). The sign with actuated beacons was effective in reducing approach speeds during the red interval and reducing red-light violations; however, the use of these signs tended to increase approach speeds during the green interval when the state of the signal was clearly visible from the sign location (2, 3, 4, 5). Since the SIGNAL AHEAD sign is used at many intersections, its use to distinguish a special circumstance, such as a signal hidden by a vertical curve, may have limited effectiveness.

BE PREPARED TO STOP Warning Signs

A second group of signs warns the motorist that they may have to stop ahead. Again, combinations of static signs, continuously flashing beacons, and actuated beacons can be used as shown in Figure 3. The BE PREPARED TO STOP signs (TMUTCD designation W20-7b) are versatile in that they are applicable in warning the motorist they should be prepared for either a

yellow or red signal ahead or a queue of stopped vehicles. Thus, actuated flashing beacons, if used, could be connected to either the traffic signal or a queue detector.

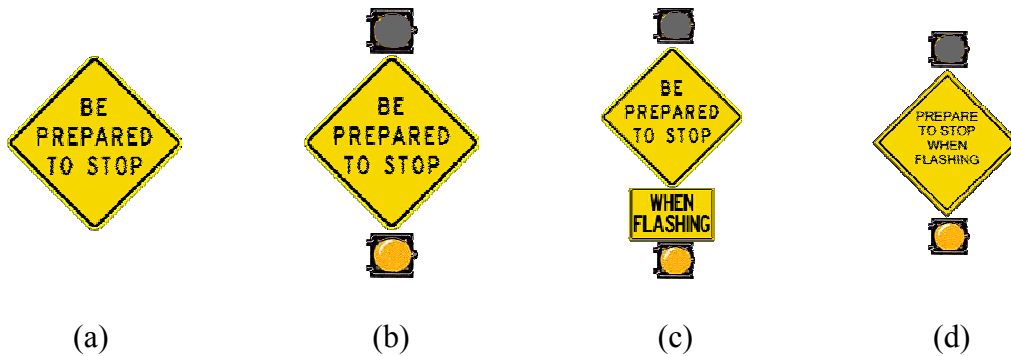


Figure 3. Uses of the BE PREPARED TO STOP Family of Signs.

WATCH FOR STOPPED VEHICLES Warning Signs

When the traffic signal heads are visible for an adequate distance but the back of the queue is hidden by the vertical curve, the use of the WATCH FOR STOPPED VEHICLES sign could be considered. This sign could be used with or without continuously flashing or actuated beacons. If actuated beacons are used, they should be connected to a queue detector and not to the active signal phase. This is to allow for the fact that stopped vehicles may remain for some time after a signal has turned green. Examples of this sign are shown in Figure 4. It should be noted, however, that the WATCH FOR STOPPED VEHICLES sign is not explicitly contained within either the state TMUTCD (1) or the national MUTCD (6).

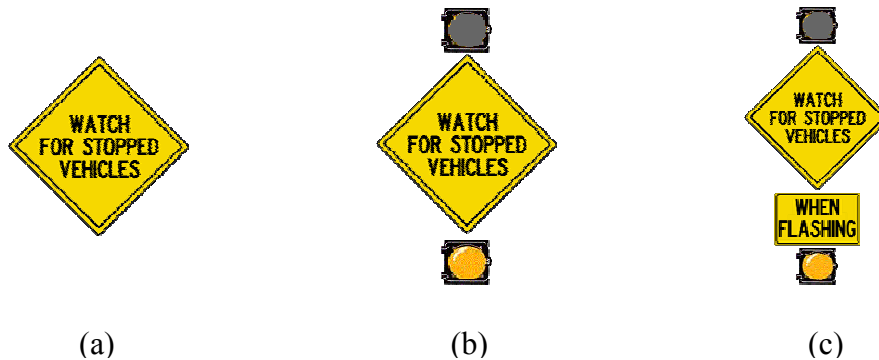


Figure 4. Uses of the WATCH FOR STOPPED VEHICLES Sign.

Additional Countermeasures

Several additional countermeasures have been used or could be applied in situations where a signalized intersection is located near a vertical curve.

HILL BLOCKS VIEW Sign

The HILL BLOCKS VIEW sign has been shown to be understood by most drivers. This sign is intended to replace the more vague LIMITED SIGHT DISTANCE sign and the undesirable HIDDEN INTERSECTION and DANGEROUS INTERSECTION signs. A symbolic version of this sign is used in Canada.

RED SIGNAL AHEAD Sign

The RED SIGNAL AHEAD sign is an actuated warning sign that is connected to the traffic signal. This sign displays the word “RED” in red letters only when the signal ahead is red (or will be red when the vehicle reaches the intersection). When the signal ahead is green, the sign simply reads SIGNAL AHEAD.

Variable Message Sign

An overhead or side-mounted variable message sign may be used on the approach to the signal to display a variety of messages to the driver. This sign could be connected to a queue detector and/or a traffic signal. This device is usually more expensive than other similar devices (i.e., signs with flashing beacons).

Rumble Strips

In-lane rumble strips may be used in conjunction with an advance warning sign to alert the driver to a situation that requires special attention. Studies have found that the installation of rumble strips should be limited to only a few locations in order to maximize their effectiveness. Furthermore, rumble strips should be considered a secondary warning device after another type of warning device has been implemented on an approach.

Supplemental High-Mounted Signal Head

In situations where the sight distance to the signal heads themselves is limited, a supplemental, high-mounted signal head could be used to increase the available sight distance. This countermeasure is most effective in situations where the back of the queue is visible but the signal heads themselves are not.

GUIDELINES FOR THE USE OF RECOMMENDED COUNTERMEASURES

Countermeasures should be considered at signalized intersections near vertical curves when the intersection or back of queue is located within a length of roadway along the approach to a signalized intersection where SSD is provided (by applying geometric design standards) but DSD is not. This region, labeled here as a “reduced decision zone” (RDZ), means that though drivers have adequate time for perceiving a need to stop and performing that action, they do not necessarily have additional time to correctly react to an unexpected signal or back of queue.

Another guideline for installing countermeasures is when a crash study at the signalized intersection reveals that there is an above average number of rear-end or right-angle collisions

involving vehicles from the approach with the vertical curve. Countermeasures have also been shown to be useful in reducing the number of red-light violations on the approach.

Due to its versatility in application and its thorough definition in the TMUTCD, the BE PREPARED TO STOP sign is recommended as the countermeasure that should be considered in the above defined situations. Continuous flashers can accompany the BE PREPARED TO STOP sign as attention-getting devices. Active flashers can be used where a queue detection system is in operation. In such a system the flashers would only be deactivated when the signal is green and the queue on the approach has cleared. Active flashers may also be used when the flashers are connected to the signal (i.e., flashing when the signal is yellow or red for the approach); however, due to uncertainty about the presence of a queue, active operation is suggested over continuous flashing only when a queue detection system is in place.

The BE PREPARED TO STOP sign should be used in conjunction with the SIGNAL AHEAD sign as described in the TMUTCD. The SIGNAL AHEAD sign should be located on the approach following the guidelines for placement that are available in the TMUTCD (as found in [Table 1](#)). The additional countermeasure, the BE PREPARED TO STOP sign, should be located such that it is legible at the beginning of the RDZ on the approach. Since the RDZ is dependent upon the geometry of the vertical curve, it is once again useful to refer to charts to determine the sign placement location. The chart shown in [Figure 5](#) should be used to locate signs on rural roadways. The chart in [Figure 6](#) should be used in urban locations. In both cases, the figure identifies the beginning of the RDZ. Since standard signs are visible at 175 feet (*I*), the actual sign location will be 175 feet closer to the vertical point of intersection (VPI) than [Figure 5](#) or [Figure 6](#) indicate.

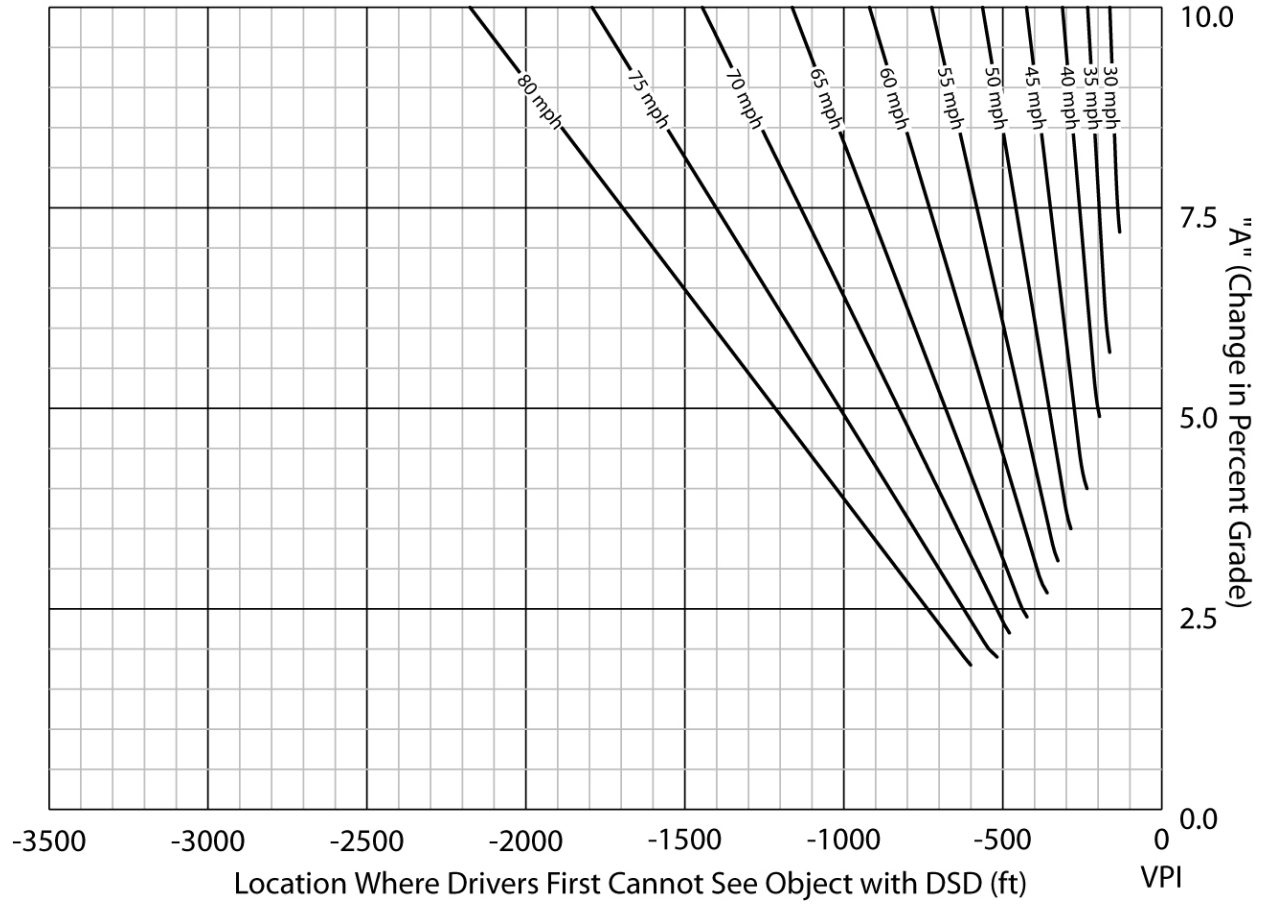


Figure 5. Countermeasure Placement Location for Rural Roadway Applications.

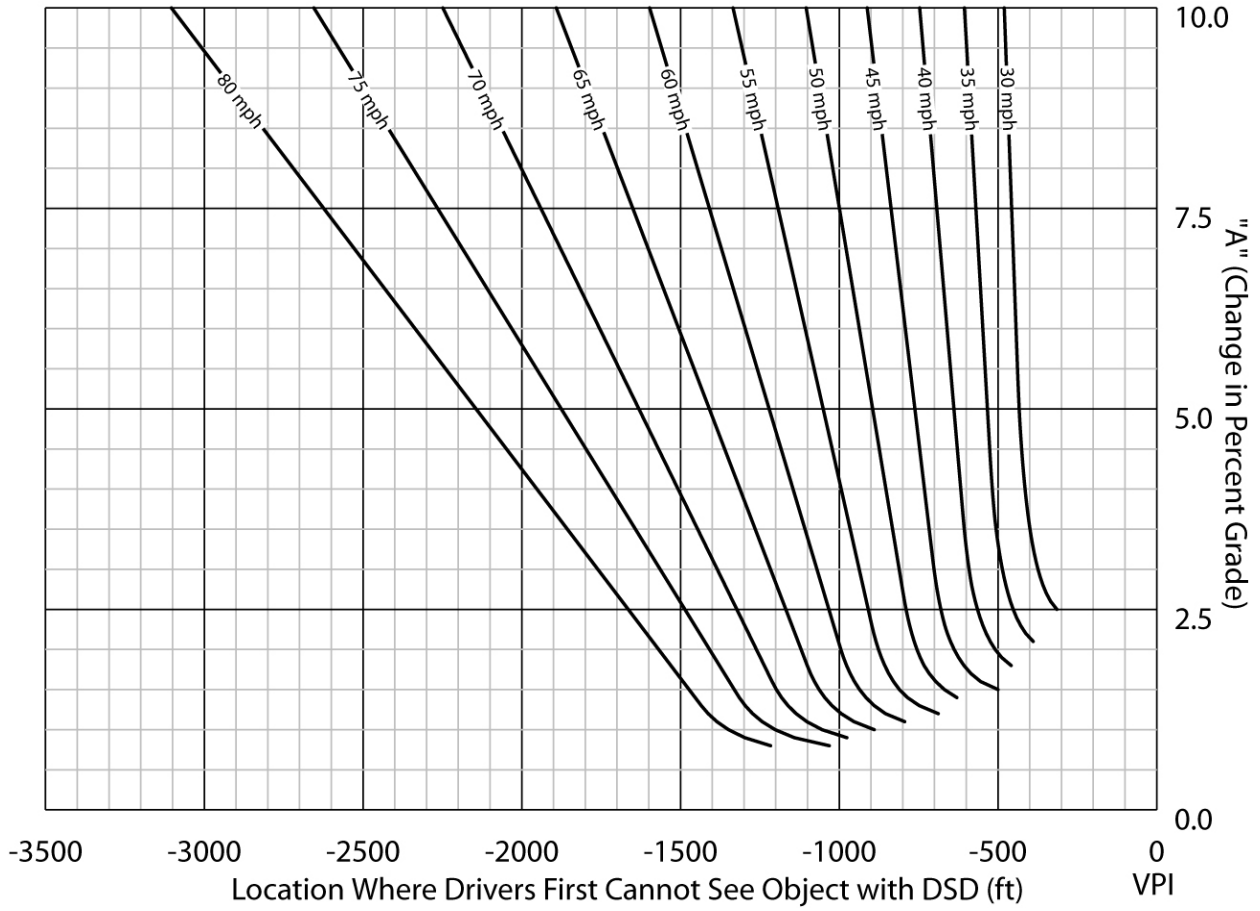


Figure 6. Countermeasure Placement Location for Urban Roadway Applications.

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