Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-14/9-1001-14-1		
4. Title and Subtitle TRAFFIC CONTROL DEVICE EVALUATION PROGRAM: TECHNICAL REPORT		5. Report Date Published: March 2015 6. Performing Organization Code
7. Author(s) Paul J. Carlson, Laura L. Higgins, Michael P. Pratt, Melisa D. Finley, LuAnn Theiss, William F. Williams, Vichika Iragavarapu, Myunghoon Ko, and Alicia A. Nelson		8. Performing Organization Report No. Report 9-1001-14-1
9. Performing Organization Name and Address Texas A&M Transportation Institute College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 9-1001-14
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office 125 E. 11th Street Austin, Texas 78701-2483		13. Type of Report and Period Covered Technical Report: August 2013–August 2014 14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Traffic Control Device Evaluation Program
URL: http://tti.tamu.edu/documents/9-1001-14-1.pdf

16. Abstract

This project provides the Texas Department of Transportation with a mechanism to quickly and effectively conduct high-priority, limited scope evaluations of traffic control devices. Work during the 2013–2014 fiscal year included three main tasks: updating the Texas Curve Advisory Speed (TCAS) program, testing alternatives to the existing exit gore sign requirements, and evaluating pilot vehicles and portable traffic control signals with and without a flagger.

The TCAS program was developed to assist practitioners in the implementation of the guidelines for setting curve advisory speeds and choosing curve traffic control devices. Researchers updated the calculations contained within the TCAS program to reflect the guidelines in the *Texas Manual on Traffic Control Devices* (TMUTCD). Researchers also added a new set of calculations so that users have the choice of applying either the TMUTCD or the *Procedures for Establishing Speed Zones*.

Exit gore signs are often hit and require constant maintenance, which puts maintenance crews at risk. The study's objective was to develop potential alternative(s) to provide the road user the same level of information but reduce or eliminate the risk during maintenance. Researchers selected alternative exit gore treatments to test in TTI's driving simulator. The vertical chevron paired with chevron pavement markings performed consistently well, but none of the alternative treatments performed notably poorly.

Typically, flaggers direct traffic when a lane on a two-lane, two-way road is closed for construction or maintenance, but Texas also uses portable traffic control signals and pilot vehicles to control operating speeds within the lane closure. Researchers conducted field studies to test driver compliance, and overall, only 3 percent of drivers did not comply with the portable traffic control signals and pilot vehicle for both conditions studied (with and without a flagger). Researchers also developed a tool to help pilot vehicle drivers estimate the minimum green time needed to clear the vehicle queue at the portable traffic signal.

The report also discusses two ongoing tasks: coordinating state asset data collection efforts and evaluating rumble devices.

17. Key Words	18. Distribution Statement
Texas Curve Advisory Speed, TCAS, Exit Gore, Pavement Markings, Delineators, Driving Simulator, Flagger	No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia 22312 http://www.ntis.gov

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	120	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

TRAFFIC CONTROL DEVICE EVALUATION PROGRAM: TECHNICAL REPORT

by

Paul J. Carlson, Ph.D., P.E.
Research Engineer
Texas A&M Transportation Institute

Laura L. Higgins
Associate Research Scientist
Texas A&M Transportation Institute

Michael P. Pratt, P.E.
Assistant Research Engineer
Texas A&M Transportation Institute

Melisa D. Finley, P.E.
Research Engineer
Texas A&M Transportation Institute

LuAnn Theiss, P.E.
Associate Research Engineer
Texas A&M Transportation Institute

William F. Williams, P.E.
Associate Research Engineer
Texas A&M Transportation Institute

Vichika Iragavarapu, P.E.
Assistant Research Engineer
Texas A&M Transportation Institute

Myunghoon Ko, Ph.D., P.E.
Associate Transportation Researcher
Texas A&M Transportation Institute

and

Alicia A. Nelson
Associate Research Specialist
Texas A&M Transportation Institute

Report 9-1001-14-1
Project 9-1001-14
Project Title: Traffic Control Device Evaluation Program

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

Published: March 2015

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

DISCLAIMER

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

ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA, and the authors thank the members of the Project Monitoring Committee for their assistance. The research team also thanks Christine Yager for her assistance in collecting data.

The authors thank Carl Johnson of the Brownwood District and the TxDOT Brady and San Saba maintenance crews for their assistance with the pilot vehicle and portable traffic control signal data collection.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

Page

CHAPTER 1. UPDATING THE TEXAS CURVE ADVISORY SPEED PROGRAM TO REFLECT NEW TRAFFIC CONTROL DEVICE GUIDELINES

BACKGROUND

The Texas Curve Advisory Speed (TCAS) program was developed to assist practitioners in the implementation of the guidelines developed in Project 0-5439 for setting curve advisory speeds and choosing curve traffic control devices. Regarding the selection of traffic control devices, the guidelines in the original version of TCAS involved choosing devices (including warning signs, advisory speed plaques, delineators, Chevrons, and others) based on the principles of side friction and kinetic energy differentials, as computed from vehicle speeds on the approach tangent and in the curve. Chapter 4 of the *Horizontal Curve Signing Handbook, Second Edition* (*1*), referred to hereafter as the *Handbook*, includes a description of these guidelines.

The engineering study methods for setting curve advisory speeds that were developed in Projects 0-5439 and 5-5439 (*2*, *3*) are now included in the 2012 edition of the Texas Department of Transportation's (TxDOT's) *Procedures for Establishing Speed Zones* (*4*), which the remainder of this report refers to as the *Procedures* document. The methods included in the *Procedures* document are acknowledged in the *Texas Manual on Uniform Traffic Control Devices* (TMUTCD). The previously used ball-bank indicator method has been phased out of policy documents. The principal advisory speed engineering study method from Project 5-5439 is the Global Positioning System (GPS) Method, but several alternative methods were also developed, including the Direct Method, the Design Method, and the Compass Method.

Table 1 shows the timeline of publication for the relevant policy documents and compliance dates. The guidelines in the *Handbook* were developed in 2007, and the *Handbook* was published in its most current form in 2009. At the time of publication of the *Handbook*, the 2006 edition of the TMUTCD was in effect (*5*). The updated federal *Manual on Uniform Traffic Control Devices* (MUTCD) was published shortly thereafter, in December 2009 (*6*). Table 2C-5 of the MUTCD provides guidelines for selecting curve traffic control devices based on speed differential, as computed from the posted regulatory speed limit and curve advisory speed. These guidelines were adopted in the 2011 TMUTCD (and its subsequent 2012 revision) as Table 2C-5 (*7*).

The *Procedures* document contains a compliance date of January 1, 2015, for the updating of curve advisory speeds using the new engineering study methods from Projects 0-5439 and 5-5439. The TMUTCD contains a Federal Highway Administration (FHWA)–established compliance date of December 31, 2019, for the posting of horizontal alignment warning signs, including the guidelines in Table 2C-5. As a result of these compliance dates, district practitioners are now implementing the GPS Method and using the TCAS program to check both their advisory speeds and the need for devices like delineators and Chevrons. However, because the TCAS program's guidelines for choosing traffic control devices do not reflect the guidelines in Table 2C-5 of the TMUTCD, practitioners who apply the recommendations provided by TCAS may treat curves in a manner that is not consistent with TMUTCD requirements. In some cases, this discrepancy may include the choice of whether or not to post an advisory speed plaque, which in turn may affect the need for posting Chevrons.

Table 1. Timeline of Policy Changes and Documents.

Date	Policy or Documentation Change
2006	TMUTCD in effect during Projects 0-5439 and 5-5439
October 2007	Publication of Project 0-5439 report, first edition of *Handbook* (including Direct, Design, and Compass Methods for setting advisory speeds), and original TCAS program
August 2009	Publication of second edition of *Handbook* (including Direct, Design, Compass, and GPS Methods for setting advisory speeds); update to TCAS to accommodate GPS Method
December 2009	Adoption of 2009 MUTCD
February 2011	Revisions to *Procedures* document (addition of GPS Method and compliance dates)
December 2011	Adoption of 2011 TMUTCD (including Table 2C-5)
November 2012	Adoption of 2011 TMUTCD *Revision 1*
January 1, 2013	Compliance date for using Project 5-5439 engineering study methods to determine advisory speeds (*4*)
August 2013	Update to TCAS to allow analysis of multiple curves
December 2013	Update to TCAS to incorporate 2011 TMUTCD Table 2C-5 guidelines
January 1, 2015	Target compliance date for updating advisory speed signs based on Project 5-5439 engineering study methods (*4*)
December 31, 2019	FHWA-established compliance date for Table 2C-5 guidelines

Researchers updated the calculations contained within the TCAS program to reflect the guidelines contained within Table 2C-5 of the TMUTCD. This effort was achieved through the following activities:

1. Policy review—thorough review of the relevant portions of the TMUTCD and the *Procedures* document.
2. Program update—The calculation routines in the TCAS program were updated. The calculation routines (i.e., those that reflect the device selection guidelines from Projects 0-5439 and 5-5439) were retained and updated as needed, and a new set of calculations reflecting only the TMUTCD were added. Hence, users of the program have the choice of applying either of the sets of guidelines.

The following two sections of this chapter describe the efforts expended to accomplish these activities.

POLICY REVIEW

Policies regarding the signing and marking of horizontal curves are found in the *Procedures* document, the TMUTCD, and the *Handbook*. The latter of these documents represents recommendations made from the findings of Projects 0-5439 and 5-5439 but does not carry the same weight as the former two documents.

Curve Evaluation Process

The process for choosing traffic control devices can be summarized as follows:

1. Conduct an engineering study to determine the curve advisory speed.
2. Decide whether the advisory speed needs to be posted.
3. Choose traffic control devices (signs and supplemental devices) to be posted.
4. Determine size and spacing for all signs and supplemental devices.

These four steps are discussed in the following subsections. Changes in the policy documents between the adoption of the 2006 and 2011 editions of the TMUTCD are highlighted, and the relationship between the TMUTCD and the *Procedures* document is addressed when needed.

Conduct Engineering Study Method

Section 2C.08 of the 2011 TMUTCD allows the following methods for setting advisory speeds:

- Test run with an accelerometer.
- Design speed equation.
- Traditional ball-bank indicator.
- Methods outlined in the *Procedures* document.

The *Procedures* document allows the following methods:

- Direct Method.
- GPS Method.
- Design Method.
- Ball-Bank Method (with a phase-out date of January 1, 2013).

Of these methods in the *Procedures* document, the GPS Method is the most commonly used by TxDOT following the phase-out of the Ball-Bank Method. The GPS Method involves driving through the curve with a laptop computer, a GPS receiver, and an electronic ball-bank indicator. The laptop computer runs the Texas Roadway Analysis and Measurement Software (TRAMS) and TCAS program and monitors the data streams from the GPS receiver and the electronic ball-bank indicator. The programs implement the guidelines developed in Project 0-5439 to determine curve advisory speed.

Decide If Posted Advisory Speed Is Needed

An advisory speed can be determined for any curve. For the most gradual of curves, the advisory speed will equal the regulatory speed limit and will not be posted. The 2006 TMUTCD does not specify when an advisory speed plaque is required, stating simply that a plaque shall be used if an engineering study indicates the need to advise road users of the advisory speed.

The *Procedures* document provides the guideline shown in Figure 1 to determine whether the advisory speed needs to be posted. The guideline is based on a comparison of 85th percentile passenger car speeds at the approach tangent and the curve midpoint, and specifies that an advisory speed plaque is recommended when the difference between these two speeds is in the range of 3–5 mph for 85th percentile approach tangent speeds of 50–75 mph.

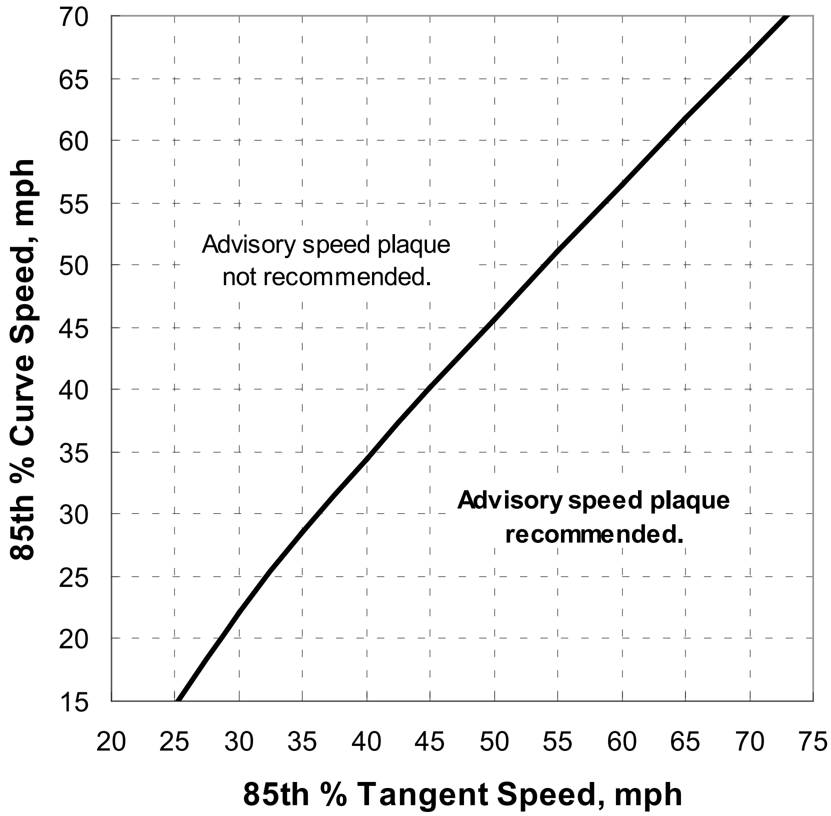


Figure 1. Guidelines for Determining the Need for an Advisory Speed Plaque (*4*).

The 2011 TMUTCD guideline for posting advisory speed plaques differs from the *Procedures* document guideline. Specifically, Table 2C-5 of the 2011 TMUTCD states that an advisory speed plaque is recommended if the difference between the regulatory speed limit and the advisory speed is 5 mph, and it is required if the difference is 10 mph or greater. Hence, the 2011 TMUTCD guideline differs from the *Procedures* document guideline in terms of both the specified difference in speeds and the speeds used to determine the difference. The *Procedures* document guideline is based on actual vehicle speeds, while the 2011 TMUTCD guideline is based on posted speeds.

Choose Traffic Control Devices

Section 2C.06 of the 2006 TMUTCD states that a curve warning sign (W1-1, W1-2, W1-3, W1-4, W1-5, or W1-11) shall be posted when engineering judgment indicates the need but does not offer specific details on what considerations should be part of the decision to post the sign. In Table 3D-3, the 2006 TMUTCD offers guidelines for using supplemental devices, including raised pavement markers (RPMs), delineators, and Chevrons, based on the difference between posted regulatory and advisory speeds. Table 2 presents these guidelines.

Table 2. Guidelines for Use of Warning Devices at Curves with Advisory Speed Limits (*5*).

Difference between Speed Limit and Advisory Speed	Warning Devices Needed
0–14 mph	RPMs
15–24 mph	RPMs and delineators
≥ 25 mph	RPMs and Chevrons

The guidelines in Table 2 indicate that RPMs are recommended for all curves, while delineators or Chevrons are only recommended for sharper curves where the advisory speed is 15–25 mph lower than the regulatory speed limit.

Figure 2 and Table 3 describe the *Handbook* guidelines for choosing curve traffic control devices. These guidelines are based on the consideration of the difference between 85th percentile passenger car speeds at the approach tangent and the curve midpoint. Note that the contour line in Figure 2 that describes the upper bound of Region B is the same contour line used in the *Procedures* document for posting advisory speeds (see Figure 1).

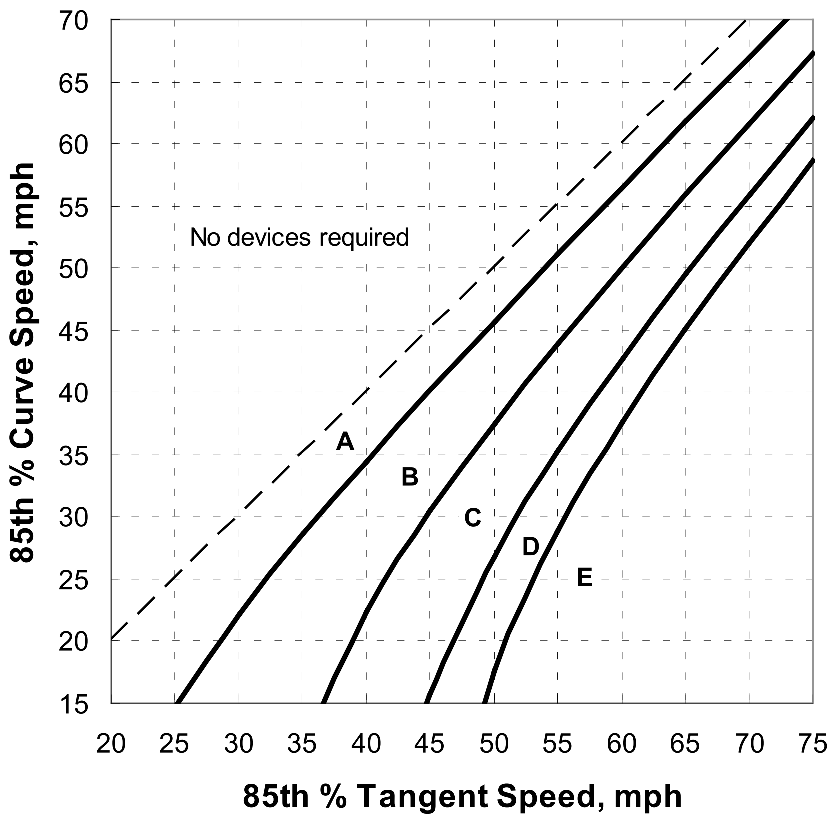


Figure 2. *Handbook* Guidelines for Choosing Curve Traffic Control Devices.

Table 3. *Handbook* Guidelines for Choosing Curve Traffic Control Devices.

Advisory Speed, mph	Device Type	Device Name	Device Number	Curve Severity Category[a]				
				A	B	C	D	E
35 mph or more	Warning Signs	Curve, Reverse Curve, Winding Road, Hairpin Curve[b]	W1-2, W1-4, W1-5, W1-11	✔	✓	✓	✓	✓
		Advisory Speed Plaque	W13-1P		✓	✓	✓	✓
		Combination Curve/ Advisory Speed	W1-2a			✔	✔	✔
		Chevrons[c]	W1-8				✓	✓
30 mph or less	Warning Signs	Turn, Reverse Turn, Winding Road, Hairpin Curve[b]	W1-1, W1-3, W1-5, W1-11	✔	✓	✓	✓	✓
		Advisory Speed Plaque	W13-1P		✓	✓	✓	✓
		Combination Turn/ Advisory Speed	W1-1a			✔	✔	✔
		One-Direction Large Arrow[c]	W1-6, W1-9T				✓	✓
Any	Delineation Devices	Raised Pavement Markers[d]		✓	✓	✓	✓	✓
		Delineators[e]				✔	✔	✔
	Special Treatments[f]							✓

[a] ✔: optional; ✓: recommended.
[b] Use the Curve, Reverse Curve, Turn, Reverse Turn, or Winding Road sign if the deflection angle is less than 135 degrees. Use the Hairpin Curve sign if the deflection angle is 135 degrees or more.
[c] A One-Direction Large Arrow sign may be used on curves where roadside obstacles prevent the installation of Chevrons, or as a supplement to Chevrons or a Turn or Reverse Turn sign.
[d] Raised pavement markers are optional in northern regions that experience frequent snowfall.
[e] Delineators do not need to be used if Chevrons are used.
[f] Special treatments could include oversize advance warning signs, flashers added to advance warning signs, wider edgelines, profiled pavement markings, and speed reduction markings.

When applied, the *Handbook* guidelines produce similar findings for the selection of delineators or Chevrons for curves with regulatory speed limits of 55–60 mph. This comparison is based on the relationship between the 85th percentile approach tangent speed and regulatory speed limit that has been observed on rural Texas highways (*2*).

Compared to the 2006 TMUTCD, the 2011 TMUTCD offers more specific guidelines for the use of most curve traffic control devices. Table 2C-5 of the TMUTCD is presented here as Table 4. The 2011 TMUTCD guidelines differ from the *Handbook* guidelines in their approach—the former document is based on the posted regulatory and advisory speeds, while the latter document is based on actual passenger car speeds at the approach tangent and the curve midpoint.

Table 4. Horizontal Alignment Sign Selection (*7*).

Type of Horizontal Alignment Sign	Difference between Speed Limit & Advisory Speed				
	5 mph	10 mph	15 mph	20 mph	≥ 25 mph
Turn (W1-1), Curve (W1-2), Reverse Turn (W1-3), Reverse Curve (W1-4), Winding Road (W1-5), and Combination Horizontal Alignment (W1-10 series)	Recommended	Required	Required	Required	Required
Advisory Speed Plaque (W13-1P)	Recommended	Required	Required	Required	Required
Chevrons (W1-8) and/or One-Direction Large Arrow (W1-6, W1-9T)	Optional	Recommended	Required	Required	Required

With respect to the various devices, the 2006 and 2011 TMUTCD guidelines differ as shown in Table 5. Compared to the 2006 TMUTCD, the 2011 TMUTCD:

- Is more specific on the guidelines for using curve warning signs and advisory speed plaques. Differences between regulatory and advisory speeds are now specified as thresholds, in addition to engineering judgment and engineering study.
- Recommends more frequent use of Chevrons. For recommending Chevrons (a "should" condition), the threshold difference between regulatory and advisory speeds is now 10 mph instead of 25 mph, which is even more frequent than the previous guidelines for delineator usage.
- Is less specific on the guidelines for using RPMs or delineators. The portions of Table 2 that address RPMs and delineators were not incorporated into Table 4.

Table 5. Comparison of Device Selection Guidelines.

TMUTCD Edition	Device	Difference between Speed Limit and Advisory Speed, mph					
		0	5	10	15	20	≥ 25
2006	Warning Sign	Engineering judgment					
	Advisory Speed Plaque	Engineering study					
	Combination Horizontal Alignment	Not allowed					
	RPMs	Rec.	Rec.	Rec.	Rec.	Rec.	Rec.
	Delineators				Rec.	Rec.	
	Chevrons (W1-8)						Rec.
2011	Warning Sign		Rec.	Req.	Req.	Req.	Req.
	Advisory Speed Plaque		Rec.	Req.	Req.	Req.	Req.
	Combination Horizontal Alignment	Engineering study					
	RPMs	No guidelines					
	Delineators	No guidelines					
	Chevrons (W1-8)		Opt.	Rec.	Req.	Req.	Req.

NOTE: Opt. = optional; Rec. = recommended; Req. = required.

Regarding sign options, the 2006 and 2011 versions of the TMUTCD are mostly identical. One notable change is that the Combination Horizontal Alignment/Advisory Speed signs (W1-1a and

W1-2a) have been added into the 2011 TMUTCD. Section 2C.10 of the 2011 TMUTCD states that these signs may be used to supplement the advance curve warning sign and advisory speed plaque based on engineering study, and if used, they must be placed at the beginning of the curve. It is also noteworthy that both versions include the version of the One-Direction Large Arrow sign that has diagonal lines (W1-9T), while the federal MUTCD does not. The guidelines for using the two versions of the One-Direction Large Arrow sign (W1-6 and W1-9T) are the same.

Determine Size and Spacing for Signs and Supplemental Devices

Table 2C-2 of the 2011 TMUTCD and the Sign Appendix of the 2006 TMUTCD specify warning sign sizes. Table 6 summarizes the changes in warning sign size standards between these two documents. The sizes are generally the same, though adjustments have been made in the roadway categories. Specifically, the 2006 MUTCD specifies different sizes for conventional roads based on speed categories (< 55 mph or ≥ 55 mph), while the 2011 TMUTCD does so based on lane count (single lane or multi-lane).

Table 6. Comparison of Warning Sign Size Standards.

TMUTCD Edition	Roadway Category	Device Size (width × height, inches)		
		Warning Sign (W1-1, W1-2, W1-3, W1-4, W1-5)	Advisory Speed Plaque (W13-1P)	Hairpin Curve (W1-11)
2006	Minimum size	24 × 24	18 × 18	24 × 24
	Low-speed conventional road (< 55 mph)	30 × 30	18 × 18	30 × 30
	High-speed conventional road (≥ 55 mph)	36 × 36	24 × 24	36 × 36
	Expressway	36 × 36	24 × 24	36 × 36
	Freeway	48 × 48	24 × 24	48 × 48
	Oversized	None specified	None specified	None specified
2011	Minimum	None specified	None specified	None specified
	Conventional road, non-state-maintained, single lane	30 × 30	18 × 18	30 × 30
	Conventional road, state-maintained, single lane	30 × 30 (standard), 36 × 36 (guidance)[a]	18 × 18	30 × 30
	Conventional road, non-state-maintained, multi-lane	36 × 36	18 × 18	30 × 30
	Conventional road, state-maintained, multi-lane	36 × 36	18 × 18	30 × 30
	Expressway	36 × 36	24 × 24	36 × 36
	Freeway	36 × 36	24 × 24	48 × 48
	Oversized	48 × 48	30 × 30	48 × 48

[a] The minimum size for diamond-shaped warning signs on state-maintained conventional roads *should* be 36 inch × 36 inch. All other signs and plaques on state-maintained conventional roadways *should* use the multi-lane size *as a standard*.

Guidelines for the spacing of delineators are identical in the two TMUTCD versions. Both versions offer tables of delineator spacing based on advisory speed (when radius or degree of curve is not known), or based on radius or degree of curve. The federal MUTCD includes only the latter table. Hence, the TMUTCD can be characterized as offering a consistent but more comprehensive set of guidelines, compared to the federal MUTCD.

The 2011 TMUTCD specifies Chevron spacing in Table 2C-6 based on both advisory speed and curve radius. The specified spacing is similar to that in Table 3D-2 of the 2006 TMUTCD, with only minor differences, likely due to rounding of radius or degree of curve values. Table 2C-6 in the 2011 TMUTCD is easier to use because it specifies ranges of radius values in each table row, eliminating the need to interpolate between rows. One notable difference is that the 2006 TMUTCD states that Chevron spacing should be chosen based on curve radius or degree of curve when this quantity is known. The 2011 TMUTCD does not specify a preference for radius/degree of curve over advisory speed.

Guidelines for Special Treatments

The *Handbook* guidelines suggest the use of special treatments for curves that are classified as Severity Category E (see Figure 1). Special treatments acknowledged in the *Handbook* include oversized curve warning signs, flashers added to warning signs, wider edgelines approaching and along the curve, and profiled pavement markings. Inclusion of special treatments in the *Handbook* framework was originally inspired by the inclusion of special treatments in candidate guidelines that were offered by Glennon (*8*). He described special treatments as "other measures to reduce speed limit, rebuild curve, etc." Because the *Handbook* was intended to address only traffic control devices, geometric treatments like straightening the curve, increasing superelevation, or increasing pavement friction were not included. The list of special treatments in the *Handbook* was compiled based on treatment options in the TMUTCD, practices of some TxDOT districts, and options discussed in National Cooperative Highway Research Program Report 500 (*9*). This synthesis is documented elsewhere (*2*).

Both the 2006 and 2011 editions of the TMUTCD acknowledge the option of using oversized signs and wider pavement marking lines (for emphasis), but neither addresses the use of flashers or profiled markings, or provides guidelines on when to use any of these treatments. The 2011 TMUTCD does include an acknowledgment of speed reduction markings (Section 3B.22) that is not included in the 2006 TMUTCD.

PROGRAM UPDATE

Researchers have updated the TCAS program to reflect the guidance changes that were discussed in the previous section. This section documents these updates and describes revised procedures for using TCAS.

Support for the *Handbook*-based guideline framework has been retained, with updates to portions of the framework that were derived from the TMUTCD, such as the sign size, sign placement, and delineator and Chevron spacing guidelines. A calculation framework has also been added to reflect a direct implementation of the TMUTCD guidelines, including the sign selection guidelines that were described in Table 4. Table 7 describes these two guideline frameworks, along with the guideline sources for the various decisions that are made in implementation of the frameworks.

Table 7. Guideline Sources for Curve Treatment Frameworks.

Decision	Source of Guideline Material by Specified Guideline Framework	
	Handbook	**TMUTCD**
Determination of advisory speed	*Handbook* and *Procedures* document	*Handbook* and *Procedures* document
Posting of advisory speed	*Handbook* and *Procedures* document	TMUTCD
Selection of warning signs, Chevrons, and large arrow	*Handbook*	TMUTCD
Use of Combination Horizontal Alignment signs	*Handbook*	*Handbook*
Use of delineators	*Handbook*	TMUTCD
Sizing and spacing of devices	TMUTCD	TMUTCD
Use of special treatments	*Handbook*	*Handbook*

Updated Guidelines Based on the *Handbook*

Figure 3 shows a screenshot of the right side of the TCAS analysis worksheet. This screenshot shows TCAS when configured to implement the *Handbook* guidelines. Updating the *Handbook* guidelines required researchers to make the following changes to TCAS:

- A blue data input cell (Cell N30) has been added so the analyst can specify the road type where the analyzed curves are located. The options are conventional road, single lane; conventional road, multi-lane; expressway; and freeway. These options correspond to the road types listed in Table 2C-2 of the TMUTCD and affect the choice of warning sign size. As it is currently formulated, TCAS requires that the road type be identical for all six curves that are entered into the left side of the analysis worksheet. If the analyst collects data from curves that are located on separate roadways that have different types, the data from these curves should be saved in separate copies of the TCAS spreadsheet.
- A blue data input cell (Cell S30) has been added so the analyst can specify whether the desired guideline source is the *Handbook* or the 2011 TMUTCD. In Figure 3, the *Handbook* is specified as the preferred guideline source for choosing traffic control devices. In this configuration, TCAS will give recommendations on the selection of traffic control devices based on the *Handbook* framework but will specify sign sizes based on the updated Table 2C-2 in the TMUTCD.
- The guideline table has been updated to reflect the addition of the Combination Horizontal Alignment/Advisory Speed signs (W1-1a and W1-2a) to the TMUTCD.
- The device numbers for the advisory speed plaques and the One-Direction Large Arrow sign have been updated.
- Images of the Combination Horizontal Alignment/Advisory Speed signs (W1-1a and W1-2a) and the One-Direction Large Arrow sign that has diagonal lines (W1-9T) have been added to the Sign Library.
- The calculations of size for warning signs, advisory speed plaques, and Combination Horizontal Alignment/Advisory Speed signs have been updated to reflect Table 2C-2 of the TMUTCD. These calculations are in Rows 50, 53, and 56 of TCAS.

- Comment boxes for the various output data cells have been updated to reflect new TMUTCD guidelines, section numbers, and table numbers.

Traffic Control Device Guideline Summary

Road type: Conventional road, single lane — Guideline framework: Horizontal Curve Signing Handbook, Second Edition

Advisory Speed, mph	Device Type	Device Name	Device Number	Curve Severity Category [6] A	B	C	D	E
35 mph or more	Warning Signs	Curve, Reverse Curve, Winding Road, Hairpin Curve [1]	W1-2, W1-4, W1-5, W1-11	✓	✔	✔	✔	✔
		Advisory Speed plaque	W13-1P		✔	✔	✔	✔
		Combination Curve/ Advisory Speed	W1-2a			✓	✓	✓
		Chevrons [2]	W1-8				✔	✔
30 mph or less	Warning Signs	Turn, Reverse Turn, Winding Road, Hairpin Curve [1]	W1-1, W1-3, W1-5, W1-11	✓	✔	✔	✔	✔
		Advisory Speed plaque	W13-1P		✔	✔	✔	✔
		Combination Turn/ Advisory Speed	W1-1a			✓	✓	✓
		One-Direction Large Arrow [2]	W1-6, W1-9T				✔	✔
Any	Delineation Devices	Raised pavement markers [3]		✔	✔	✔	✔	✔
		Delineators [4]				✓	✓	✓
	Special Treatments [5]							✔

Notes:
1 – Use the Curve, Reverse Curve, Turn, Reverse Turn, or Winding Road sign if the deflection angle is less than 135 degrees. Use the Hairpin Curve sign if the deflection angle is 135 degrees or more.
2 – A One-Direction Large Arrow sign may be used on curves where roadside obstacles prevent the installation of Chevrons, or as a supplement to Chevrons or a Turn or Reverse Turn sign.
3 – Raised pavement markers are optional in northern regions that experience frequent snowfall.
4 – Delineators do not need to be used if Chevrons are used.
5 – Special treatments could include oversize advance warning signs, flashers added to advance warning signs, wider edgelines, profiled pavement markings, and speed reduction markings.
6 – ✓: optional; ✔: recommended.

Sign Library

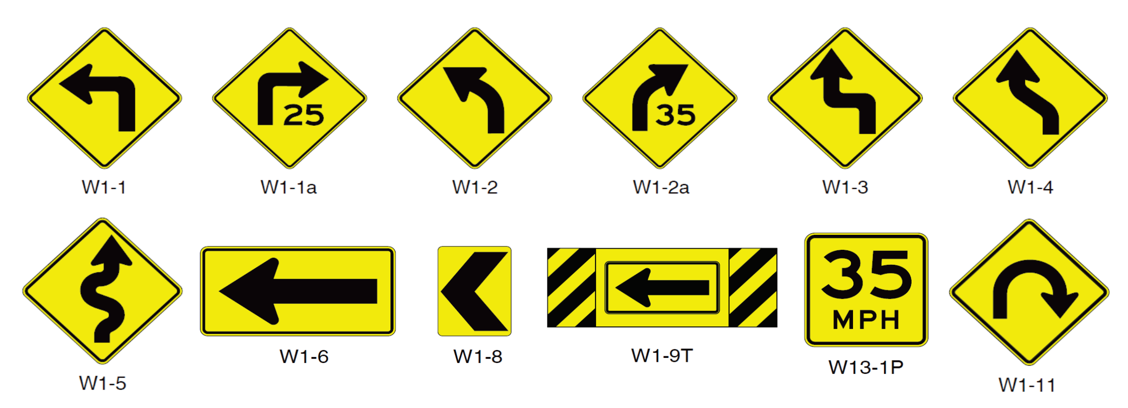


Figure 3. TCAS Screenshot for *Handbook* Guidelines Application.

Updated Guidelines Based on the TMUTCD

To use the updated TMUTCD guidelines in Table 4 to select curve traffic control devices, the analyst must specify the 2011 TMUTCD as the guideline framework in Cell S30. Figure 4 illustrates this choice.

Traffic Control Device Guideline Summary

Road type: Conventional road, single lane   Guideline framework: 2011 Texas Manual on Uniform Traffic Control Devices

Type of Horizontal Alignment Sign	Difference Between Speed Limit & Advisory Speed				
	5 mph	10 mph	15 mph	20 mph	≥ 25 mph
Turn (W1-1), Curve (W1-2), Reverse Turn (W1-3), Reverse Curve (W1-4), Winding Road (W1-5), and Combination Horizontal Alignment (W1-10 series)	*Rec.*	**Req.**	**Req.**	**Req.**	**Req.**
Advisory Speed Plaque (W13-1P)	*Rec.*	**Req.**	**Req.**	**Req.**	**Req.**
Chevrons (W1-8) and/or One Direction Large Arrow (W1-6, W1-9T)	Opt.	*Rec.*	**Req.**	**Req.**	**Req.**

Opt. = optional
Rec. = recommended
Req. = required

Figure 4. TCAS Screenshot for TMUTCD Guidelines Application.

When the analyst specifies the TMUTCD as the guideline framework, TCAS provides recommendations on the use of curve traffic control devices based on Table 4 (which is Table 2C-5 of the TMUTCD). The calculated recommendations reflect the following additional considerations:

- Section 2C.07 of the TMUTCD states that the Hairpin Curve sign may be used if the curve deflection angle is 135 degrees or greater. TCAS has three rows to show guidelines for the use of the three main types of horizontal alignment signs (Curve, Turn, and Hairpin Curve, in Rows 47–49). The TCAS computations always show a preference for the Hairpin Curve sign over the Curve or Turn signs when the deflection angle is 135 degrees or greater.
- The TMUTCD now allows the Combination Horizontal Alignment/Advisory Speed signs but specifies "engineering study" as the only criterion for their use. Hence, the *Handbook* framework guidelines for these signs are incorporated into the TMUTCD framework. Specifically, the signs are considered optional for curves with Severity Category C or greater (see Figure 2 and Table 3).
- The TMUTCD no longer recommends RPMs for all curves, so RPMs are stated as optional for all curves.
- The guidelines for delineator use that were added into the 2006 TMUTCD (see Table 2) were not retained in the 2011 TMUTCD, and a review of the 2011 TMUTCD guidelines suggests that delineators will often be supplanted by Chevrons (see Table 5). Both of these editions of the TMUTCD state that delineators are likely not needed if the degree of curve is one or less. Hence, in the TMUTCD framework, delineators are stated as optional for all curves with a degree of curve of one or more.
- Neither the 2006 nor the 2011 edition of the TMUTCD contains guidelines on when to apply special treatments. Therefore, the *Handbook* framework guidelines for special treatments are incorporated into the TMUTCD framework. Specifically, special treatments are recommended for curves with Severity Category E (see Figure 2 and Table 3).

CHAPTER 2. EXIT GORE SIGNS

INTRODUCTION

Background

Exit gore signs are used to provide road users a reference point concerning exit locations. Because of where they are located, exit gore signs are often hit and require constant maintenance. The maintenance of these signs puts maintenance crews at constant risk. This study tested alternatives to the existing exit gore sign requirements in the Texas A&M Transportation Institute's (TTI's) desktop driving simulator. The study's objective was to develop potential alternative(s) to provide the road user the same level of information as the standard exit gore sign but reduce or eliminate the risk that currently exists regarding the need for continual maintenance of exit gore signs.

The 2009 MUTCD Section 2E.37 defines the gore area as the area between the main roadway and the ramp just beyond where the ramp branches from the main roadway (*6).* The MUTCD specifies that the exit gore sign is to be located in the gore area and shall carry the word EXIT or EXIT XX and an appropriate upward slanting arrow.

Section 2E.37, Support: 01 states the following:

> The Exit Gore (E5-1 or E5-1a) sign (see Figure 2E-28) in the gore indicates the exiting point or the place of departure from the main roadway. Consistent application of this sign at each exit is important.

The TMUTCD has the addition in Section 2E.37 Standard 02 (*5*):

> The EXIT GORE sign shall be installed at all freeway exits.

Figure 5 shows Figure 2E-28 from the MUTCD illustrating an exit gore sign.

Figure 5. Figure 2E-28 from the MUTCD Illustrating an Exit Gore Sign.

Support for an alternative device in the gore area can be found in Section 2C.65, which discusses object markers for obstructions adjacent to the roadway:

> Obstructions not actually within the roadway are sometimes so close to the edge of the road that they need a marker. These include underpass piers, bridge abutments, handrails, ends of traffic barriers, utility poles, and culvert headwalls. In other cases there might not be a physical object involved, but other roadside conditions exist, such as narrow shoulders, drop-offs, gores, small islands, and abrupt changes in the roadway alignment, that might make it undesirable for a road user to leave the roadway, and therefore would create a need for a marker.

Current Policy Regarding Exit Gore Signs

Section 2E.37 of the national MUTCD covers exit gore signs. The MUTCD includes the following information related to exit gore sign placement:

> The gore shall be defined as the area located between the main roadway and the ramp just beyond where the ramp branches from the main roadway. The Exit Gore sign shall be located in the gore… (*1*).

The *TxDOT Freeway Signing Handbook* does not further address exit gore signing.

Other State Policies and Related Research

California Department of Transportation (Caltrans) researchers conducted a related project just as this study was beginning. The Caltrans project examined the risks and benefits of exit gore signs, addressing maintenance and safety concerns similar to TxDOT's. Interviews with other state departments of transportation (DOTs) were conducted to explore how those agencies addressed exit gore sign design, placement, and supplemental elements. Approaches described by the surveyed agencies included the following:

- Relocating exit gore signs farther back into the gore (four states).
- Using pavement markings to identify exit lanes (six states).
- Using Type 1 object markers to increase conspicuity of the gore and sign.
- Enhancing the visibility of the exit gore sign post with reflective sheeting (*2*).

Literature Review

Because of their exposure to high-speed traffic and lack of adequate clear zone, installing and maintaining exit gore signs present a significant safety challenge for DOT personnel. Over the past few decades, limited research has been published with respect to safety issues and design modifications to exit gore signs. This literature review synthesizes research conducted on exit gore sign placement alternatives, as well as gore-area traffic control devices and their effectiveness.

A 2011 Texas study conducted a survey of TxDOT district officials that identified highway segments with frequently hit roadside signs (*10*). Sixty-two percent of the district officials indicated they had safety issues with frequently hit gore-area or other roadside signs; however, only a quarter indicated that they recorded auto-sign crashes. A high number of respondents (7/18) ranked exit gore signs as the most frequently hit signs (shown in Table 8 as the highlighted cell). Most respondents of the survey indicated that on average, the number of monthly sign hits ranged from five to 20 (as shown in Figure 6). As Figure 7 shows, respondents indicated that the most frequently hit signs were located on curves (28 percent), followed by the exit gore area (26 percent). The respondents also indicated that a high proportion of sign hits (44 percent) resulted from a lack of driver attention (as shown in Figure 8). Additional comments from the respondents on the reasons for the hits can be found in Table 9. The study also included a before-after analysis for removing exit gore signs and found that lack of exit gore signs did not have any negative impact (i.e., no statistically significant difference) on vehicle speeds, deceleration behavior, and erratic maneuvers. The study concluded that at locations where overhead signs provide sufficient advance warning, exit gore signs may not be needed (*10*).

Table 8. TxDOT District Officials Survey on Frequency of Roadway Sign Type Hits (*10*).

Roadway Sign	Rank			
	1	**2**	**3**	**4**
Exit Sign	7	2	3	2
Keep Right Signs	2	3	4	3
T-Intersection Signs	3	5	3	4
Other:				
Chevron on Curves	3	3		
Do Not Enter Signs	1			
One Way Signs	2			
Stop Signs	2	3		
Speed Limit Signs	1			
Other Roadside Signs	2		2	

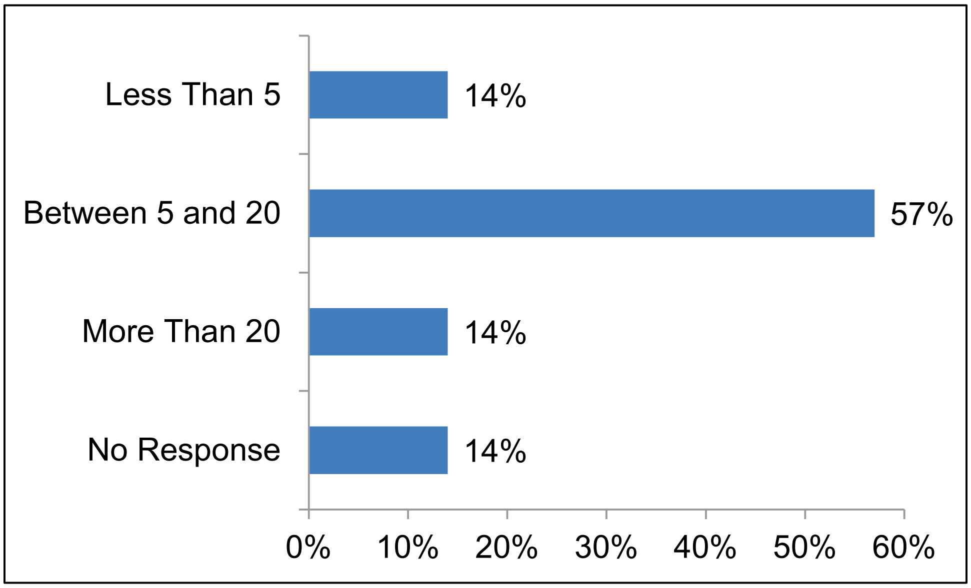


Figure 6. TxDOT District Officials Survey on Monthly Sign Hits (*10*).

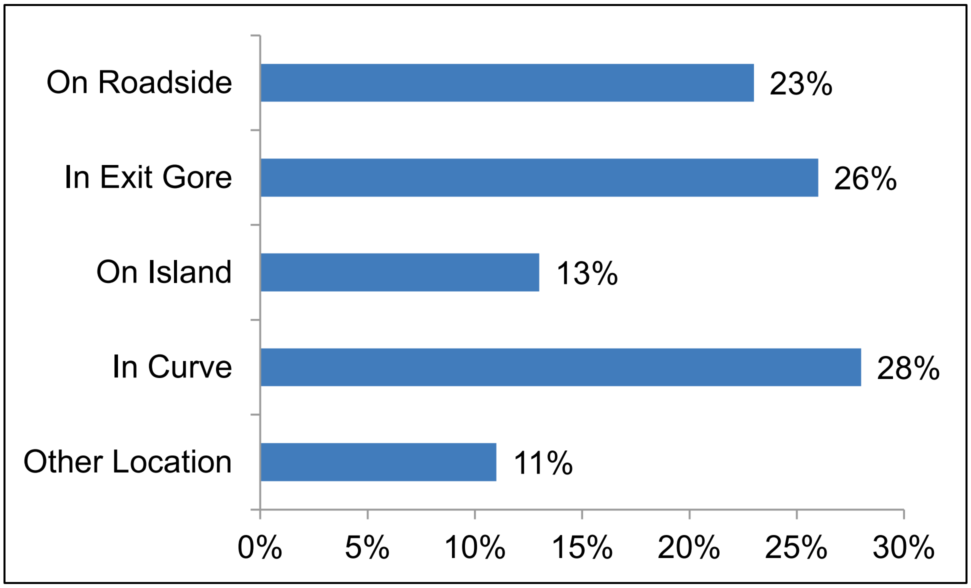


Figure 7. TxDOT District Officials Survey on Most Frequently Hit Roadway Sign Locations (*10*).

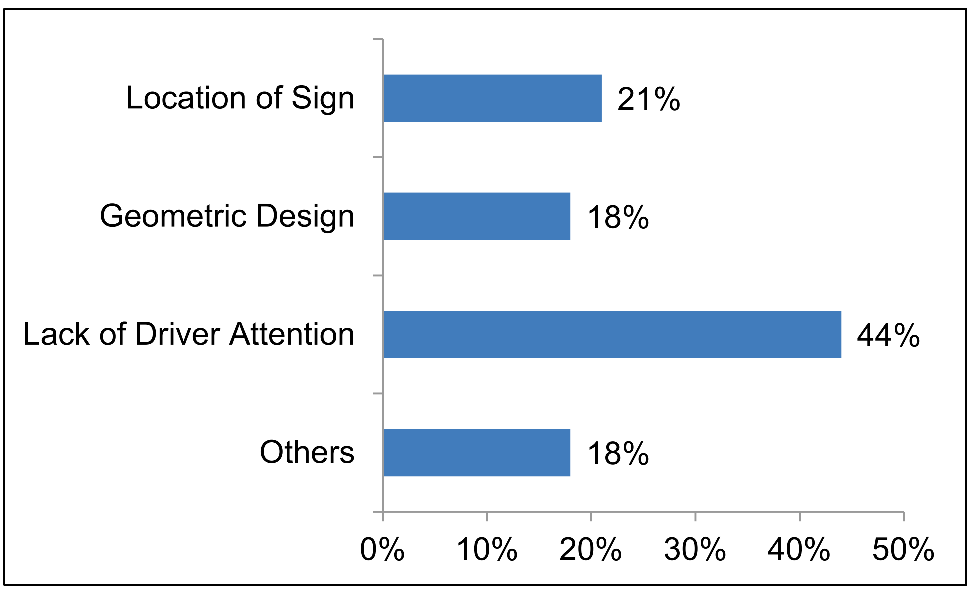


Figure 8. TxDOT District Officials Survey on Reasons for Sign Hits (*10*).

Table 9. TxDOT District Officials Survey on Reasons for Frequent Sign Hits (*10*).

Reasons for Frequent Sign Hits	Quoted Comments Made by Respondents
Location of signs	Sign too far in gore on slip ramp In island tight spaces Exit gores are probably the most susceptible Too close to gore The most frequently hit signs are in exit gores, followed by intersections Exit gore, proximity to driveways
Geometric design	Signs in curves Button hook ramps Small radius at intersection
Lack of driver attention	Texting on cell phone Cell phones Not paying attention Drivers just don't care about signs Large trucks don't maintain control intakes Most signs are hit on straight sections of road Stop signs are usually vandalized Distracted and speeding Cell phones, wet weather driving Fatigue
Other	Weather Going too fast Wide farm equipment Vandalism Impaired and speeding Speed

A more recent and nationwide survey of practices (via members of the American Association of State Highway and Transportation Officials subcommittee on maintenance) and literature review were conducted in 2013 to identify alternative placement methods or practices for signing freeway exits that can improve safety for field personnel (*11*). Eighteen state DOTs responded with information on a variety of practices to address the issue of sign hits; however, there was no consensus on how to accomplish this. Following are highlights of the survey findings:

- Relocating exit gore signs, using overhead sign structures, and installing pavement markings.
    - Four states—Indiana, North Dakota, Ohio, and Rhode Island—reported relocating signs farther back into the exit gore.
    - Only one state—Texas—responded to questions about placement of exit gore signage on the far right-hand edge of the freeway or shoulder. TxDOT has considered these locations and others to remove the exit sign from the gore area to limit risk to maintenance personnel when replacing these signs.

    - Overhead sign structures are used in place of ground-mounted signs in urban areas within Illinois and have been used in Colorado to sign an urban off-ramp with a challenging layout.
    - Pavement markings to identify exit lanes are used in six states—Colorado, Indiana, Kentucky, New Hampshire, Rhode Island, and Washington. Applications include the use of route marker shield logos, arrows, wide dotted lines, and diagonals or chevrons.
- Considering alternative sign placement methods.
    - South Carolina DOT is experimenting with a lightweight, easy-to-replace system for exit gore signs that is composed of two square tube posts and a two-piece sign blank constructed of Alpolic material supplemented with SignFix channels and clamps for mounting.
    - TxDOT has delayed exit gore sign replacement until a lane closure could be made at an exit where an employee was recently killed and where other near misses of maintenance personnel have been reported.
    - South Carolina DOT is in its third year of an on-call vendor contract to repair signs. While major guide and directional signs are replaced fairly quickly after damage or removal under this contract, it can take up to 90 days for exit signs to be replaced because these sign replacements are typically completed in groups within a given area.
    - South Carolina and Texas DOTs noted that exit gore signs may not be needed when other signage (for example, an overhead sign) is used to provide adequate indication of the exit gore.
- Increasing the conspicuity of exit gore signs.
    - North Dakota and Rhode Island DOTs use Type 1 object markers (diamond-shaped retroreflective markers used to mark obstructions within or adjacent to the roadway) on or in conjunction with exit gore signs.
    - Washington State DOT applies retroreflective sheeting on exit gore sign posts for I-5 exits near Seattle.

In a February 2014 meeting of the California Traffic Control Device (TCD) committee, Caltrans officials shared that some preliminary work in Caltrans District 6 has been done to install larger, two-post E5-1 FHWA specification signs downstream of the gore point to reduce knockdowns and allow for additional room to perform maintenance in a protected work zone environment. The officials also shared that other options being considered are to move the exit gore sign to the far right-hand shoulder, or in the case of multi-lane exits in high-volume freeway corridors, delete the exit gore sign completely as a roadside sign and consider other locations or options. The meeting minutes indicate that Caltrans is in discussion with FHWA to scope a request to experiment the alternatives (*12*).

In the past, researchers have made significant efforts to develop cushioning or energy-dissipating measures for use in front of fixed objects.

Collision with concrete abutments and "T" mounts resulted in 27 percent of freeway fatalities in Houston, Texas. A 1969 Texas study conducted an in-service evaluation of the Texas modular crash cushion designed to reduce crash severity in the freeway gore area (*13*). The Texas modular crash cushion was composed of 55-gal steel barrels positioned so that they provided a relatively soft, deformable cushion between an errant vehicle and a fixed object. The crash cushion was installed at five sites, and satisfactory results were observed. In the three years before installation, eight fatal crashes were reported at the study sites, whereas in the one year after installation, 13 crashes with no serious injuries or fatalities were reported at the study sites (*13*).

A 1971 study evaluated two types of barriers (Hi-Dro Cushion Cells and Fitch Inertial Barriers) on an experimental basis at selected gore locations on Kentucky highways (*14*). After the installation, four crashes involving the Fitch barrier and one involving the Hi-Dro Cell barrier were reported. In these crashes, the vehicle damage was minimized and one life was saved due to the presence of the barrier. It was believed that the crashes would have been serious injury crashes otherwise.

Viner and Tamanini evaluated the in-service effectiveness of protective highway barriers using crash data in 1971. Review of 129 crashes revealed that had impact attenuators not been present, 30 of those crashes would have resulted in serious injuries or fatalities, whereas only three serious injuries and one fatality were reported in the 129 cases (*15*).

A 1973 study examined erratic maneuvers in the exit gore area to understand causative factors, effective remedial treatments, and design and traffic control changes to minimize these issues in future (*16*). State-of-the-art reviews of erratic maneuver patterns and on-site interviews with drivers (who had made erratic maneuvers) showed that more than one causative factor could be attributed to each site. Generally, the factors were classified as:

- Driver-related problems:
  - Driver distraction or inattention.
  - Last-minute change of mind.
  - Driver not sure of direction.
- Information deficiencies:
  - Misleading or missing sign legend.
  - Insufficient advance warning.
  - Inadequate sign visibility.
  - Inadequate road markings or delineators.
- Geometric deficiencies:
  - Inadequate sight distance to exit area.
  - Other design features like lane drops, tangential exits, etc.

The study included nine sites with varying geometric issues, where remedial measures such as markings, signing changes, delineators, etc., were installed (*16*). Erratic maneuver rates observed at these sites (before installation of safety countermeasures) ranged from 0.2 percent (i.e., two out of every 1000 vehicles) to 5.2 percent of all vehicles approaching the exit-ramp area. It was observed that erratic maneuvers could be reduced by application of standard traffic control devices (as shown in Table 10).

A TTI study in 1987 conducted a field evaluation of four gore-area crash cushion delineation treatments at three sites on an urban freeway in El Paso, Texas (*17*). The treatments evaluated were (a) existing, (b) yellow diamond-shaped object marker, (c) yellow-and-black chevron-patterned nose panel, and (d) yellow-and-black chevron-patterned nose and back panel. The study measured encroachments into the gore area using low-light-level cameras and time-lapse video recorders over three days at each site. The study found that delineation requirements may not have been the same at all gore areas; presence of complex geometrics and inadequate sight distance might have warranted more extensive delineation. Table 11 and Table 12 summarize the crossover encroachments at each of the three sites. The results show that at Site 1, there was a significant difference in the daytime rates among the treatments, with the existing treatment having a higher crossover rate. At Site 2, all treatments had similar crossover rates, and there was no statistically significant difference in the daytime and nighttime crossover rates. Similar observations were made for Site 3. Overall, the results indicated that based on the limited sample collected for the study, increased delineation did not always reduce crossover rates, especially at locations where sight distance to the gore was not a critical factor.

Table 10. Summary of Before and After Remedial Treatment Erratic Maneuver Rates (*16*).

Site Number	Safety Treatment	Erratic Maneuver Rate		Significant Change; Level of Confidence (%)
		Before	After	
1	1. Change of destination on signs 2. Removal of non-standard directional sign 3. Crystal post delineators placed along through route	1.17	0.86	> 95
2 (Left Ramp)	1. Rearrangement of sign legend 2. Post-mounted EXIT signs installed in gores 3. Post delineators placed in gore areas 4. Interchange illuminated	0.28	0.19	80
2 (Right Ramp)		0.51	0.39	80
3 (Left Ramp)	1. Removal of one destination from signs 2. Addition of route shields and cardinal directions on signs 3. EXIT ONLY tabs over lane drop 4. Rearrangement of sign legend 5. Change to standard EXIT gore sign 6. Removal of inconsistent post-mounted directional sign 7. Interchange illuminated	5.15	1.73	> 95
3 (Right Ramp)		2.39	2.36	< 50
4	1. EXIT ONLY tabs over exit lane drop 2. Special painted lane line between the outside and middle lane; 8" wide with 10' mark and 10' gap 3. Gore markings repainted 4. EXIT gore sign installed	0.60	0.33	> 95
5	1. Change of destination on signs 2. EXIT gore sign installed 3. Post delineators installed throughout diverge area	0.20	0.08	> 95
6	1. EXIT ONLY tabs installed over exit lane drop 2. Reorientation of arrows on signs 3. EXIT gore sign installed 4. Line separating exit lane and throughway painted 8" wide and solid for a distance of 600' upstream from gore 5. Post delineators installed on median and in gore area 6. Gore markings repainted	0.30	0.26	60
7	1. EXIT ONLY tab placed on last overhead sign over exit lane drop 2. Post delineators installed throughout diverge area	0.80	1.50	> 95
8	1. Additional route designation on advance signing	0.39	0.21	> 95

Table 11. Crossover Encroachment Rate at Study Sites (*17*).

Treatment	Rate (Cross/1000 vehicles)		
	Site 1	Site 2	Site 3
Nighttime (9 p.m.–4 a.m.)			
Existing	1.1[a]	1.0[b]	4.2[c]
Object Marker	0.7	0.7	3.7
Nose Panel	0.6	2.0	2.9
Nose and Back Panel	0.6	2.6	3.9
Daytime (9 a.m.–4 p.m.)			
Existing	1.2	2.1	4.3
Object Marker	0.4	2.3	3.1
Nose Panel	0.6	2.8	3.0
Nose and Back Panel	0.5	3.2	4.2

[a] Black-and-white chevron-patterned wraparound nose panel and MUTCD Type 1 diamond-shaped object marker.
[b] Black-and-white chevron-patterned wraparound nose panel, one MUTCD Type 1 object marker in the front, and two MUTCD Type 2 object markers (one vertical and one horizontal) in the rear.
[c] Black-and-white chevron-patterned wraparound nose panel, one MUTCD Type 1 diamond-shaped object marker, and two rows of small rectangular yellow reflective-tape sections arranged in a checkerboard pattern.

Table 12. Chi-Square Test of Daytime and Nighttime Crossover Encroachment Rate (*17*).

Time Period	Site 1	Site 2	Site 3
Nighttime (9 p.m.–4 a.m.)			
Chi-square value	—	7.00	0.58
p-value	—	0.07	0.90
Daytime (9 a.m.–4 p.m.)			
Chi-square value	9.69	4.12	4.38
p-value	0.02	0.25	0.22

A 1989 study evaluated the long-term effectiveness of experimental crash cushion delineation treatments in Houston, Texas (*18*). These treatments (listed in Table 13) were installed as part of a previous (1982) study that evaluated their short-term effectiveness. Researchers compared crash cushion repair records for four years before the installation and four years after the installation at eight sites. The study found that delineator crash cushions installed several years prior still held their effectiveness. Table 14 summarizes the reduction in crash cushion repair frequency for each treatment level over the eight-year period. The results show that delineation treatments using a combination of nose and back panels (Treatments 2, 3, and 4) continued to be effective over time. The nose panel alone (Treatment 1) showed a reduction in crash cushion repair, but the results were inconclusive regarding whether the reduction was related to the treatment itself or occurred by chance.

Table 13. Delineation Elements Included in Each Treatment Level (*18*).

Treatment Level	Nose Panel	Painted[a] Barrels with Reflectorized Stripe	Raised Reflective Pavement Markers	Chevron[b] Back Panel[c]	Alignment Signs	Flashing[d] Lights
1	X	X	X			
2	X	X	X	X		
3	X	X	X	X	X	
4	X	X	X	X	X	X

[a] Yellow barrels and reflectorized stripe.
[b] Yellow and black alternating stripes (reflectorized).
[c] MUTCD Sign No. W1-8 (reflectorized).
[d] Amber lenses.

Table 14. Reduction in Crash Cushion Repairs by Delineation Treatment (*18*).

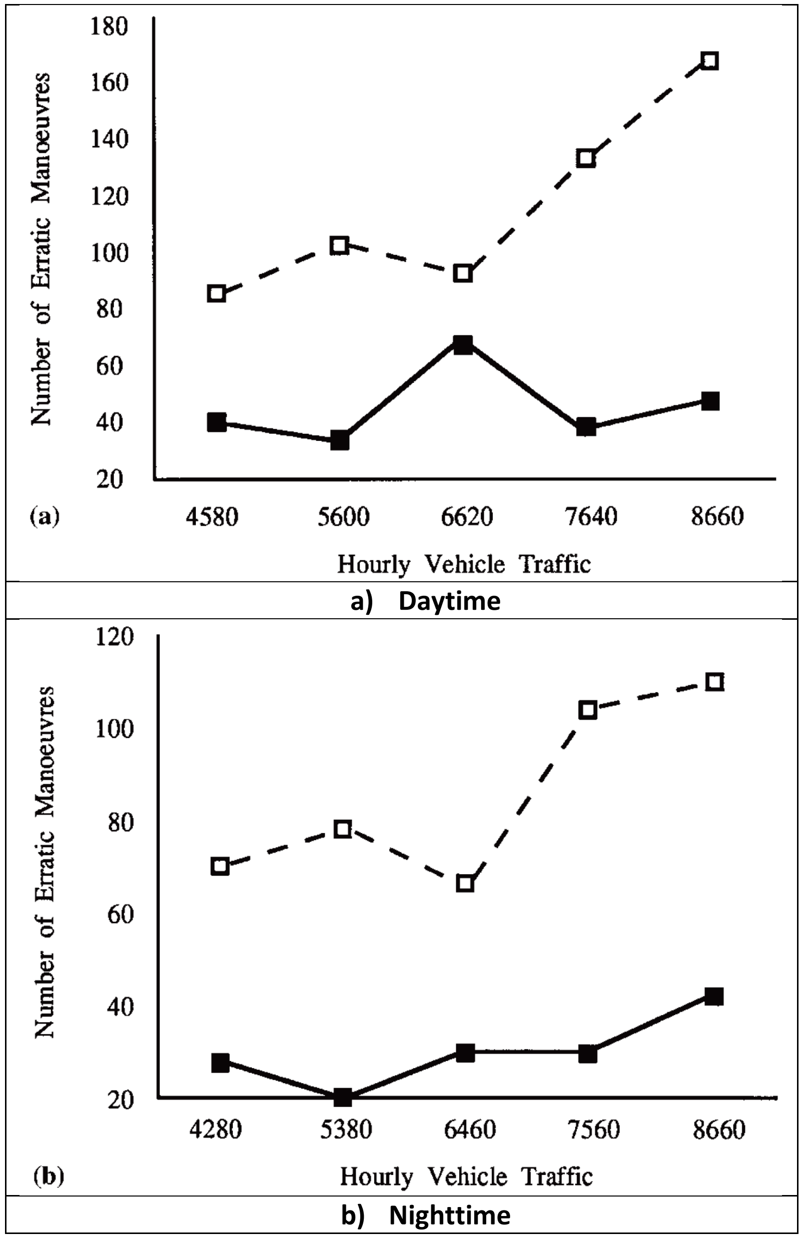
Treatment Level	Total Accidents Before Delineation	Total Accidents After Delineation	Percent Change	Statistically Significant?[a]
1	26	17	−35	No
2	43	19	−56	Yes
3	51	23	−55	Yes
4	76	36	−53	Yes

[a] Statistically significant based on chi-square test with 0.05 level of significance.

A 1998 study evaluated the efficiency of a bollard treatment at the exit gore area of highways in Israel (*19*). A review of crashes on two highways in Israel showed that exit and entrance areas were involved in 69 percent of interchange area crashes, while gore-area crossings occurred in only 23 percent of exit crashes. Thirty-five percent (9/26) of exit-area accidents occurred when the vehicles were changing lanes, whereas 27 percent (7/26) of exit-area crashes occurred when vehicles in the same lane did not maintain an appropriate distance and collided rear-end (shown in Table 15). The application of bollards was found to be relevant for 11 percent of the crashes. Field observations of driver behavior before and after bollard installation showed a 60 percent daytime and 65 percent nighttime reduction in erratic maneuvers (shown in Figure 9). Researchers also observed that the bollards became dirty very quickly and hence could not function properly (in terms of visibility) for extended periods. The study concluded that if the number of crashes per gore area reached at least one in three years, installation of bollards was warranted. Also, researchers recommended that the first one-third of the gore area be painted, without bollards.

Table 15. Accident Distribution According to Accident Location and Vehicle Maneuvers prior to a Collision (*19*).

Accident Location with Reference to Interchange	Vehicle's Maneuvers prior to a Collision					Total
	Single Vehicle, Loss of Control	Two Vehicles Moving in the Same Direction			Others	
		Changing a Lane	Parallel Lanes, Non-Intended Deviation	The Same Lane, Not Keeping Distance		
UNDER	1	1	3	4	1	10
ON	1	2	2	13	6	24
EXIT	5	9	4	7	1	26
ENTER	1	5	2	4	—	12
BETWEEN	13	13	13	23	5	67
Total	21	30	24	51	13	139



a) Daytime

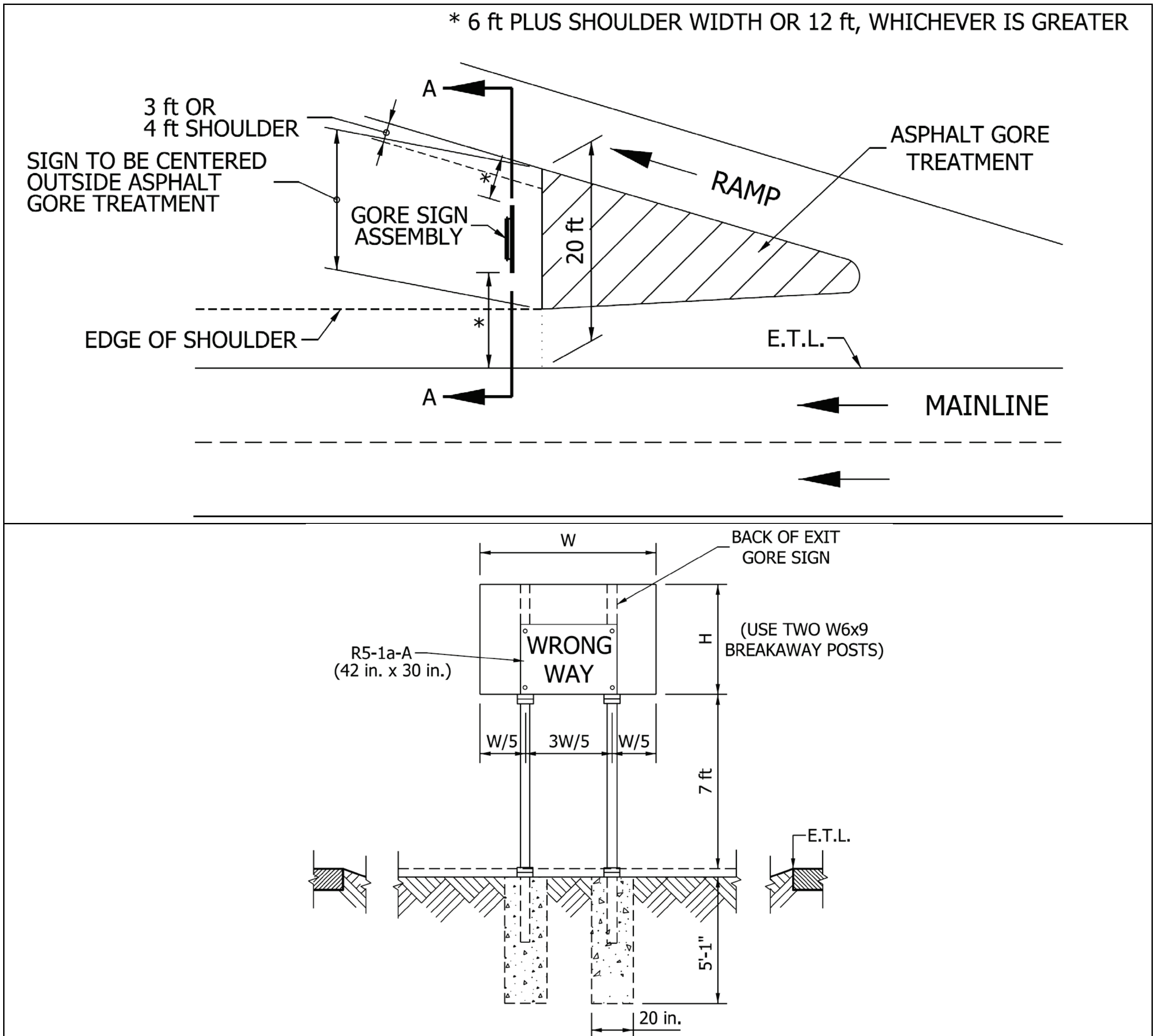
b) Nighttime

Figure 9. Changes in Driver Behavior after Bollard Installation: (a) Daytime; (b) Nighttime (*19*).

Review of State Guidance

The TTI team conducted a desktop search of guidelines and manuals from all 50 states to review their current policies and guidelines pertaining to exit gore signs. The main online source for state manuals used for this review was the FHWA website, under MUTCDs and Traffic Control Devices Information by State (http://mutcd.fhwa.dot.gov/resources/state_info/).

Most states include the national MUTCD language provided in Section 2E.37 in their state manuals/supplements. The Utah MUTCD stresses that consistent application of the exit gore sign at each exit is important (*20*). The Indiana traffic design manual suggests that gore signs be placed on each freeway gore area in the manner shown in Figure 10 (*21*). The Maryland MUTCD also has standard statements for the use of exit gore signs at all exits (*22*). The New Mexico striping manual recommends use of the E5-1a sign with the exit number within the sign area (*23*). The New York State MUTCD suggests using the E5-1bP exit number plaque in conjunction with the E5-1 exit gore sign (*24*). The *TxDOT Freeway Signing Handbook* says all exit gore signs must remain white on green (*25*).



Section A-A

Figure 10. Gore Sign Treatment (*21*).

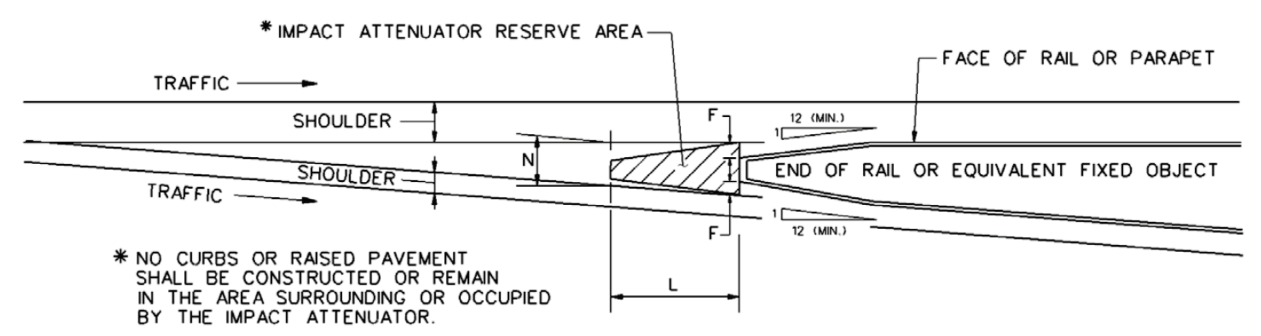
Colorado DOT advises that a clear view of the entire exit terminal be available to the driver (*26*). The *Connecticut Highway Design Manual* suggests using a 0.0-inch-high object (as the object in this case is the pavement surface) for estimating the decision sight distance for freeway exit gore (*27*).

Many states recommend that sign posts and other objects be removed or relocated to beyond the clear zone (*26*, *27*, *28*, *29*). The *California Traffic Manual* recommends a 30-ft clear zone for high-speed highways and a 20-ft clear zone for conventional highways (*28*). The *Maine Highway Design Manual* suggests that the gore nose be free of signs and luminaire supports for approximately 300 ft beyond the gore nose (*30*). The Maryland MUTCD provides guidance on lateral clearance based on available shoulder width; when the shoulder is less than 10 ft wide, the gore sign is to be moved farther away from the edge of the shoulder so that the minimum lateral clearance from the edge of the traveled roadway is 16 ft (*22*). The Maryland MUTCD also says that the preferred spacing between the gore sign and physical gore be 50 ft. If the exit gore sign is greater than 50 ft back from the physical gore or greater than 300 ft back from the theoretical gore, an object marker (OM) should be placed in front of the exit gore sign. When used, the OM should be placed 4 ft back from the physical gore. If the roadway has a speed limit of 55 mph or greater, a modified Type 3 OM should be used; otherwise, a Type 1 OM should be used (*22*).

Route shield markers are also suggested at sites with high numbers of crashes at the gore or frequently hit crash attenuators (*31*). Chevron markings in the neutral area, dotted extensions of the lane line or the right edge line, and lane-reduction arrow markings are also suggested for use when there is a need to provide additional guidance to motorists (*32*). The *Pennsylvania Traffic Engineering Manual* recommends installation of RPMs within exit-ramp gore areas of all freeways and highways, unless the pavement is in poor condition or if the department plans to resurface the pavement within four years (*33*).

Many states recommend installing crash cushions where fixed objects cannot be economically removed or made to break away and where other protective systems such as guardrails are not suitable (*22*, *26*, *27*, *28*, *29, 30*, *34*, *35*). Crash cushions are recommended at gore areas because they are narrow and relatively short (*36*). Maine highway program design guidance on crash cushions suggests use of Category 3—Low Maintenance and/or Self-Restoring Crash Cushions for gore areas. This system is designed to suffer little, if any, damage on impact and can be easily pulled back into full operating condition (*30*).

The impact attenuator design needs to be compatible with the traffic and physical conditions at the site. There is some concern about using unanchored inertial systems on elevated structures because they may walk or crash due to the vibration of the elevated structure. The reserve area for impact attenuators in gores illustrated in the *Connecticut Highway Design Manual* is shown in Figure 11 (*27*).



Design Speed on Mainline (mph)	Dimensions for Impact Attenuator Reserve Area (ft)								
	Minimum						Preferred		
	Restricted Conditions			Unrestricted Conditions					
	N	L	F	N	L	F	N	L	F
50	6	17	2	8	25	3	12	33	4
55	6	20	2	8	30	3	12	39	4
60	6	23	2	8	35	3	12	44	4
65	6	25	2	8	40	3	12	50	4
70	6	28	2	8	45	3	12	55	4

Figure 11. Reserve Area for Impact Attenuator in Gores (Figure 13-7B in *27*).

TREATMENT SELECTION

State of the Practice

Researchers used Google Earth to conduct a virtual scan of exit gore treatments in the United States and in other countries. Figure 12 through Figure 17 show examples of what was found during the scan. In addition to MUTCD-style exit gore signs, exit gore treatments included chevron pavement markings, arrow pavement markings pointing to the exit, Chevron signs, various types of vertical delineators, and guardrail end-cap structures with checkered markings.

Pavement Markings and Delineators

Pavement marking arrows point to the main lane and toward the exit on a highway in Spain (Figure 12). On the same highway in Spain, pavement markings and delineators outline the exit gore (see Figure 13).

Figure 12. Pavement Markings ahead of Exit Gore, Spain.

Figure 13. Exit Gore Pavement Markings and Delineators, Spain.

On a highway in Pennsylvania, vertical delineators in the exit gore again provide additional visual cues ahead of the exit gore sign (Figure 14). Pavement markings, though they are faded, provide an additional visual identifier for the gore area.

Figure 14. Exit Gore Sign, Pavement Markings, and Delineators—Pennsylvania, United States.

Chevron Signs and Devices

An additional short Chevron sign calls attention to the sign post on a highway in Canada (see Figure 15). In place of an MUTCD-style exit gore sign, a Chevron sign combined with chevron pavement markings marks an exit gore in Sweden (Figure 16).

Figure 15. Exit Gore Sign plus Vertical Chevron Reflector, Canada.

Figure 16. Exit Gore Chevron Sign and Chevron Pavement Markings, Sweden.

Pavement markings and a checkered structure at the end of a guardrail mark an exit gore on a highway in Japan (see Figure 17).

Figure 17. Exit Gore Vertical Structure and Chevron Pavement Markings, Japan.

MUTCD Guidance Used in Consideration of Alternative Devices

Color. Section 1A.12, Standard 03 includes the general meaning of the following colors being considered for possible devices:

- A. Black—regulation.
- G. Green—indicated movements permitted and direction guidance.
- L. White—regulation.
- M. Yellow—warning.

Longitudinal markings. Section 3A.05, Standards 01–02 and 08–09 state the following:

> 01 Markings shall be yellow, white, red, blue, or purple. The colors for markings shall conform to the standard highway colors. Black in conjunction with one of the colors mentioned in the first sentence of this paragraph shall be a usable color.
>
> 02 When used, white markings for longitudinal lines shall delineate:
>
> > A. The separation of traffic flows in the same direction, or
> >
> > B. The right-hand edge of the roadway.
>
> 08 Black may be used in combination with the colors mentioned in the first sentence of Paragraph 1 where a light-colored pavement does not provide sufficient contrast with the markings.
>
> 09 When used in combination with other colors, black is not considered a marking color, but only a contrast-enhancing system for the markings.

Section 3B.04, Standard 01 reinforces that:

> When used, lane line pavement markings delineating the separation of traffic lanes that have the same direction of travel shall be white.

Transverse markings. Section 3B.13, Standard 01 states:

> Transverse markings, which include shoulder markings, word and symbol markings, arrows, stop lines, yield lines, crosswalk lines, speed measurement markings, speed reduction markings, speed hump markings, parking space markings, and others, shall be white unless otherwise provided in this Manual.

Warning Classification Object Markers. Perhaps the most relevant section of the MUTCD for developing a new exit gore device would be guidance on object markers. Section 2C.63 discusses object marker design and placement height. Support 01 explains that Type 1, 2, and 3 object markers are used to mark obstructions within or adjacent to the roadway. In addition, this section describes the Type 1–3 markers in more detail (see Figure 18), as follows:

- Type 1—a diamond-shaped sign, at least 18 inches on a side, consisting of either a yellow (OM1-1) or black (OM1-2) sign with nine yellow retroreflective devices, each with a minimum diameter of 3 inches, mounted symmetrically on the sign, or an all-yellow retroreflective sign (OM1-3).
- Type 2—either a marker (OM2-1V or OM2-1H) consisting of three yellow retroreflective devices, each with a minimum diameter of 3 inches, arranged either horizontally or vertically on a white sign measuring at least 6 × 12 inches, or an all-yellow horizontal or vertical retroreflective sign (OM2-2V or OM2-2H), measuring at least 6 × 12 inches.
- Type 3—a striped marker, 12 × 36 inches, consisting of a vertical rectangle with alternating black and retroreflective yellow stripes sloping downward at an angle of 45 degrees toward the side of the obstruction on which traffic is to pass. The minimum width of the yellow and black stripes shall be 3 inches.

Section 2C.64, Standard 04 describes the pattern for object markers for obstructions within the roadway that Figure 18 shows:

> The alternating black and retroreflective yellow stripes (OM3-L, OM3-R) shall be sloped down at an angle of 45 degrees toward the side on which traffic is to pass the obstruction. If traffic can pass to either side of the obstruction, the alternating black and retroreflective yellow stripes (OM3-C) shall form chevrons that point upwards.

Also, with respect to the exit gore sign in particular, the MUTCD states:

> To improve the visibility of the gore for exiting drivers, a Type 1 object marker may be installed on each sign support below the Exit Gore sign.

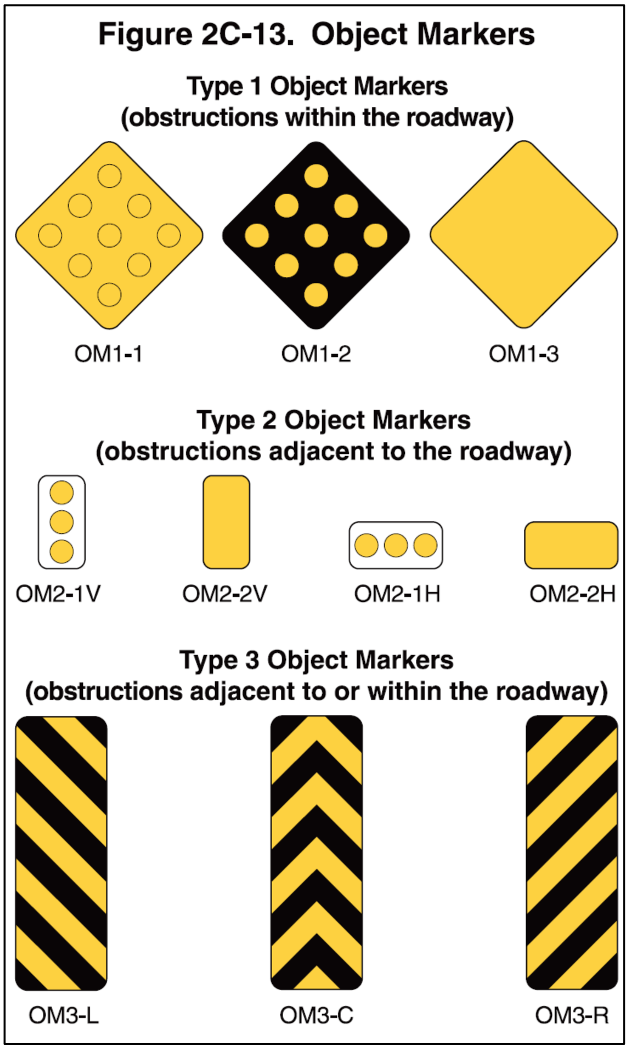


Figure 18. Figure 2C-13 from the MUTCD Illustrating Object Markers.

Pavement Markings.

Longitudinal markings. Section 3A.06, Standard 01 states the general functions of longitudinal lines shall be:

> A. A double line indicates maximum or special restrictions,
>
> B. A solid line discourages or prohibits crossing (depending on the specific application),
>
> C. A broken line indicates a permissive condition, and
>
> D. A dotted line provides guidance or warning of a downstream change in lane function.

Section 3B.05 describes the use of other white longitudinal devices such as channelizing lines or markings within the gore area. Option 02 and Standards 05 and 07 indicate:

> 02 Channelizing lines may be used to form channelizing islands where traffic traveling in the same direction is permitted on both sides of the island.
>
> 05 Channelizing lines at exit ramps as shown in Figures 3B-8 and 3B-10 define the neutral area, direct exiting traffic at the proper angle for smooth divergence from the main lanes into the ramp, and reduce the probability of colliding with objects adjacent to the roadway.
>
> 07 For all exit ramps and for entrance ramps with parallel acceleration lanes, channelizing lines shall be placed on both sides of the neutral area.

Transverse pavement markings. Recently there has been much interest in using transverse markings on freeways. Section 3B.13 provides the following applicable guidance and options on the appearance and placement of traverse or horizontal markings:

> 02 Because of the low approach angle at which pavement markings are viewed, transverse lines should be proportioned to provide visibility at least equal to that of longitudinal lines.
>
> 05 Letters and numerals should be 6 ft or more in height.
>
> 06 Word and symbol markings should not exceed three lines of information.
>
> 07 If a pavement marking word message consists of more than one line of information, it should read in the direction of travel. The first word of the message should be nearest to the road user.
>
> 09 The number of different word and symbol markings used should be minimized to provide effective guidance and avoid misunderstanding.
>
> 11 Pavement word, symbol, and arrow markings should be proportionally scaled to fit within the width of the facility upon which they are applied.

Section 3B.20, Support 01 indicates how these types of markings are to supplement signage, and Option 02 lists the currently available markings:

> 01 Word, symbol, and arrow markings on the pavement are used for the purpose of guiding, warning, or regulating traffic. These pavement markings can be helpful to road users in some locations by supplementing signs and providing additional emphasis for important regulatory, warning, or guidance messages, because the markings do not require diversion of the road user's attention from the roadway surface. Symbol messages are preferable to word messages. Examples of standard word and arrow pavement markings are shown in Figures 3B-23 and 3B-24.
>
> 02 Word, symbol, and arrow markings, including those contained in the "Standard Highway Signs and Markings" book, may be used as determined by engineering judgment to supplement signs and/or to provide additional emphasis for regulatory, warning, or guidance messages. Among the word, symbol, and arrow markings that may be used are the following:

A. Regulatory:
   1. STOP
   2. YIELD
   3. RIGHT (LEFT) TURN ONLY
   4. 25 MPH
   5. Lane-use and wrong-way arrows
   6. Diamond symbol for HOV lanes
   7. Other preferential lane word markings

B. Warning:
   1. STOP AHEAD
   2. YIELD AHEAD
   3. YIELD AHEAD triangle symbol
   4. SCHOOL XING
   5. SIGNAL AHEAD
   6. PED XING
   7. SCHOOL
   8. R X R
   9. BUMP
   10. HUMP
   11. Lane-reduction arrows

C. Guide:
   1. Route numbers (route shield pavement marking symbols and/or words such as I-81, US 40, STATE 135, or ROUTE 10)
   2. Cardinal directions (NORTH, SOUTH, EAST, or WEST)
   3. TO
   4. Destination names or abbreviations thereof

With respect to transverse arrows only, lines 20–27 provide the following support, guidance, and options:

> 20 Lane-use arrow markings (see Figure 3B-24) are used to indicate the mandatory or permissible movements in certain lanes

21 Lane-use arrow markings (see Figure 3B-24) should be used in lanes designated for the exclusive use of a turning movement, including turn bays, except where engineering judgment determines that physical conditions or other markings (such as a dotted extension of the lane line through the taper into the turn bay) clearly discourage unintentional use of a turn bay by through vehicles. Lane-use arrow markings should also be used in lanes from which movements are allowed that are contrary to the normal rules of the road

22 An additional arrow or arrows may be used in a turn lane. When arrows are used for a short turn lane, the second (downstream) arrow may be omitted based on engineering judgment.

25 Where through lanes approaching an intersection become mandatory turn lanes, lane-use arrow markings (see Figure 3B-24) shall be used and shall be accompanied by standard signs.

26 Where through lanes approaching an intersection become mandatory turn lanes, ONLY word markings (see Figure 3B-23) should be used in addition to the required lane-use arrow markings and signs (see Sections 2B.19 and 2B.20). These markings and signs should be placed well in advance of the turn and should be repeated as necessary to prevent entrapment and to help the road user select the appropriate lane in advance of reaching a queue of waiting vehicles.

27 On freeways or expressways where a through lane becomes a mandatory exit lane, lane-use arrow markings may be used on the approach to the exit in the dropped lane and in an adjacent optional through-or-exit lane if one exists.

Figures 19–21 show illustrations of transverse pavement markings from the MUTCD.

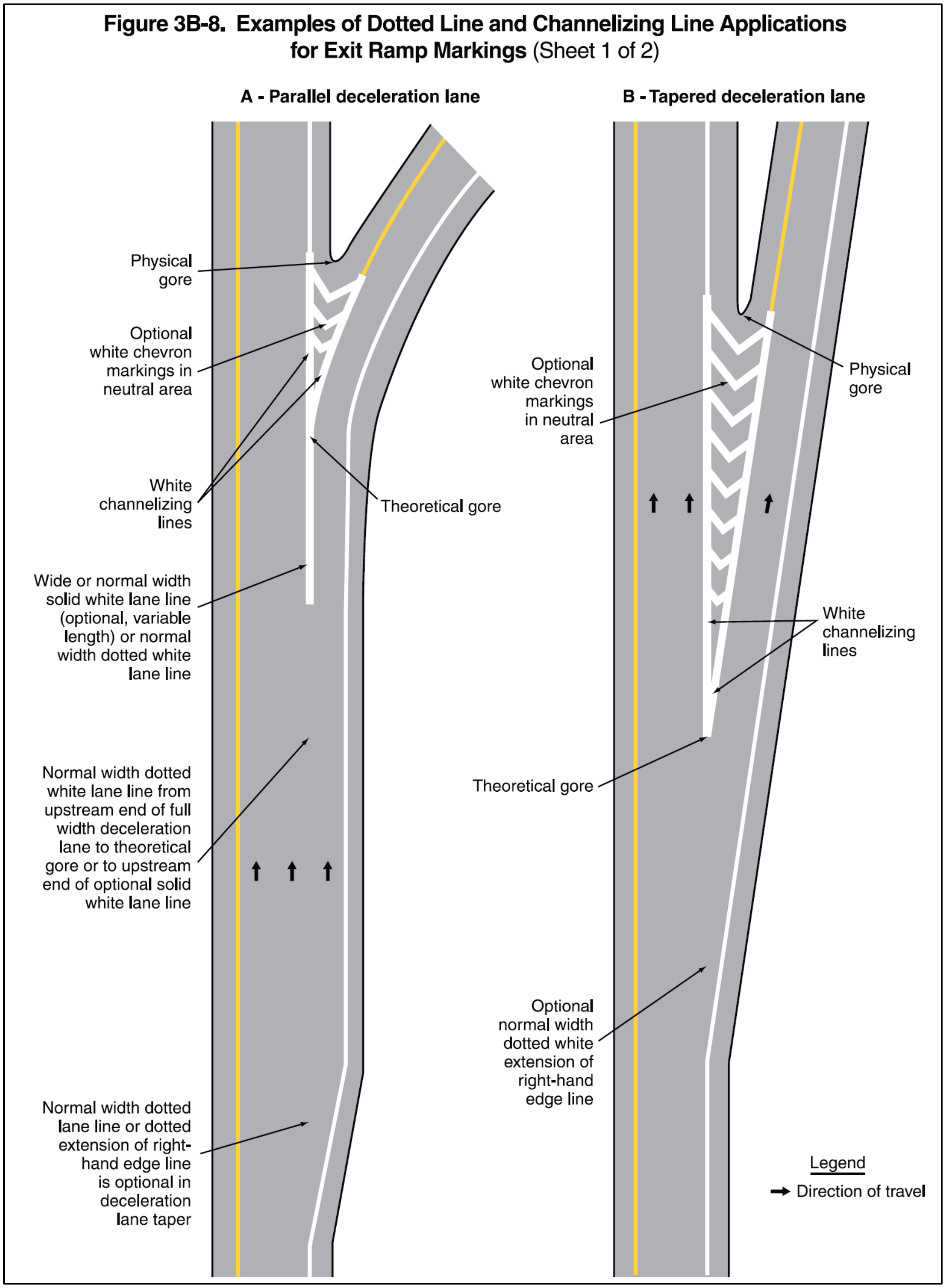


Figure 19. Figure 3B-8 from the MUTCD with Examples of Markings for an Exit Ramp.

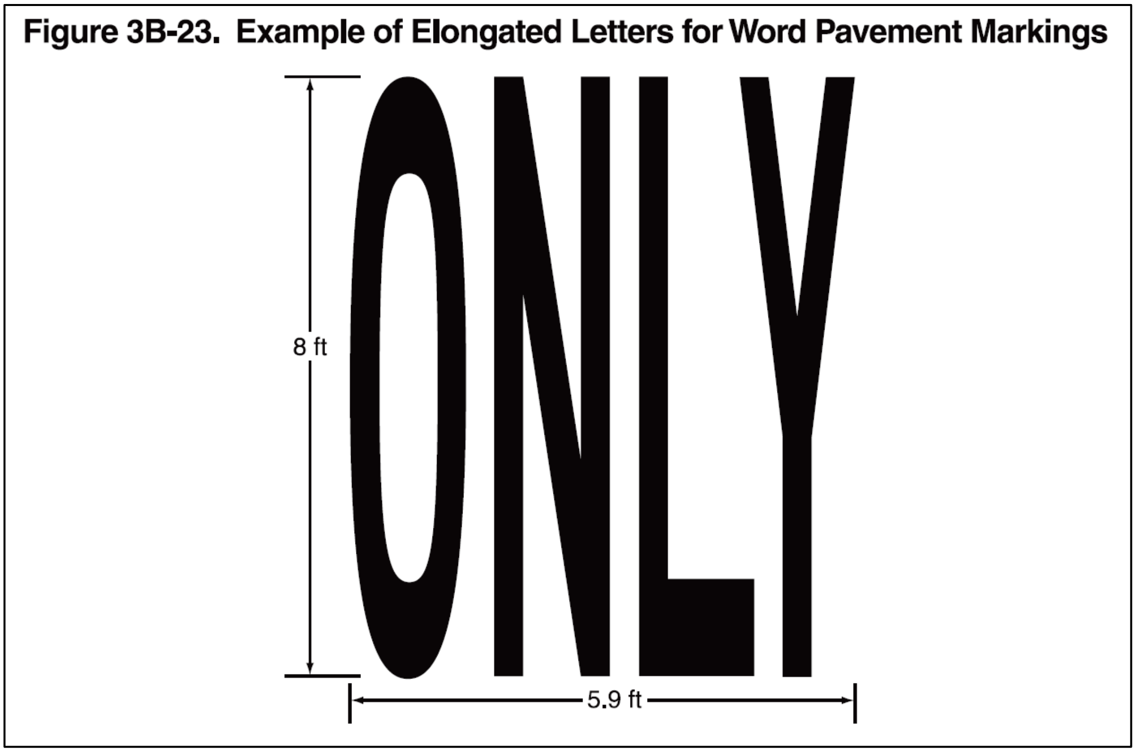


Figure 20. Figure 3B-23 from the MUTCD Displaying Example of an Elongated Transverse Marking.

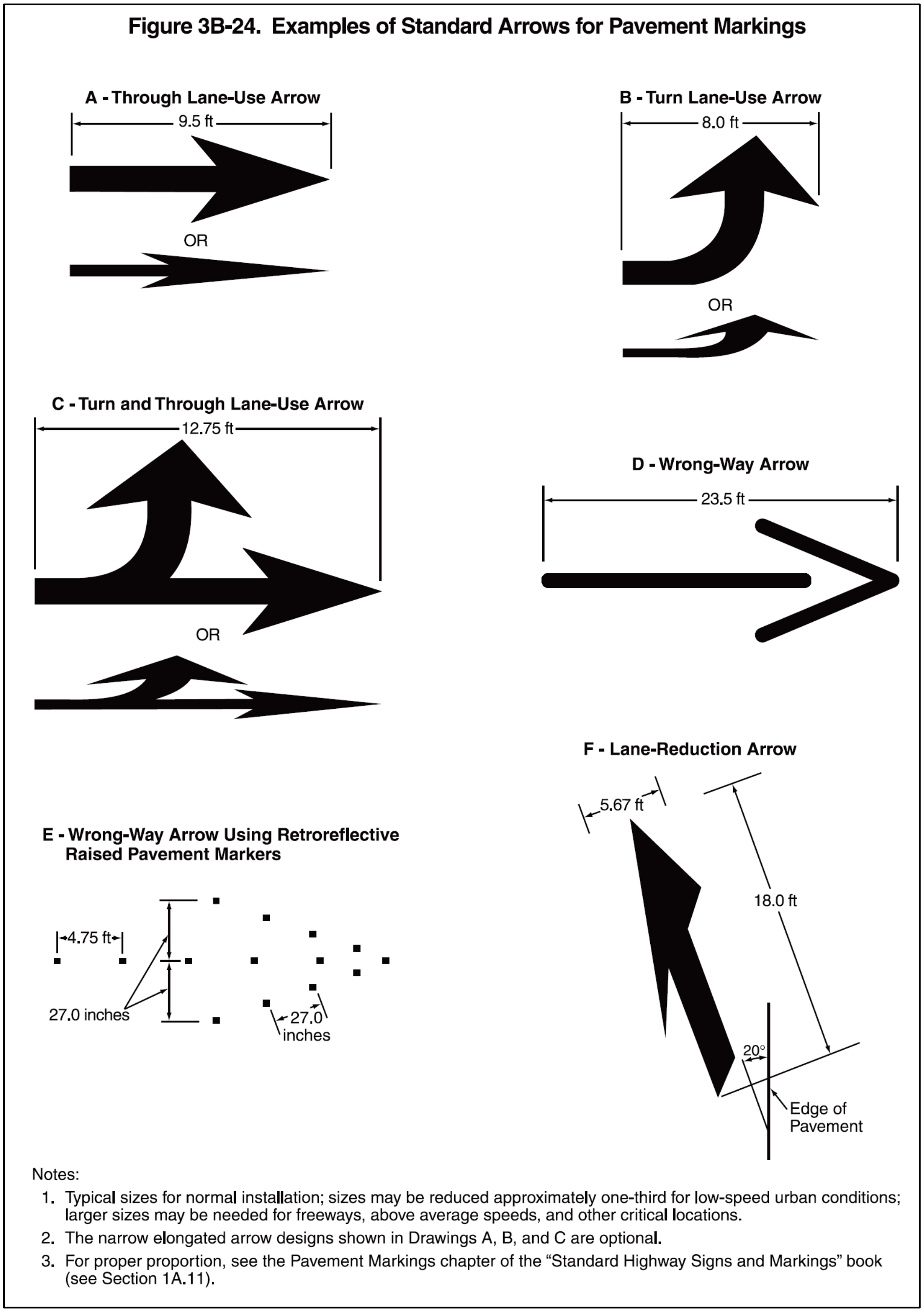


Figure 21. Figure 3B-24 from the MUTCD Displaying Example of Arrow Transverse Markings.

Final Selection of Treatments

Beginning with the examples found in the state of practice and the existing guidelines in the MUTCD, researchers selected (and in some cases modified) several different types of exit gore treatments to test in TTI's driving simulator. The test treatment designs that were ultimately developed and tested (see Figure 22) were:

- S—the existing MUTCD-prescribed exit gore sign.
- C1—a vertical device displaying a large chevron pattern (chevrons pointing up).
- C2—a vertical device displaying an alternative chevron pattern (chevrons pointing right and left).
- M—diagonal-shaped pavement markings.
- MC1—diagonal-shaped pavement markings plus the vertical chevron device C1.
- HM—a horizontal pavement sign reading EXIT with an arrow pointing to the exit ramp.

Treatment M and MC1 were chosen to display diagonal-shaped markings because of their ease of installation, and to avoid excess flickering in the simulation of the more complicated chevron design due to limited resolution.

In order to keep simulation drive time to a minimum, researchers made the following justifications in finalizing the list of treatments.

- If the chevron pattern, C1, performed better or worse in combination with diagonal markings, M, then the same results would hold true for the combination of C2 and M and this combination did not also need to be tested.
- Horizontal markings, HM, would only be used in practice to supplement another signing or device; therefore, if they performed favorably here, then it could be assumed they would make an appropriate supplement.
- If the addition of the diagonal markings, M, to the C1 device performed better than C1 alone, then it could be assumed that the addition of M to the sign-only condition, S, would also increase performance.

S	MUTCD Sign Only	
C1	Up Chevron Device	
C2	Horizontal Chevron Device	
M	Markings Only	
C1M	Up Chevron Device with Markings	
HM	Horizontal Pavement Markings	

Figure 22. Six Test Treatments.

EXPERIMENTAL DESIGN

Simulation Description

TTI houses a Realtime Technologies, Inc., desktop driving simulator that was operated with three screens for viewing the roadway (Figure 23). The driving environment included a two-lane rural freeway with frontage roads and moderate traffic. Traffic signs and devices other than the test treatments were placed alongside the road in such a way as to encourage the participants' scan patterns but not to interfere with the viewing of the treatments. The simulation consisted of two different scenarios.

Figure 23. TTI's Desktop Driving Simulator.

Scenario 1: Push-Button Response by Driver

For the first scenario, participants were asked to drive along a roadway that included multiple right-hand exits and to push a button located on the simulator's steering wheel as soon as they saw each exit. Participants were instructed to remain on the roadway rather than exit at any of the exits. The exit gores were viewed at a long distance (on a flat roadway segment) and a short distance (with a vertical curve ahead of the gore, as seen in Figure 24). The primary measure of effectiveness was the distance (measured to the exit gore) at which participants pressed the button indicating that they had seen the location of the exit gore/ramp. Upon passing each treatment, the participants were asked a visibility question.

Figure 24. Short Condition: Small Vertical Curvature Prior to Gore.

Scenario 2: Exit Response

The second scenario consisted of six shorter drives. On the same roadway environment used for Scenario 1, participants drove behind a lead truck that was positioned in such a way that it blocked the view of the exit gore and exit gore treatment until the gore was approximately 200 ft away (Figure 25). Participants were told to exit at the first available exit on the drive. The primary measure of effectiveness was the distance (measured to exit gore) at which the driver began his/her lane change maneuver to exit. Any excessive lateral acceleration, speed changes, or other adverse driving behaviors were recorded.

Figure 25. Blocked Driving Condition.

Procedure

Upon arrival, the participants read and signed an informed consent document (Appendix B). Following consent, the participants were given a brief purpose of the study and were shown the test treatments they would be viewing. It was clarified that the study was only interested in what was placed at the exit itself where the roadway split, and not in any advance signs telling drivers that an exit was up ahead.

Pre-Simulation Questioning

As they were shown the six test treatments, the participants were asked the following three questions:

- Which treatments are being used on the roadways to mark exits?
- Which treatment(s) do you think work the best, and why?
- Which treatment(s) do you think work the least, and why?

In addition to the above questions, the participants were asked to look specifically at Treatment HM (the horizontal pavement markings) and were asked "If you could not see what was happening to the roadway ahead, if you stayed in the right lane, do you think you would have to exit ahead?"

Practice

Before beginning the experimental drives, the participants completed a short practice drive to become familiar with driving in the simulator. The following instructions were read to the participants:

> The driving simulator you are in will react to your steering and pedal inputs to provide a realistic driving experience. During your drive in the simulator, please drive in a normal fashion. I can adjust your pedals at a position that is comfortable for you. You will only be using the accelerator and brake and will not need to use the clutch on the far left, nor will you use the paddles on the wheel. You will not be using your turn signal today, but will be using the red buttons on top of the steering wheel. You'll notice there are three insets on your screens, one for your rearview mirror and two for your side mirrors.
>
> *[Adjust pedals and point out paddles or mirrors if there is any confusion]*
>
> We will begin with a practice session to get you comfortable with driving in the simulator. You can slowly pull out onto the roadway and as you become comfortable, and accelerate to a speed of 55 to 65 mph. Don't worry about driving at an exact speed limit; just do your best to try to stay in that range.
>
> *[Participant should be pulling out]*
>
> *[Once they are up to speed]* How are you doing? Practice switching back and forth from the accelerator to the brake to get comfortable with the pedals. Also, practice switching lanes.
>
> *[Once you feel they are driving comfortably]* Do you feel you've had enough practice?
>
> *[If no, allow them to practice a little longer]* Please slowly coast to a stop.

Experimental Sessions

Once a participant was comfortable, the following instructions were read for the experimental sessions:

> For the experimental sessions, I will have you drive two different types of scenarios that I will explain each time before you begin.
>
> Please remember to drive between 55 and 65 mph and drive only in the right lane. At points during your drive, I will ask you the following question: <u>From a distance</u>, on a scale of 1 to 5, with 5 being the most obvious and 1 being the least obvious, how obvious was it that an exit was splitting off? Always continue driving until I ask you to stop. Do you have any questions?
>
> For the first scenario, you will be asked to drive along a roadway that includes a series of exits and you will push a button located on the top of the simulator's steering wheel as <u>soon as you are sure</u> you see an exit. *[Refer to one of the still shots to explain it's when they are sure they see the lanes splitting, not advance signage]* If you feel like you have prematurely indicated that you see the exit by hitting the button too soon, you can re-hit it

> when you are sure. You will remain on the roadway and continue going straight rather than exiting.
>
> *[After completion of the first drive]*
>
> For the second scenario, you will drive six short drives on the highway, and you will want to take the first available exit for each drive.

During the drives, after each treatment was passed, the facilitator asked the following:

> From a distance, on a scale of 1 to 5, with 5 being the most obvious and 1 being the least, how obvious was it that an exit was splitting off?

Experiment Groups and Orders

Participants were divided into four groups to introduce different treatment presentation orders to reduce bias. Table 16 and Table 17 display these orders, as well as the treatment codes that are referenced in the results section of this document. The treatment code is defined by the previously mentioned nomenclature, followed by Long for Scenario 1's flat condition, Short for Scenario 1's vertical curve condition, and Blocked for Scenario 2's lead truck condition.

Table 16. Scenario 1 Group Treatment Orders (Single Long Drive).

Treatment Order	Group A	Group B	Group C	Group D
1	M_Long	S_Short	C2_Long	C1_Short
2	C1_Short	C1_Long	MC1_Long	S_Long
3	C2_Long	C2_Long	M_Short	MC1_Long
4	S_Short	M_Short	S_Long	M_Long
5	MC1_Short	MC1_Short	C1_Short	C2_Short
6	C2_Short	M_Long	S_Short	M_Short
7	C1_Long	S_Long	C1_Long	C1_Long
8	M_Short	MC1_Long	C2_Short	C2_Long
9	MC1_Long	C2_Short	MC1_Short	S_Short
10	S_Long	C1_Short	M_Long	MC1_Short

Table 17. Scenario 2 Group Treatment Orders (Six Separate Drives).

Treatment Order	Group 1	Group 2	Group 3	Group 4
1	S_Blocked	C1_Blocked	M_Blocked	HM_Blocked
2	C2_Blocked	HM_Blocked	MC1_Blocked	MC1_Blocked
3	MC1_Blocked	C2_Blocked	S_Blocked	M_Blocked
4	HM_Blocked	M_Blocked	C1_Blocked	S_Blocked
5	C1_Blocked	MC1_Blocked	HM_Blocked	C2_Blocked
6	M_Blocked	S_Blocked	C2_Blocked	C1_Blocked

Participant Recruitment

Participants were recruited from the Bryan/College Station community through TTI's existing recruiting pool, through social media, and by word of mouth. Data from 40 participants were collected, split between Groups A–D. Ages ranged from 21 to 79, with an average age of 44. There were 20 males and 20 females. Table 18 summarizes the age and gender distribution of the 40 participants.

Table 18. Participant Age and Gender.

Age	Female	Male	Total
18–35	7	8	15
36–55	8	5	13
56+	5	7	12
Total	20	20	40

RESULTS

Pre-Simulation Questioning

Prior to seeing any of the treatments in simulation, the participants were shown still shots of the treatments in context and asked the following questions:

- Which treatments are being used on the roadways to mark exits? (Results shown in Table 19).
- Which treatment(s) do you think work the best, and why? (Results shown in Table 20).
- Which treatment(s) do you think work the least, and why? (Results shown in Table 20).
- Looking at (Treatment HM), if you could not see what was happening to the roadway ahead, if you stayed in the right lane, do you think you would have to exit ahead?

Which Treatments Are Being Used on the Roadways to Mark Exits?

For this question, participants were allowed to select multiple treatments for their answers. Results in Table 19 show that most participants recognized the existing MUTCD devices: the sign (S) at 90 percent, and the markings (M) at 67.5 percent.

Table 19. Percentage of Participants Who Recognized Each Treatment as Already Being Used to Mark Exits (n = 40).

Treatment	%
M	67.5
C1	15.0
C2	0.0
S	90.0
MC1	37.5
HM	32.5

Which Treatments Do You Think Work the Best and Least?

For these questions, participants were also allowed to select more than one treatment. The percentage results for each treatment are shown in Table 20, while the comments are found in Appendix C. When reading the comments, it is important to note that it became evident that participants used the term "sign" when referring to both the green guide sign and the unfamiliar chevron devices.

Approximately half of the participants believed that both the markings in combination with a chevron pattern (MC1 at 50.0 percent) and the horizontal markings (HM at 55.0 percent) worked the best. For MC1, participant explanations frequently mentioned the contrast and visibility and the combination of a pavement component with a vertical device. A little less than half (42.5 percent) of the participants believed the markings alone (M) were the least effective at marking the exit location. These explanations focused on the markings alone not being enough to warn the driver that the exit was approaching.

Table 20. Percentage of Participants Who Thought Each Treatment Worked the Best and Least (n = 40).

Treatment	Best	Least
M	20.0%	42.5%
C1	5.0%	22.5%
C2	2.5%	30.0%
S	32.5%	25.0%
MC1	50.0%	7.5%
HM	55.0%	25.0%

If You Stayed in the Right Lane, Do You Think You Would Have to Exit Ahead? (HM Specific Question)

When shown the roadway and asked to imagine that they could not see what was happening up ahead, 77.5 percent (n = 40) of the participants answered yes to this question. Of the nine participants who answered no, several mentioned it was because the text did not include the word "only."

Experimental Sessions

In the experimental sessions, participants viewed the treatments from a long and short distance (Scenario 1) and also with the approach blocked by a large truck (Scenario 2). The HM condition was only tested in Scenario 2 since the focus was to test it for any last-second reactions. The results can be broken into the ratings data, provided by a verbal response, and the driving data.

For Scenario 2, it is important to note that it was discovered that if the participant dropped his/her speed down to 50 mph or lower, there was a possibility it affected the programming of the lead truck, and the headway may have varied from subject to subject as a result. For these data, a subset was also created with those participants removed.

Ratings Data

The same ratings question was asked for all treatments across both scenarios. Ratings were on a scale of 1 (least obvious) to 5 (most obvious). Rating scores were analyzed in two different ways.

First, the means of the ratings for each treatment under each condition were calculated for visual comparison (see Table 21 and Figure 26) and were tested for differences using a paired t-test. Because the ratings are ordinal data rather than interval data (i.e., there is no previously established consistent interval between a 1 rating and a 2 rating), a paired t-test produces less-reliable results than it would if the data were continuous. To partially address this issue, researchers used a stricter alpha level ($p \leq 0.01$ instead of 0.05) in the paired t-test for detecting significance.

Table 21. Average Rating Scores.

Treatment	Long (n = 40)	Short (n = 40)	Blocked (n = 40)	Average
M	2.73	2.90	2.73	2.78
C1	3.05	2.90	3.08	3.01
C2	2.83	3.20	2.75	2.93
S	3.00	3.83	3.35	3.39
MC1	3.68	4.05	3.28	3.67
HM	n/a	n/a	3.53	n/a

NOTE: n/a = not applicable.

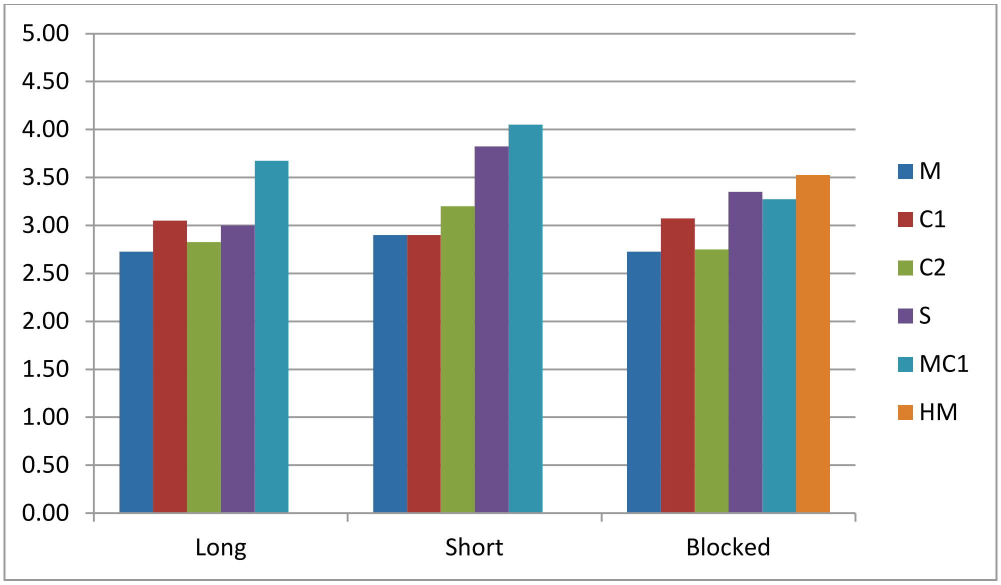


Figure 26. Comparison of Rating Averages for Long, Short, and Blocked Drives.

Second, the scores from all 40 participants for each of the treatments under the three viewing conditions (long, short, blocked) were compared using a Wilcoxon signed-ranks test. This is a statistical test specially intended for detecting differences between paired groups of ordinal data.

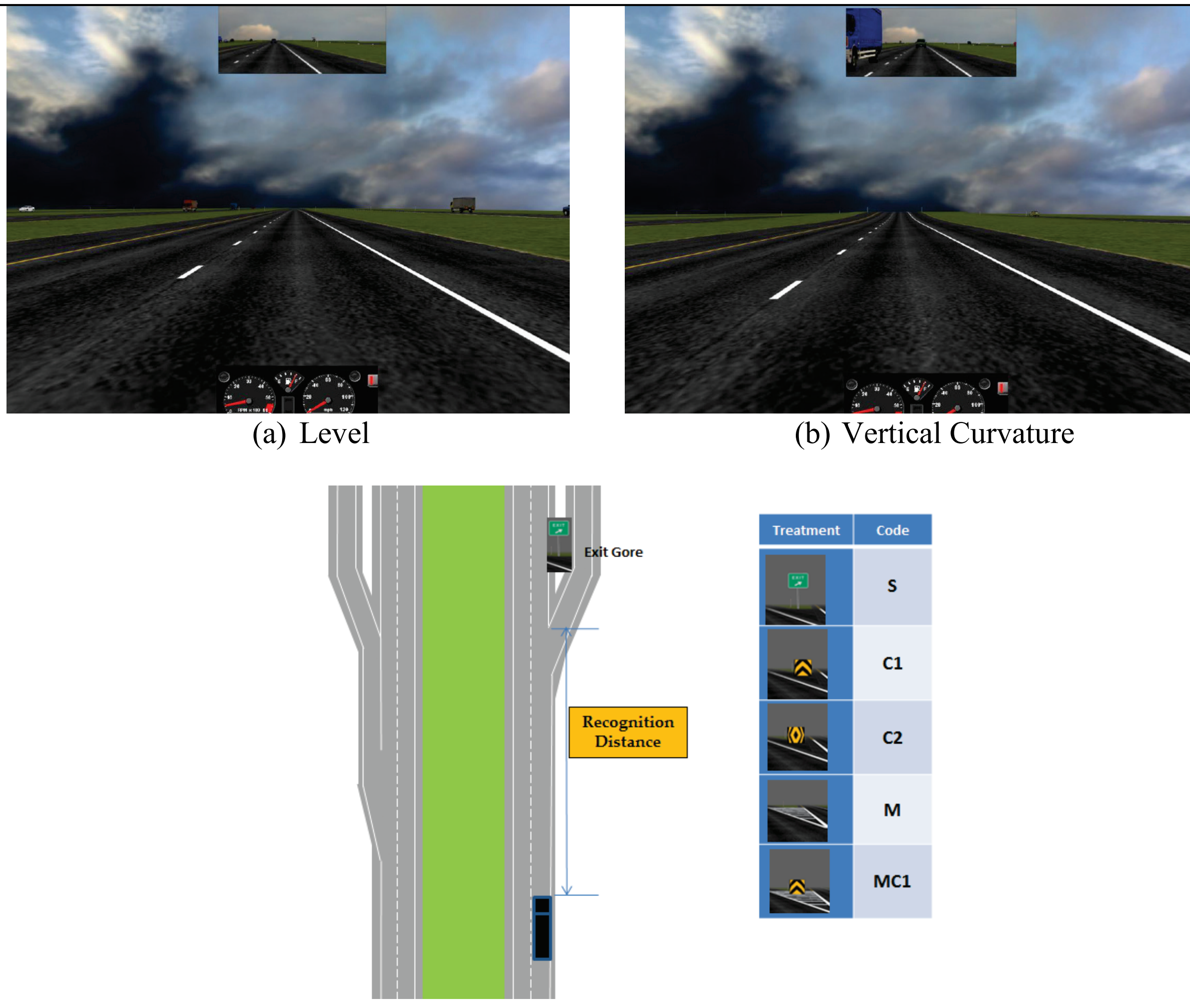
The results of the Wilcoxon signed-ranks test detected the following significant differences among the exit gore treatments under each of the viewing conditions. In most cases, these results and the paired t-test results identified the same significant differences.

- Long Viewing Condition:
  - Both the Wilcoxon signed-ranks test and the paired t-test found that the MC1 treatment was rated significantly higher overall than any of the other four treatments.
  - No significant differences were found in the ratings of treatments M, C1, C2, and S.
- Short Viewing Condition:
  - MC1 and S were found by both tests to be rated significantly higher than the other three treatments.
  - No significant differences were found between MC1 and S, or between M, C1, and C2.
- Blocked Viewing Condition:
  - HM, MC1, and S were found by both tests to be rated significantly higher than C2 and M.
  - The Wilcoxon signed-ranks test found C1 to be rated significantly higher than C2, but the paired t-test did not.
  - Neither test found significant differences between C1 and the top three (HM, MC1, S) or between C1 and M.

The complete set of p-values for both statistical analyses can be found in Appendix D.

Scenario 1—Button Response Data

Distance of Exit Recognition. In simulation, participants drove with a vehicle speed between 55 and 65 mph along a roadway with both level sections (see Figure 27a) and sections with vertical curvature (see Figure 27b). The roadway included a series of exits treated with either the MUTCD exit gore sign (S), Chevron Option 1 (C1), Chevron Option 2 (C2), pavement markings (M), or Chevron Option 1 on pavement markings (MC1). While driving, participants would push a button located on the top of the simulator's steering wheel as soon as they identified the location of each exit. They were instructed to remain on the roadway rather than exit**.**



(a) Level

(b) Vertical Curvature

(c) Exit Gore Treatments and Recognition Distance

Figure 27. Illustration of Exit Gore Treatments and Roadway.

The recognition distance (the simulated roadway distance from the button-push location and the start of the exit gore) was measured for each of the five gore treatments within two conditions—long viewing distance and short viewing distance. This resulted in 10 distance measurements for each of the 40 participants.

Table 22 presents these distances for the 40 participants; however, because two participants missed one button push each, the statistical analysis, which required equal sample sizes, could only be completed for 38 participants. On a level roadway, the longest average distance at which participants could recognize an exit was 965 ft, for gore treatment MC1. The shortest average recognition distance was 783 ft, for gore treatment C1.

In the statistical significance analysis using the Wilcoxon signed-rank test, C1 was the only treatment for which a significant difference in recognition distance was found compared to the standard exit gore sign (S). There was no significant difference between the other treatments and the S treatment.

On roadway segments with vertical curvature, participants could recognize an exit treated with S at the farthest distance (986.6 ft on average). Treatment C2 had the shortest average recognition distance of 817.8 ft. In the comparison with the S treatment using the Wilcoxon signed-rank test, the recognition distances of all treatments except for MC1 were significantly different.

Table 22. Recognition Distance to the Physical Gore by Treatments and Roadway Characteristics.

Participant	Treatment									
	Level					Vertical Curve				
	S	**C1**	**C2**	**M**	**MC1**	**S**	**C1**	**C2**	**M**	**MC1**
1	483.3	578.3	778.6	209.2	452.5	978.9	619.0	725.9	383.2	648.5
2	977.1	516.1	409.7	1387.8	547.4	872.5	892.3	830.5	638.2	874.5
3	522.2	971.6	1102.4	596.3	1460.6	1428.7	826.0	869.3	483.1	811.0
4	765.1	962.4	984.9	1013.6	860.2	1064.4	971.0	998.6	924.6	924.7
5	270.0	510.5	662.8	788.1	1119.2	1422.5	448.7	789.0	943.3	851.6
6	418.2	399.1	523.4	446.4	384.7	697.2	502.7	397.1	456.9	599.4
8	827.5	424.1	538.1	457.8	769.7	898.2	770.3	785.6	856.8	953.8
9	315.5	297.4	354.6	397.0	367.6	475.7	315.4	316.7	362.1	346.4
10	1186.6	924.3	1485.9	1239.0	2306.7	1074.9	1029.9	1060.2	934.8	1088.6
11	1919.2	739.1	1222.3	1681.5	n/a	1489.3	2853.2	1261.3	1082.5	1271.2
12	404.5	472.9	199.2	666.4	688.4	417.0	431.1	455.0	942.8	803.3
13	1034.0	957.5	534.8	370.6	703.6	961.6	655.7	821.2	873.9	917.8
14	1308.3	776.2	1127.9	1252.3	888.3	913.9	959.0	972.9	921.5	943.1
15	676.8	896.4	1508.9	580.1	1426.2	1017.9	886.8	876.0	900.5	786.7
16	332.5	598.3	846.4	n/a	406.1	616.6	453.5	631.9	385.6	691.1
17	864.2	976.1	717.9	566.7	1080.5	959.8	894.1	946.4	980.0	901.0
19	466.9	681.8	573.7	720.6	652.6	928.3	459.6	883.9	839.8	912.2
20	619.8	535.0	807.1	949.1	818.9	921.6	930.5	857.5	967.8	976.3
21	726.6	748.6	797.1	1014.1	1170.1	880.5	429.1	834.1	916.2	769.1
22	1225.2	446.4	1257.5	924.3	889.0	281.6	535.7	729.0	1049.1	904.8
23	1923.4	1139.3	1014.6	691.0	1279.1	1862.7	868.8	904.9	3221.0	2377.5
24	927.9	1162.5	1453.4	1306.1	1193.9	1083.1	927.7	508.9	995.8	1074.8

Table 22. Recognition Distance to the Physical Gore by Treatments and Roadway Characteristics (Continued).

Participant	Treatment									
	Level					Vertical Curve				
	S	**C1**	**C2**	**M**	**MC1**	**S**	**C1**	**C2**	**M**	**MC1**
25	1352.7	1138.6	1050.8	1151.0	1509.0	958.0	931.5	1031.2	975.7	1022.1
26	969.1	1059.1	917.8	1101.8	1583.0	944.0	919.8	923.6	911.9	980.7
27	1103.7	734.7	1341.2	821.3	795.5	941.1	897.7	990.4	898.6	2041.3
28	1078.6	1109.4	1338.8	1129.5	1273.1	952.3	1047.0	1036.1	1014.6	2178.0
29	883.0	1024.4	543.1	335.1	460.3	915.4	700.2	680.7	726.1	759.8
30	1637.0	1252.1	1483.2	757.1	1368.4	1497.7	875.7	954.7	1679.0	1008.9
31	690.9	697.2	420.0	653.7	1040.5	1009.3	456.1	637.2	214.4	339.2
32	1168.5	882.7	1291.3	1543.7	1650.4	1004.8	1048.9	921.1	999.8	969.8
33	931.0	516.7	762.4	608.0	323.5	983.4	361.4	419.3	637.7	544.9
34	1711.0	757.3	779.4	386.6	1157.0	1846.0	1914.3	948.6	937.7	1174.3
35	1896.4	1181.5	981.9	1234.1	1480.4	993.3	996.7	974.6	961.2	877.8
36	430.2	750.6	931.8	465.2	558.6	791.7	638.3	1008.0	965.0	1041.9
37	745.2	850.4	738.9	1335.2	1131.9	989.9	784.7	662.5	793.9	841.7
38	1630.6	992.6	1447.1	638.0	1005.6	1281.5	988.2	1043.7	838.6	1029.4
39	481.3	295.2	537.4	397.5	401.0	280.5	433.0	380.6	374.9	586.7
40	1108.0	802.0	1158.6	983.7	505.4	855.8	759.7	1006.7	586.4	630.4
Min.	270.0	295.2	199.2	209.2	323.5	280.5	315.4	316.7	214.4	339.2
Max.	1923.4	1252.1	1508.9	1681.5	2306.7	1862.7	2853.2	1261.3	3221.0	2377.5
Average	947.7	783.1	911.2	832.4	965.1	986.6	826.7	817.8	883.5	959.3
St. Dev.	470.6	264.2	362.2	377.0	453.0	346.1	447.5	221.2	474.4	420.4
Wilcoxon Signed-Rank Test (vs. Exit Sign Treatment)										
p-value		0.026*	0.41	0.11	0.36		<0.001*	<0.001*	<0.001*	0.09

NOTE: unit, ft.
* Significance of $p < 0.05$.

Scenario 2—Exit Response Data

In Scenario 2, participants exited the highway at the first available exit. In place of the button push in Scenario 1, the distances at which participants identified the location of highway exits were measured using driving data. Researchers also looked at exiting angle and gore invasion as indicators of the last-minute decision making.

Distance at Which Lateral Acceleration Increased. Participants were instructed to keep their vehicle speed between 55 and 65 mph and to take the first available exit. Figure 28 exemplifies two participants' output data, showing plots between lateral acceleration and distance to the exit's physical gore. Before they could see an exit, both participants maintained a fairly consistent lateral position in the right lane of the highway, so lateral acceleration remained close to zero, as shown in Figure 28a and b. When Participant 1 recognized an available exit, at a distance of 374 ft from the exit's location, he or she prepared to take the exit, and lateral acceleration increased; similarly, Participant 2's lateral acceleration began to increase 318 ft from the exit location. The distance at which each driver recognized an available exit and prepared to take the exit is labeled in Figure 28a and b as the turning point distance, identifiable by the significant increase in lateral acceleration.

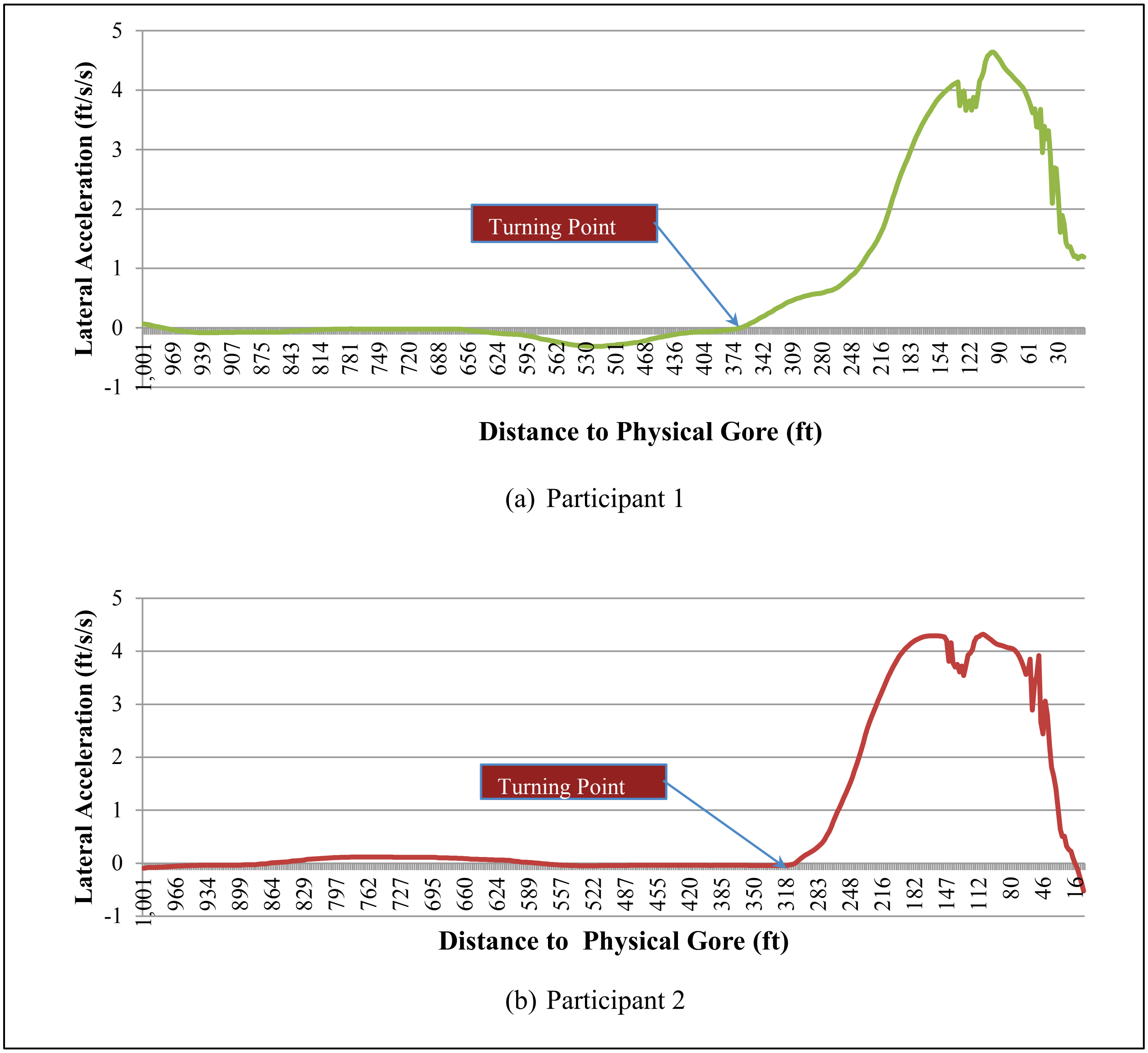


Figure 28. Lateral Acceleration by Distance.

Table 23 presents the turning point distance for the short drives completed by each participant. In cases when a driver failed to keep his or her vehicle speed above 50 mph, the distance data were excluded because the headway distance between the driver and the lead truck may have increased beyond the 200 ft that had been programmed, possibly giving the participant a longer effective viewing distance than was intended for the blocked viewing condition. In the comparison with the S treatment using the Wilcoxon signed-rank test, there were no significant differences in the recognition distances of any of the treatments.

Table 23. Distance to the Physical Gore Related to Turning Point of Lateral Acceleration (ft).

Participant	Treatment					
	C1 (n = 40)	C2 (n = 38)	S (n = 37)	HM (n = 37)	M (n = 38)	MC1 (n = 38)
1	365.4	264.1	302.3	494.6	589.8	462.1
2	305.5	500.3	223.8	286.8	775.7	448.4
3	438.0	589.2	448.5	378.0	546.3	437.9
4	409.9	872.6	319.5	208.9	390.4	376.2
5	415.9	422.6	347.7	476.1	263.5	268.5
6	410.5	401.9	321.4	257.9	488.7	444.9
7	339.5	389.3	391.5	519.5	392.3	n/a
8	449.0	314.7	619.5	463.5	296.8	550.2
9	308.7	311.0	n/a	n/a	350.3	n/a
10	572.9	770.4	388.7	788.0	451.4	370.1
11	410.5	625.7	354.9	257.0	276.6	392.8
12	429.5	364.5	429.5	193.8	493.7	396.0
13	285.7	398.2	324.7	303.7	276.2	309.8
14	257.4	360.0	407.6	544.2	303.8	330.2
15	636.2	n/a	218.0	297.9	374.6	350.6
16	328.3	345.3	n/a	n/a	225.5	414.4
17	547.3	289.2	506.9	307.0	359.5	402.1
18	350.3	n/a	408.7	548.3	367.3	245.0
19	297.7	136.3	465.2	235.4	296.4	403.3
20	231.1	332.5	284.5	640.6	511.0	346.8
21	679.3	409.1	466.0	304.2	316.2	355.7
22	254.8	383.0	329.3	261.1	373.5	261.2
23	276.9	289.3	403.4	433.8	229.2	234.0
24	641.0	393.0	514.0	414.2	574.8	819.7
25	647.9	285.1	716.3	422.1	546.0	664.0
26	402.8	204.7	479.8	511.6	348.4	290.5
27	475.8	512.7	n/a	584.8	n/a	559.6
28	298.9	562.7	189.8	486.7	233.5	182.2
29	250.6	839.7	976.1	921.7	275.9	290.9
30	299.7	653.7	826.4	333.6	437.7	431.2
31	301.5	853.7	779.9	700.1	386.4	471.1
32	326.7	258.2	342.0	303.7	426.8	306.8
33	267.0	290.7	333.6	326.8	291.1	266.4
34	319.4	399.7	574.3	210.0	234.4	377.8
35	402.7	298.3	322.9	662.5	n/a	313.8
36	283.6	289.0	290.1	365.6	302.8	448.2

Table 23. Distance to the Physical Gore Related to Turning Point of Lateral Acceleration (ft) (Continued).

Participant	Treatment					
	C1 (n = 40)	C2 (n = 38)	S (n = 37)	HM (n = 37)	M (n = 38)	MC1 (n = 38)
37	561.5	324.5	460.8	458.2	323.4	411.4
38	291.5	495.5	384.2	n/a	684.8	395.7
39	526.4	627.7	279.1	321.6	576.6	299.8
40	450.8	300.6	375.1	221.6	519.2	595.2
Min.	231.1	136.3	189.8	193.8	225.5	182.2
Max.	679.3	872.6	976.1	921.7	775.7	819.7
Average	**393.7**	**430.5**	**427.2**	**417.4**	**397.6**	**392.7**
St. Dev.	124.5	183.5	171.3	172.8	134.0	124.6
Wilcoxon Signed-Rank Test (vs. exit sign treatment)						
p-value	0.32636	0.5		0.28434	0.35197	0.15866

NOTE: unit, ft.
n/a: Not Applicable

Exiting Angle. In the simulation, the exit ramp was designed with a 4.7-degree deflection angle (see Figure 29). If a driver prepared to take an exit in advance of the ramp, he or she would exit at an angle shallower than that of the ramp deflection angle. In contrast, if a driver made a last-second maneuver to exit the highway (perhaps because he or she did not have enough time and distance between seeing and taking an exit), his or her exiting angle would be sharper than the deflection angle.

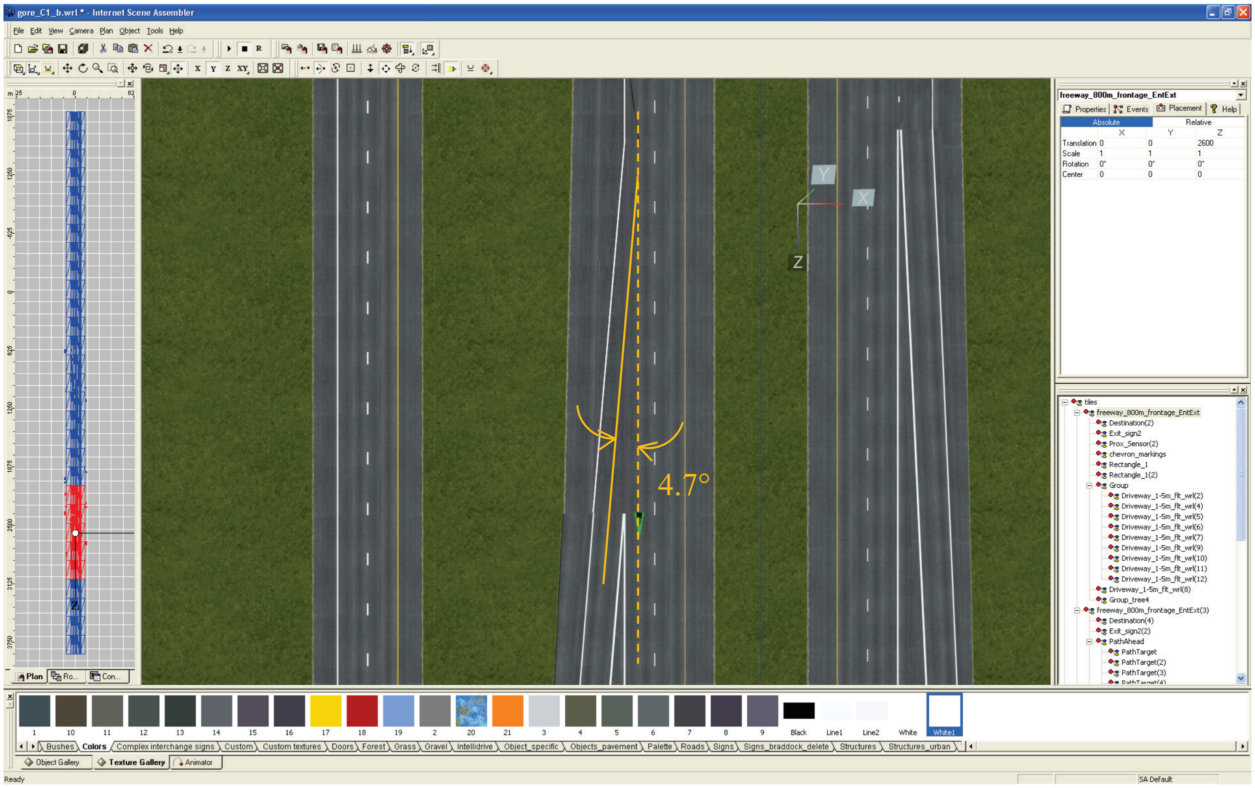


Figure 29. Illustration of Exiting Angle in Simulation World.

Table 24 presents the exiting angle from up to six short drives by the 40 participants. In cases where vehicle speed was under 50 mph during the drive, the data were excluded. The highlighted values represent exiting angles sharper than the ramp deflection angle (4.7 degrees), indicating a last-second exit maneuver. The exit angle results were mixed: in comparison with the standard exit gore sign treatment, only the MC1 treatment was significantly different in average exit angle (with a sharper average exit angle than the sign treatment); however, the number of exit angles that were sharper than the ramp deflection angle were similar across all treatments, with C1 having the fewest instances. The results also show, however, that a few participants had a tendency to exit with a sharper angle than others, and these within-subject patterns may have biased the between-subject results.

Table 24. Exiting Angle by Treatments (Angular Degrees, °).

Participant	Treatment					
	C1 (n = 40)	C2 (n = 38)	S (n = 37)	HM (n = 37)	M (n = 38)	MC1 (n = 38)
1	3.42	2.30	3.23	4.12	2.68	3.81
2	3.82	2.46	1.81	3.88	3.74	3.68
3	3.03	2.77	2.35	2.65	2.85	3.42
4	2.95	2.89	3.63	1.16	3.36	2.46
5	3.58	4.57	3.66	5.05	4.73	5.66
6	4.35	5.41	3.42	3.65	5.17	5.21
7	2.51	2.44	3.05	2.85	3.13	n/a

Table 24. Exiting Angle by Treatments (Angular Degrees, °) (Continued).

Participant	Treatment					
	C1 (n = 40)	C2 (n = 38)	S (n = 37)	HM (n = 37)	M (n = 38)	MC1 (n = 38)
8	4.68	3.24	3.78	3.99	3.89	4.32
9	4.24	3.76	n/a	n/a	2.73	n/a
10	2.86	2.09	3.66	3.57	2.85	3.49
11	3.49	4.44	2.78	3.73	3.95	2.61
12	3.50	3.23	2.67	2.67	4.32	4.17
13	3.86	4.13	4.81	4.62	4.39	4.62
14	3.58	3.68	4.15	3.72	3.74	4.36
15	3.73	n/a	2.63	2.38	5.68	4.45
16	4.46	4.54	n/a	n/a	2.71	3.10
17	4.13	4.90	3.71	4.46	4.32	4.87
18	2.61	n/a	3.58	3.92	4.37	4.63
19	2.62	0.79	3.05	2.85	2.15	3.10
20	2.16	3.65	2.95	2.67	2.25	2.87
21	3.61	3.91	3.35	2.71	2.85	3.39
22	2.68	2.98	4.07	4.48	3.38	3.53
23	4.52	4.25	2.73	3.43	1.99	3.89
24	3.56	3.81	3.74	2.83	3.50	2.63
25	1.64	4.45	2.04	2.54	2.35	1.57
26	3.81	2.19	2.09	2.63	3.79	3.12
27	3.34	3.30	n/a	1.73	n/a	3.80
28	3.78	2.76	0.76	1.60	1.77	1.59
29	1.80	3.82	0.52	2.89	2.56	3.94
30	2.25	2.90	3.02	3.48	4.02	3.02
31	2.71	2.62	2.68	3.03	2.65	2.70
32	3.22	3.98	3.85	0.49	3.00	4.58
33	2.73	2.27	3.59	3.46	3.13	4.03
34	3.84	5.18	2.52	1.69	2.16	1.39
35	3.23	4.46	3.95	4.88	n/a	4.69
36	3.54	3.79	3.82	4.78	3.71	3.29
37	3.33	4.07	4.75	3.22	5.56	3.72
38	3.80	4.12	3.29	n/a	3.58	3.68
39	2.31	2.42	2.70	3.75	2.62	3.14
40	4.91	4.73	5.67	1.92	4.51	3.39

Table 24. Exiting Angle by Treatments (Angular Degrees, °) (Continued).

Participant	Treatment					
	C1 (n = 40)	C2 (n = 38)	S (n = 37)	HM (n = 37)	M (n = 38)	MC1 (n = 38)
Min.	1.64	0.79	0.52	0.49	1.77	1.39
Max.	4.91	5.41	5.67	5.05	5.68	5.66
Average	3.36	3.51	3.19	3.18	3.43	3.58
St. Dev.	0.78	1.01	1.01	1.07	0.99	0.97
Number of Cases (sharper exiting angle)	1	4	3	3	4	3
Percent of Cases (sharper exiting angle)	**2.50%**	**10.53%**	**8.11%**	**8.11%**	**10.53%**	**7.89%**
Wilcoxon Signed-Rank Test (vs. Exit Sign Treatment)						
p-value	0.15625	0.39743		0.11314	0.10935	0.02222

NOTE: unit, angular degree (°).
The highlighted values represent exiting angles sharper than the ramp deflection angle (4.7 degrees),

Invading Gore Area While Exiting

Collected locational information of the exit gores and the vehicle paths from each drive identified a handful of cases in which drivers invaded the physical gore area while exiting. For the exit gore treated with Chevron Option 1 and pavement markings, there was one instance in which a driver invaded the gore area while exiting (Table 25). There were three cases of exit gore invasion at the gore treated with Chevron Option 2. However, as with the exit angles discussed above, the very few gore invasions were more likely random and attributable to the steering tendencies of some participants, rather than the exit gore treatments.

Table 25. Number of Cases in Which Drivers Invaded Gore Area.

	Treatment					
	C1 (n = 40)	C2 (n = 38)	S (n = 37)	HM (n = 37)	M (n = 38)	MC1 (n = 38)
Invading	1	3	2	1	2	0
Percentage	**2.50%**	**7.89%**	**5.41%**	**2.70%**	**5.26%**	**0%**

Figure 30 shows the percentage of sharper exiting angles and gore invasions made by participants in the same illustration for comparison.

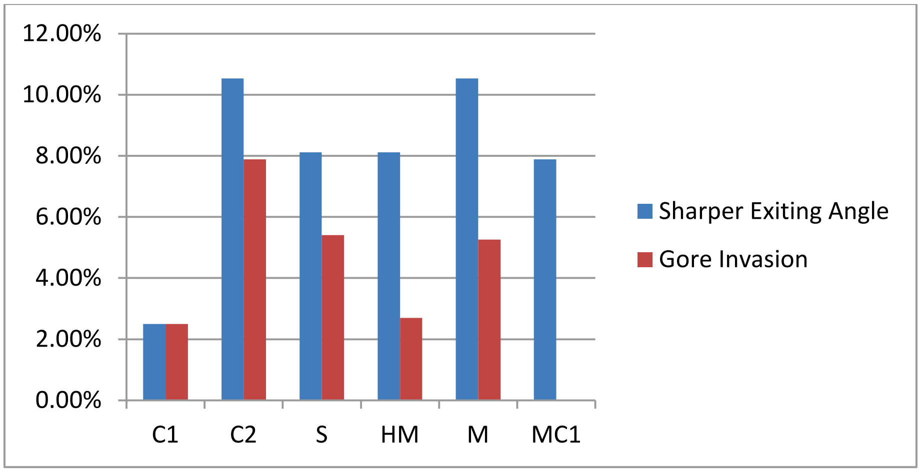


Figure 30. Comparison of Percentage of Sharper Exiting Angles and Gore Invasions by Treatment.

CONCLUSIONS

Pre-simulation Questioning

There was some recognition of the C1 device used alone and with markings (MC1) already being used. Since the C1 device is not in use currently, there could be some confusion with this pattern being used for another application.

With 55 percent of the participants believing HM treatment was one of the best treatments, but 77.5 percent also believing they would be forced to exit from the right lane if they saw these markings, further research may be needed to determine if there is a better message to help prevent unnecessary lane changes out of the lane, or horizontal markings should only be used in lane-drop scenarios.

Experimental Sessions

Ratings

The MC1 treatment was one of the highest-rated treatments under all three viewing conditions. At the long viewing distance, participants rated it significantly higher than all other treatments including the exit gore sign. For the shorter viewing distance, MC1 and the exit gore sign were both rated significantly higher than C1, C2, and M. From the ratings and from participant comments, MC1 appears to have the advantage of combining a high-contrast vertical object with markings that further delineate the gore itself. The exit gore sign ratings rose to match the MC1 treatment ratings in the shorter viewing distance (vertical curve in the roadway), with its height providing an advantage over shorter treatments.

Under blocked viewing conditions, MC1, the exit gore sign, and the horizontal EXIT markings were rated significantly higher than the other three treatments. While the HM treatment, which was not tested in the long and short viewing conditions, received high ratings for its visibility in the blocked condition, participants still felt that the MC1 and sign functioned well when visibility was limited.

Scenario 1—Button Response

Under the long viewing distance condition, treatment C1 was recognized significantly later than the other treatments. The exit gore sign, C2, M, and MC1 were all identified at similar distances.

Under the shorter viewing distance condition, the exit gore sign and treatment MC1 were recognized significantly earlier than the other three treatments.

Scenario 2—Exit Response

The exit response results for the blocked viewing distance were inconclusive; individual driving styles of the participants appear to have had more effect on the exit angles than the treatments did, and there were no significant differences in the distances at which participants began to decelerate for the exit.

Overall Conclusions

From the ratings and the button response data, it appears that alternate exit gore treatments may be viable alternatives to the exit gore sign. MC1 (vertical chevron paired with chevron pavement markings) performed consistently well, generally equaling or exceeding the performance of the exit gore sign; but none of the alternate treatments performed notably poorly.

Recommendations

The driving simulator study suggests that some alternate treatments for a highway exit gore have the potential to be as visually conspicuous as the exit gore sign. The simulator, however, is not well suited to test real-world visibility distance, nor can it test the conspicuity of treatments at night. For these reasons, the next recommended step is to test the visibility of selected exit gore treatments against the exit gore sign on a closed driving course. Additional research recommendations based on the simulator study results are as follows:

- Further examine driver comprehension of the horizontal pavement message EXIT (by a curved arrow) to see if drivers are likely to associate this message with a mandatory exit/lane drop. If so, this treatment option may only be appropriate in lane-drop scenarios, using the message EXIT ONLY.
- Further explore whether the C1 chevron pattern is the most appropriate for an exit gore application.

The following recommendations for possible improved performance have been derived from the MUTCD:

- Section 3A.05, Standard 08 and 09 discuss using black in combination with white for pavement markings as a contrast-enhancing system.
- Section 2C.64, Standard 04 states that a Type 1 object maker (see Figure 18) can be installed on the sign support below an exit gore sign to increase visibility.

- Section 3B.20, Option 22 allows for additional transverse pavement arrow or arrows placed in a turn lane. That section provides guidance on the spacing of the markings.

CHAPTER 3.
AN EVALUATION OF PILOT VEHICLES AND PORTABLE TRAFFIC CONTROL SIGNALS WITH AND WITHOUT A FLAGGER

INTRODUCTION

When a lane is closed on a two-lane, two-way road for construction or maintenance activities, provisions must be made to alternate one-way movement of traffic. Typically, flaggers are positioned at each end of the lane closure to control the flow of traffic through the work zone. However, in Texas, the use of temporary traffic control signals (also known as portable traffic control signals) is becoming more prevalent.

Portable traffic control signals have been in the MUTCD since the 1961 edition (*37*) but have experienced increased use since 2000. The use of portable traffic signals removes the need for flaggers. By removing flaggers from the transition area, where traffic is moved out of its normal path, their safety is improved. In addition, former flaggers can perform other work, thus increasing productivity. To date, portable traffic control signals have been used successfully in Texas, as well as many other states.

In rural areas in Texas, the speed limit on two-lane, two-way roads is typically 70 mph. Thus, traffic approaching and traveling through lane closures on these roads does so at higher speeds. Unfortunately, Texas law makes the implementation of a reduced work zone speed limit for routine maintenance activities difficult (*38*). Thus, TxDOT maintenance personnel recently began using pilot vehicles with portable traffic control signals in an effort to control operating speeds within the lane closure. Pilot vehicles also provide positive guidance with respect to which lane is open for travel. This is especially important when the work is being performed on both sides of the road (i.e., the open lane changes throughout the duration of the maintenance operation).

While the 2009 MUTCD (*6*) and 2011 TMUTCD (7) do not prohibit the use of a pilot vehicle in conjunction with portable traffic control signals, both of these manuals require that a flagger be stationed on the approach to the activity area where a pilot vehicle is being used to guide the queue of vehicles through the work zone (Section 6C.13, Paragraph 4).

> A flagger shall be stationed on the approach to the activity area to control vehicular traffic until the pilot vehicle is available.

This requirement has been in the MUTCD since the 1961 edition (*39*). It was added to prohibit the situation where a pilot vehicle is used without any other type of temporary traffic control at each end to direct traffic (e.g., flaggers) until the pilot vehicle is available to lead vehicles through the one-lane section. While portable traffic control signals may be used in lieu of flaggers, the standard above states that flaggers must be used with a pilot vehicle.

In a letter from FHWA on August 31, 2010 (*39*), FHWA stated that its official interpretation was that a pilot vehicle may be used in conjunction with portable traffic control signals for a lane closure on a two-lane road (Typical Application 12) provided that a flagger was also stationed on

In a letter from FHWA on August 31, 2010 (*39*), FHWA stated that its official interpretation was that a pilot vehicle may be used in conjunction with portable traffic control signals for a lane closure on a two-lane road (Typical Application 12) provided that a flagger was also stationed on each approach to the activity area. FHWA further stated the following reasons for Section 6C.13, Paragraph 4:

- To reassure drivers that they have encountered an active work zone and will eventually be given an opportunity to proceed.
- To alert the work crew and pilot vehicle operator if anyone violates the portable traffic control signal.

Unfortunately, the requirement to have a flagger on each approach negates the following advantages to using a pilot vehicle with portable traffic control signals:

- Improving flagger safety by moving them from the transition area to within the work activity area where the pilot vehicle regulates speed and provides path guidance.
- Allowing former flaggers to conduct other work, which is especially important as the workforce size decreases.

Based on TxDOT's desire to utilize portable traffic control signals in conjunction with pilot vehicles without flaggers, TxDOT submitted a request to FHWA to experiment with this type of temporary traffic control. FHWA approved this request on February 13, 2013 (*40*). In May 2013 and October 2013, TTI researchers conducted field studies to assess compliance at lane closures on two-lane, two-way roads with pilot vehicles and portable traffic control signals with and without flaggers. The following sections describe the treatments, experimental design, sites, data reduction and analysis, and results.

TREATMENTS

Researchers evaluated the following treatments:

- A portable traffic control signal at both ends of the lane closure with a pilot vehicle directing traffic through the work zone.
- A portable traffic control signal and a flagger at both ends of the lane closure with a pilot vehicle directing traffic through the work zone.

Figure 31 depicts the pilot vehicle used in May 2013. The truck had a PILOT CAR FOLLOW ME sign (G20-4) mounted on the back of the truck and a truck-mounted changeable message sign (CMS) that displayed the same message in two phases (i.e., PILOT CAR/FOLLOW ME). The truck also had standard blue and yellow vehicle lighting mounted on the cab roof. The pilot vehicle used in October 2013 was similar except it did not have a static PILOT CAR FOLLOW ME sign mounted on the back of the truck.

Figure 31. Pilot Vehicle.

The pilot vehicle driver drove approximately 30 mph through the lane closure. The pilot vehicle driver used a remote control to operate the portable traffic control signals at each end of the lane closure. Dependent upon the length of the vehicle queue at the signal and the presence of commercial vehicles, the pilot vehicle driver could choose a preset green time of 30, 60, or 90 seconds.

When used, a flagger was located on the shoulder immediately upstream of each portable traffic control signal. Each flagger used a stop/slow paddle in conjunction with the portable traffic control signal to direct traffic. At one site, the flaggers had to quit using the stop/slow paddles due to wind load; handheld flags were used instead. Figure 32 shows a flagger at a portable traffic signal.

Figure 32. Flagger at Portable Traffic Signal.

Figure 33 shows the draft traffic control plan (TCP) used by the work crews. In some cases, a pilot vehicle was also used with TCP (1-7a). When this occurred, a WAIT FOR PILOT CAR sign was used, similar to that shown in TCP (1-7b).

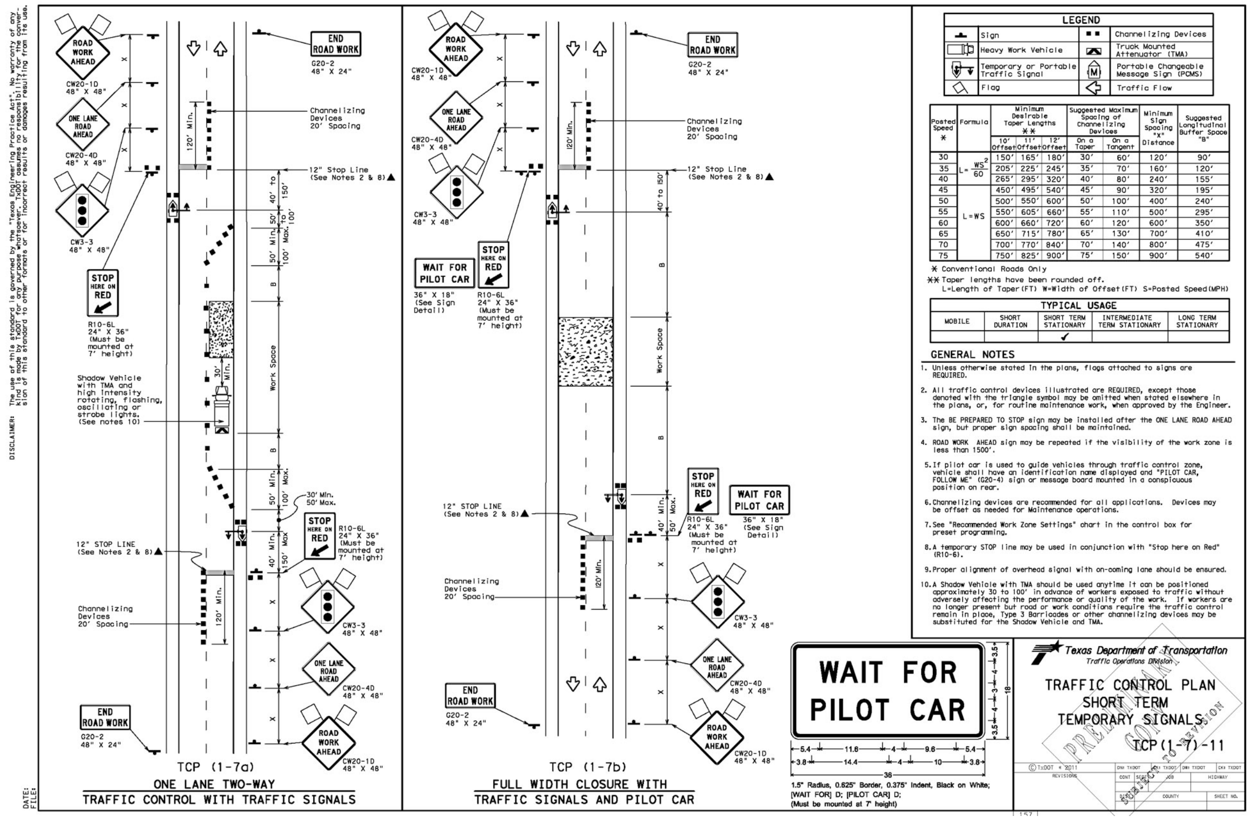


Figure 33. Draft Traffic Control Plan.

EXPERIMENTAL DESIGN

The primary measure of effectiveness for the field studies was driver compliance with the temporary traffic control used at the ends of the lane closure. Researchers were located off the roadway upstream of each portable traffic control signal. The observational data collected at each end of the lane closure during each cycle included:

- The time (hour:minutes:seconds) the portable traffic control signal displayed a steady circular red indication (i.e., the beginning of the stop phase).
- The number and type of vehicles that arrived during the stop phase.
- The time (hour:minutes:seconds) the portable traffic control signal displayed a steady circular green indication (i.e., the end of the stop phase and the beginning of the proceed phase).
- The total number and type of vehicles that arrived during the proceed phase.
- The number and type of vehicles that had been present during the previous stop phase that did not clear during the proceed phase.
- The number of violations and a description of each event.
- Whether or not the end of the queue going in the same direction was visible to stopped vehicles.
- Whether or not approaching traffic from the opposite direction was visible to stopped vehicles.

- Whether or not the work activity was visible to stopped vehicles.
- Whether or not the other end of the lane closure (i.e., portable traffic control signal) was visible to stopped vehicles.

Researchers collected these data for each treatment at each site on a standardized form. Researchers also documented the characteristics of the roadway and work zone at each site.

SITES

In total, researchers collected data during the day at eight sites in the Brownwood District where TxDOT maintenance work was already planned (Table 26). All of the sites were in rural areas on two-lane, two-way roads. The work activities consisted of cleaning under guardrail, pavement level-up, milling, and patching. The 2011 approximate average annual daily traffic (AADT) ranged from 470 to 2800 vehicles per day (vpd). The speed limit was 70 mph at all sites except two (which were 55 mph and 75 mph). The length of the lane closures ranged from approximately 2160 ft to 7480 ft. While traffic volume, speed limit, and lane closure length varied among the sites, researchers did not specifically design the study to examine the impacts of these variables.

Table 26. Site Characteristics.

Site	Road	2011 AADT[a]	Speed Limit (mph)	Lane Closure Length[b] (ft)	Could Drivers at Each PTCS See the Work Activity?	Could Drivers at One PTCS See the Other PTCS?
1	SH 71	2150	70	4440	No	No
2	FM 580	470	55	2160	Yes	Yes
3	US 281	2800	70	3030	Yes	No
4	US 87	2500	70	2900	Yes	Yes
5	US 67	1300	75	5500	Yes & No[c]	No
6	US 180	1300	70	6820	Yes & No[c]	No
7	US 180	1300	70	7480	Yes & No[c]	No
8	US 180	1300	70	4320	Yes & No[c]	No

NOTE: AADT = Average Annual Daily Traffic; SH = State Highway; FM = Farm-to-Market; US = United States; PTCS = Portable Traffic Control Signal.
[a] Approximated.
[b] Rounded. Measured from portable traffic control signal to portable traffic control signal.
[c] The work activity moved such that at times the work activity could be seen.

At Sites 2 and 4, drivers at each end of the lane closure could see the work activity and the other end of the lane closure. In contrast, at all other sites (1, 3, 5, 6, 7, and 8), drivers at each end of the lane closure could not see the other end of the lane closure. In addition, in both directions at Site 1 and in one direction at Sites 5–8, drivers could not see the work activity.

DATA REDUCTION AND ANALYSIS

First, researchers entered all the data collected for each treatment into spreadsheets to facilitate analysis. Using the onset of the red and green signal indications, researchers computed the duration of the stop and proceed phases, as well as the cycle time, for each observed period. Researchers then computed the number of vehicles in the queue during each stop phase, the number of vehicles that had been present during the previous stop phase that did not clear during the proceed phase, and the percent of the time the queue did not completely clear. Researchers also determined the number of vehicles that traveled through the lane closure during each observed period.

Researchers then reviewed the compliance data. Drivers were considered to be noncompliant (or in violation) anytime they passed the portable traffic control signal (i.e., entered the one-lane section) when a steady circular red indication was displayed. For each violation, researchers noted whether the violator was present during the previous stop phase but did not clear during the proceed phase, could see the end of the queue going in the same direction, could see opposing vehicles approaching, could see the work activity, and could see the other end of the lane closure.

RESULTS

Table 27 summarizes the observation period information by treatment and site. Overall, researchers collected data for over 65 staff hours (3901 staff minutes) of work activity. During this time, researchers observed 661 stop periods and 3822 vehicles for both directions of travel.

Table 27. Observation Period Information by Treatment and Site.

Site	PTCS with Pilot Vehicle and Flagger			PTCS with Pilot Vehicle Only		
	Duration (staff min)	Number of Stop Periods[a]	Number of Vehicles[a]	Duration (staff min)	Number of Stop Periods[a]	Number of Vehicles[a]
1	400	75	578	544	97	772
2	185	20	29	225	18	26
3	111	30	226	214	52	351
4	186	48	288	245	54	372
5	205	30	160	108	17	104
6	181	25	113	257	32	149
7	300	39	166	296	37	171
8	224	42	141	220	45	176
Total	1792	309	1701	2109	352	2121

NOTE: PTCS = Portable Traffic Control Signal.
[a] Number of stop periods and vehicles for both directions of travel.

Table 28 contains a summary of the signal phasing and queuing information for each site. In general, the average stop phase duration ranged from three to eight minutes and averaged about five minutes. The longer average stop phase duration at Site 2 was due to the low traffic volume (i.e., when there was no demand at one or the other end, the portable traffic control signal remained in the stop phase). The longer average stop phase duration at Sites 5, 6, and 7 was due to a longer work zone setup (over 1 mile each).

The majority of the time (about 85 percent), the pilot vehicle driver used a 30-second green time. Higher commercial vehicle traffic volume at Site 1 required the use of the 60-second and

90-second green times more often. The average number of vehicles in the queue ranged from one to seven and averaged around five for all sites. Ninety-five percent of the time, all of the vehicles in the queue at a portable traffic control signal cleared during the next proceed phase, showing that the majority of the time, the pilot vehicle driver chose an adequate green time. When the queue did not clear, on average two vehicles remained.

Table 28. Signal Phasing and Queuing Information by Site.

Site	Average Stop Phase Duration (min:sec)	Percent Time Each Green Time Duration Used			Average Number of Vehicles in Queue Per Stop Phase	Percent Time Queue Did Not Clear	Average Number of Vehicles that Did Not Clear
		30 sec	60 sec	90 sec			
1	4:39	62	34	4	7	7	2
2	8:00	100	0	0	1	0	NA
3	3:14	95	4	1	7	13	2
4	3:34	86	14	0	6	6	2
5	5:40	93	5	2	5	5	2
6	7:09	96	2	2	4	0	NA
7	6:56	93	7	0	4	0	NA
8	4:32	93	6	1	3	0	NA
Total	5:02	85	14	1	5	5	2

NOTE: NA = Not Applicable.

Table 29 contains the violation statistics for each treatment. The violation rate represents the number of violations per 100 stop cycles. Surprisingly, the violation rate for the portable traffic control signals with a flagger (14.9) was higher than when a flagger was not present (13.9), although this difference was not found to be significantly different (based on a test of proportions using a 5 percent significance level [$\alpha = 0.05$]). The majority of all violations for both treatments (91 percent) occurred at the end of the proceed phase (i.e., when the portable traffic signal changed from a steady circular green indication to a steady circular yellow indication, and then to a steady circular red indication) and were either:

- Vehicles in the queue during the previous stop phase that were going to be stopped again.
- Vehicles approaching the portable traffic control signal at higher rates of speed.

For the latter, some drivers attempted to slow down but most likely could not come to a safe stop in time, so they proceeded through. When a flagger was present, typically he would wave vehicles in these two situations through even though the portable traffic control signal was displaying a steady circular red indication. Even though the flagger directed the drivers to proceed, these actions were considered violations in order to not bias the treatment with a flagger. In all of these cases, the noncompliant driver could see the end of the queue going in the same direction a relatively short distance ahead. Overall, the violation rate for these types of violations was 13.0 violations per 100 stop cycles.

Table 29. Field Study Violation Statistics.

Treatment	Number of Violations	Percent Non-Compliance	Violations Per 100 Stop Cycles[a]
PTCS/Pilot Vehicle/Flagger	46	2.7	14.9
PTCS/Pilot Vehicle	49	2.3	13.9
Total	95	2.5	14.4

NOTE: PTCS = Portable Traffic Control Signal.
[a] Rate computed as violations/stop cycles × 100.

The remaining 9 percent of violations occurred during the stop phase (i.e., when the portable traffic control signal was displaying a steady circular red indication). In all cases, the noncompliant driver could not see the end of the queue going in the same direction or opposing vehicles approaching. These noncompliant drivers were stopped by the flagger, pilot vehicle driver, or other TxDOT personnel. Overall, the violation rate for this type of violation was 1.4 violations per 100 stop cycles.

Researchers noted that previous TTI research (*41*) found that this same type of violation occurred at red/yellow lens automated flagging assistance devices (AFADs) at a rate of 2.2 violations per 100 stop cycles. While AFADs located at each end of a lane closure must be operated by at least one flagger, the flagger does not have to be in the immediate vicinity of the AFADs.

Researchers also noted that this type of violation may occur when a portable traffic control signal is used without a pilot vehicle (i.e., when a flagger is not required). Without a pilot vehicle or flagger, the violator could meet an oncoming vehicle before TxDOT personnel are aware of the situation. In contrast, since the pilot vehicle leads the vehicle platoon through the lane closure, the pilot vehicle driver can always be alert for violators and direct traffic as needed to avoid a collision and resolve the situation.

Researchers further investigated whether violations without a flagger present appeared to be influenced by whether a driver could see the work activity and/or the other end of the lane closure (Table 30). As expected, sites where drivers could see the work activity and the other end of the lane closure resulted in the lowest violation rate (11.1 violations per 100 stop cycles). Comparatively, the sites where drivers could not see the work activity or the other end of the lane closure resulted in the highest violation rate (15.1 violations per 100 stop cycles). Not surprisingly, the sites where drivers could see the work activity but not the other end of the lane closure resulted in a violation rate between the other two (14.1 violations per 100 stop cycles). Thus, it does appear that a general trend exists; however, no significant differences between any of these violation rates were found (based on a test of proportions using a 5 percent significance level [$\alpha = 0.05$]).

Researchers further examined the impact of whether a driver could see the work activity and/or the other end of the lane closure by separating the violation rates into the two types previously discussed: violations during the stop phase and violations at the end of the proceed phase. As Table 30 shows, the violation rates during the stop phase exhibited a similar trend to the overall violation rates. This again indicates that what a driver can see may impact his or her decision to comply with portable traffic control signals when a flagger is not present. Due to the small sample size, statistical analysis could not be used to assess whether there were any significant differences in these violation rates. The violation rates at the end of the proceed phase (i.e., vehicles joining the departing queue) did not exhibit the same trend. As Table 30 shows, those violation rates remained practically the same (between 11 and 12 violations per 100 stop cycles). This is not surprising since all the drivers that violated the portable traffic signal at the end of the proceed phase could see the departing vehicle queue, negating the impact of visible work activity or the other end of the lane closure.

Table 30. Without Flagger Violations by Site Type.

Could Drivers at Each PTCS See the Work Activity?	Could Drivers at One PTCS See the Other PTCS?	Violations Per 100 Stop Cycles		
		End of Proceed Phase	During Stop Phase	Total
Yes	Yes	11.1	0.0	11.1
Yes	No	12.4	1.7	14.1
No	No	11.3	3.8	15.1

NOTE: PTCS = Portable Traffic Control Signal.

While researchers did not specifically design the study to examine the impacts of traffic volume and lane closure length, researchers did examine the general trends associated with these variables. Researchers found higher-than-normal violation rates at Site 5 (i.e., site with approximately 1300 vpd and a lane closure length of approximately 5500 ft) but considered these findings an anomaly. A review of the site characteristics and data did not reveal any obvious differences between this site and all the other sites, so the authors did not remove the data. Figure 34 shows that the relationship between the traffic volume and the violation rate without a flagger present is not closely correlated for either violation type (i.e., only 6 percent or less of the variability in violations is accounted for by the traffic volume). Similarly, Figure 35 shows that the relationship between lane closure length and the violation rate without a flagger present is not closely correlated for either violation type (i.e., only 16 percent or less of the variability in violations is accounted for by the traffic volume). Overall, researchers could not define thresholds for traffic volume and lane closure length for the implementation of portable traffic control signals and a pilot vehicle without at flagger. Instead, researchers recommend that supervisors and on-site personnel use their judgment to select sites that are appropriate for this type of operation, bearing in mind that what the drivers can see (i.e., work activity and/or other end of the lane closure) may impact the potential for violations during the stop phase.

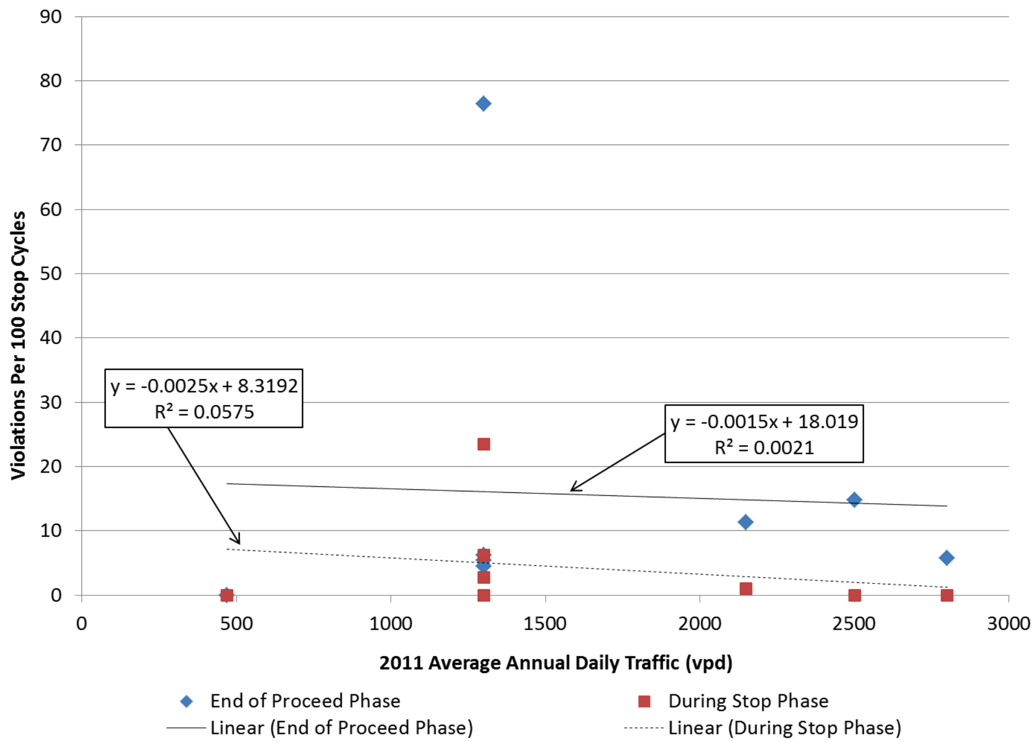


Figure 34. Without a Flagger Violations by Traffic Volume.

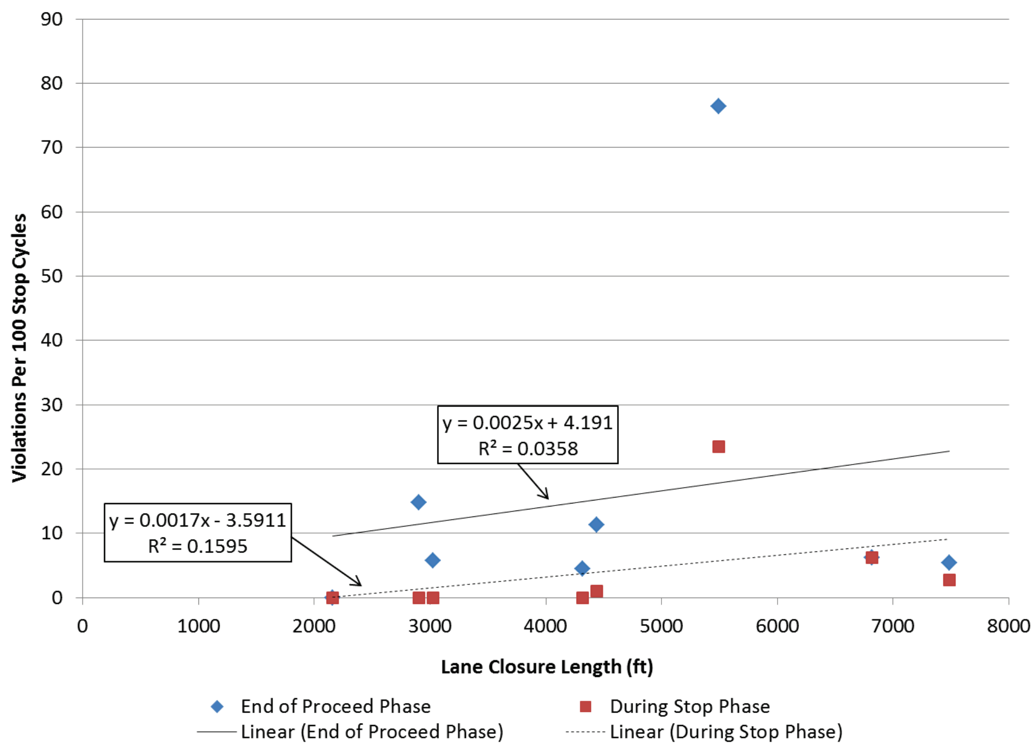


Figure 35. Without a Flagger Violations by Lane Closure Length.

GUIDELINES FOR SELECTING AN APPROPRIATE GREEN TIME

As indicated previously, the pilot vehicle driver used a remote control to operate the portable traffic control signals at each end of the lane closure. Dependent upon the length of the queue at the signal, the presence of commercial vehicles, and other site conditions (vertical curvature, whether or not commercial vehicles were loaded, etc.), the pilot vehicle driver chose a preset green time of 30, 60, or 90 seconds. Ninety-five percent of the time, the pilot vehicle driver chose a green time that allowed all of the vehicles in the queue to proceed through the lane closure. Nevertheless, TxDOT asked TTI to develop guidelines to help pilot vehicle drivers, especially those with less experience, select appropriate green times. Since the guidelines would be used in the field during pilot vehicle operations, researchers wanted the final product to be a quick and easy tool.

Based on previous research (*42*), researchers assumed that each vehicle axle would require one second of green time. In other words, a two-axle passenger car would need two seconds of green time. Researchers also needed to account for the start-up lost time at the beginning of each proceed phase. Assuming the worst-case scenario of a commercial vehicle being the first vehicle in the queue, researchers decided to utilize a start-up lost time of four seconds. Using these data, all a pilot vehicle driver has to do is count the number of axles in the queue and add four seconds to get an estimate of the minimum green time needed to clear the queue. For example, the estimated minimum green time for a queue consisting of one commercial vehicle (five axles) and four passenger cars (two axles each) would be 17 seconds (i.e., [1*5]+[4*2]+4=5+8+4=17). Rounding up to the nearest preset option would yield a 30-second green time. Figure 36 shows the estimated minimum green times computed using this method and the associated preset green time value.

Number of Commercial Vehicles	Number of Passenger Cars										
	0	1	2	3	4	5	6	7	8	9	10
0	4	6	8	10	12	14	16	18	20	22	24
1	9	11	13	15	17	19	21	23	25	27	29
2	14	16	18	20	22	24	26	28	30	32	34
3	19	21	23	25	27	29	31	33	35	37	39
4	24	26	28	30	32	34	36	38	40	42	44
5	29	31	33	35	37	39	41	43	45	47	49
6	34	36	38	40	42	44	46	48	50	52	54
7	39	41	43	45	47	49	51	53	55	57	59
8	44	46	48	50	52	54	56	58	60	62	64
9	49	51	53	55	57	59	61	63	65	67	69
10	54	56	58	60	62	64	66	68	70	72	74

Use 30-second preset green time
Use 60-second preset green time
Use 90-second preset green time

Figure 36. Estimated Minimum Green Times Using Vehicle Axle Method.

This method does not account for the position of a commercial vehicle(s) in the queue or other site conditions (e.g., vertical curvature, loaded versus unloaded commercial vehicles) that may require a longer green time. Therefore, this method should be used to provide an initial estimate of the minimum green time and the associated preset green time. Pilot vehicle drivers should watch traffic and choose a higher preset green time as needed in order to minimize the queue length and driver wait time.

OTHER CONSIDERATIONS

TxDOT maintenance personnel at the sites preferred to utilize portable traffic control signals in conjunction with pilot vehicles without flaggers to increase productivity. They also believed the overall safety of the work zone was increased since the flaggers were moved from the transition area to within the work activity area and the pilot vehicle regulated speed and provided path guidance throughout the lane closure. Communication between the pilot vehicle driver and the work crew was essential to ensure that workers could be notified of any noncompliant drivers.

Very few malfunctions occurred with the portable traffic control signals, and these malfunctions were generally quickly addressed by the pilot vehicle driver or other TxDOT personnel. The malfunctions typically resulted from a loss of signal between the remote control in the pilot vehicle and the portable traffic control signal (i.e., the two devices must be in close proximity to each other to ensure proper communication).

Previous research (*43*) recommended that the maximum reasonable wait time for a driver at a rural work zone controlled by portable traffic signals was four minutes (240 seconds), especially if the driver cannot see the work activity or the other end of the lane closure. Unfortunately, researchers did not document the individual vehicle arrival times, so researchers could not assess the validity of this recommendation for the use of portable traffic signals and a pilot vehicle without a flagger present.

SUMMARY AND RECOMMENDATIONS

To assess compliance with pilot vehicles and portable traffic control signals with and without flaggers, TTI researchers conducted field studies at lane closures on two-lane, two-way roads in Texas. Overall, only 3 percent of drivers did not comply with the portable traffic control signals and pilot vehicle for both conditions studied (with and without a flagger). The similar violation rates between treatments showed that there was no significant or practical difference between violations at a portable traffic control signal with and without a flagger when a pilot vehicle was used. While researchers did identify a general trend for violations to increase when a driver could not see the work activity and the other end of the lane closure, no significant difference between violations based upon what a driver could see was found. In addition, researchers did not find a strong correlation between violations, traffic volume, and lane closure length. Therefore, researchers could not define thresholds for traffic volume and lane closure length for the implementation of portable traffic signals and a pilot vehicle without a flagger. Instead, researchers recommend that supervisors and on-site personnel use their judgment to select sites that are appropriate for this type of operation, bearing in mind that what the drivers can see may impact the potential for violations.

Overall, TTI researchers recommend that TxDOT be allowed to use portable traffic control signals and a pilot vehicle without a flagger to control traffic at lane closures on two-lane, two-way roadways. In an effort to provide pilot vehicle drivers, especially those with less experience, an initial estimate of the minimum green time needed to clear the vehicle queue at the portable traffic signal, researchers developed a quick and easy tool. All a pilot vehicle driver has to do is count the number of axles in the queue and add four seconds to get an estimate of the minimum green time needed to clear the queue. The pilot vehicle driver then rounds up to the nearest preset green time option. Since a variety of site-specific conditions can impact the minimum green time needed to clear the queue, pilot vehicle drivers should watch traffic and choose a higher preset green time as needed in order to minimize the queue length and driver wait time.

CHAPTER 4. ONGOING TASKS

INTRODUCTION

There are at least two tasks that are continuing into the next fiscal year. The tasks are described below. It is expected that these tasks will be completed in time to be included as chapters in next year's annual report.

COORDINATING STATE ASSET DATA COLLECTION EFFORTS

State agencies use extensive data to manage their infrastructure assets. These data are useful for many applications, such as planning, maintenance, safety evaluation, performance monitoring, and intra-agency coordination. Asset data collection is an important function because highway systems are constantly changing and agencies need to have comprehensive and up-to-date roadway information. Setting up an asset data collection plan requires coordination between divisions and selection of the most appropriate data collection technologies.

Introduction

The objective of this effort is to coordinate with the relevant divisions concerning their asset data collection needs. The results will help clarify the statewide data collection needs and how they can be coordinated in a goal to be more efficient in terms of using shared resources to provide better information for decision making and funding allocation.

Work Tasks

The following tasks have been set to meet the objectives of this work, culminating with a report documenting the efforts.

1. Identify the relevant divisions that are collecting statewide data related to asset management.
2. Set up and visit with each division to discuss its data collection needs. Examples of some potential questions that will be used at each meeting are:
    a. What are your specific data needs?
    b. What is the appropriate quality, and how frequent are updates needed?
    c. How are the data currently being collected (technology, state forces, contractors, etc.)?
    d. What level of expenditures is being spent to collect the data?
    e. How are the data used?
    f. What management tools are used (software)?
    g. How are the assets being referenced (linear referencing, GIS, etc.)?
    h. How are the data verified (QA/QC)?
3. Coordinate the results in the form of a report including suggestions for bundling data collection efforts using various data collection technologies as appropriate.
4. Deliver a draft report 60 days after the start of the project.
5. Prepare and deliver a PowerPoint presentation 75 days after the start of the project.

EVALUATION OF RUMBLE DEVICES

Rumble strips have proven to be a cost-effective safety countermeasure in all categories of roadways. Unfortunately, rumble strips cannot be milled into many seal-coat roadways due to insufficient roadway structure or limited shoulder width. Several alternative systems have been tried on seal-coat roadways to provide similar sound and vibration alerts to drivers. In this task, researchers will evaluate the performance of several of these rumble strip alternatives.

Study Design

The study design describes the equipment used, the data collection locations, and how the researchers will collect the data. The goal of the study design is to provide the plan for conducting the data collection.

Data Collection Equipment

The two main metrics for evaluating the effectiveness of the various rumble devices are sound level measured in decibels (dB) and vibration measured in gravitational acceleration (g). To capture sound data, the research team will use an integrating sound level meter. This device will record sound pressure levels as the researchers drive through the test areas. The sound level meter is capable of outputting instantaneous sound pressure level, equivalent sound pressure level, and sound exposure level. Instantaneous sound level is the decibel level at any given moment during the data collection. Equivalent sound pressure level is the average sound pressure level over a period of time. Sound exposure level is the total sound energy produced over a period of time. To capture vibration data, the research team will use an accelerometer that is connected to a laptop. The accelerometer will record the change in vertical acceleration that is caused by the rumble devices.

Data Collection Locations

The majority of the data collection will take place in TxDOT's Atlanta District. The Atlanta District has numerous locations of profiled pavement markings, rumble strips, and rumble bars of various designs. Some examples of sections to test in the Atlanta Districts are:

- 6-inch profiled marking at 16-inch spacing.
- 6-inch profiled markings at 30-inch spacing.
- Standard edgeline rumble strips at 12-inch spacing on Portland cement concrete (PCC), asphalt, and seal coat.
- Standard centerline rumble strips at 12-inch spacing with rumble bars placed in between at 12-inch spacing.
- Centerline rumble bars at 36-inch spacing.
- Centerline rumble bars at 48-inch spacing.
- Centerline rumble bars at 60-inch spacing.

In addition to the data collection in the Atlanta District, the research team will collect data at several other locations to generate additional data for comparison. The research team will collect data at two locations along SH 21 in the Bryan District. The Bryan District has the standard 4-inch-wide profiled pavement marking at 12-inch spacing, as seen in Figure 37. This will provide a comparison to the 6-inch-wide version in the Atlanta District. The Bryan District also has a section where rumble strips were milled into an asphalt road surface and then later overlaid with a seal-coat surface treatment (see Figure 38). On SH 290 in the Austin District, a contractor has recently installed a new type of profiled pavement marking. The research team will evaluate how this form of profiled marking compares to the standard form.

Figure 37. Profiled (Audible) Pavement Marking.

Figure 38. Rumble Strip That Has Been Overlaid with Seal Coat.

Data Collection

The data collection team will conduct data collection by driving through the sites numerous times. Up to three runs per factor level combination will be conducted. Sound and vibration data will be collected inside the vehicle. Sound data will be collected adjacent to the driver's head. The vibration data will be collected at the base of the driver's seat. Sound data will also be collected outside the vehicle at a stationary location adjacent to the roadway to evaluate the noise pollution created by the audible devices. The research team will collect data while the vehicle encounters the rumble device and also in an ambient condition where the vehicle is not on the device. The research team will drive through the section at two different speeds if the conditions allow. The research team will also use two different vehicle types for data collection. A summary of the different factors being considered are listed below:

- Vehicle—car, passenger truck.
- Speed—55 mph, 70 mph.
- Position of device on roadway—edgeline, centerline.
- Road surface—asphalt, PCC, seal coat.
- Condition—ambient, on device.
- Measurement location—in vehicle, adjacent to roadway.
- Noise pollution distance from road—50 ft, 100 ft.

While at the data collection sites, the research team will evaluate the condition of the rumble devices and take measurements of the devices' physical properties. The research team will measure the height/depth, length, width, and spacing of the devices. The research team will take notes on the road surface type and the condition of the road surface.

Data Analysis

The sound and vibration data that are collected will be analyzed in numerous ways to determine the effectiveness of the various rumble devices. The data will be summarized to determine the sound (in and outside the vehicle) and vibration levels for the various rumble devices. These values will be determined for the ambient condition and the condition when the rumble device is being encountered.

The research team will calculate the change in sound from the ambient condition to the condition when the rumble device is encountered. This change in sound level will be determined for inside the vehicle (the noise to alert the driver) and outside the vehicle (noise pollution). The change in vibration from the ambient condition to the condition when the rumble system is encountered will also be calculated. The change from the ambient condition is what provides the alerting benefit to drivers.

Next Steps

The next step for this task is to collect the sound and vibration data. The data collection is scheduled for late August and September of 2014. After the data are collected, the researchers will summarize the data and conduct the analysis. The researchers will develop findings and present the work in a report.

REFERENCES

1 Bonneson, J., M. Pratt, J. Miles, and P. Carlson. *Procedures for Setting Advisory Speed: Course Notes—Appendix A. Horizontal Curve Signing Handbook, 2nd Edition*. Report FHWA/TX-09/5-5439-01-P1, College Station, Texas, 2009.

2 Bonneson, J., M. Pratt, J. Miles, and P. Carlson. *Development of Guidelines for Establishing Effective Curve Advisory Speeds*. Report FHWA/TX-07/0-5439-1, College Station, Texas, 2007.

3 Pratt, M., J. Miles, and J. Bonneson. *Workshops on Using the GPS Method to Determine Curve Advisory Speeds*. Report FHWA/TX-10/5-5439-01-1, College Station, Texas, 2009.

4 Procedures for Establishing Speed Zones. Texas Department of Transportation, Austin, Texas, 2012.

5 Texas MUTCD: Manual on Uniform Traffic Control Devices. Texas Department of Transportation, Austin, Texas, 2006.

6 Manual on Uniform Traffic Control Devices. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2009.

7 Texas MUTCD: Manual on Uniform Traffic Control Devices, Revision 1. Texas Department of Transportation, Austin, Texas, 2012.

8 Glennon, J.C. *Thoughts on a New Approach for Signing Roadway Curves*. http://www.crashforensics.com/papers.cfm?PaperID=18. Accessed Nov. 25, 2013.

9 Torbic, D., D. Harwood, D. Gilmore, R. Pfefer, T. Neuman, K. Slack, and K. Hardy. *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan. Volume 7: A Guide for Reducing Collisions on Horizontal Curves.* NCHRP Report 500. TRB, National Research Council, Washington, D.C., 2004.

10 Pesti, G., K. Obeng-Boampong, P. Songchitruksa, and L. Theiss. *Treatments to Reduce the Frequency of Freeway Exit Sign Hits.* Texas Department of Transportation Report No. FHWA/TX-11/0-6120-1, January 2011.

11 Howe, D. E. *Freeway Exit Gore Signage: A Survey of State Practice and Related Research.* CTC & Associates, LLC, Preliminary Investigation Report to Caltrans Division of Research and Innovation. December 2013.

12 Agenda for Caltrans CA TCD Committee Meeting Feb 19-20, 2014. Accessed on May 2014 from http://www.dot.ca.gov/hq/traffops/engineering/ctcdc/agenda/agenda-02-19&20-2014.pdf.

13 White, M. C., D. L. Ivey, and T. J. Hirsch. *In-Service Experience of Installations of Texas Modular Crash Cushions.* Texas Highway Department Report No. 146-2, 1969.

14 Siria, B. S., W. M. Seymour, D. L. Cornette, and J. L. Miller. *Experimental Installations of Impact Attenuation Devices.* Interim Report KYHPR-7`-64, 1971.

15 Viner, J.G., and F. J. Tamanini. Effective Highway Barriers. *Accident Analysis and Prevention,* Vol. 5, pp. 203-214, 1973.

16 Taylor, J. I., and H. W. McGee. *Improving Traffic Operations and Safety at Exit Gore Areas.* NCHRP Report 145, 1973.

17 Creasey, F. T., C. L. Dudel, and R. D. Huchingson. Evaluation of the Effectiveness of Crash Cushion Delineation. In *Transportation Research Record* 1111, pp. 93-103, 1987.

18 Creasey, F. T., G. L. Ullman, and C. L. Dudel. Delineation of Urban Freeway Gore Area Crash Cushion in Texas. In *Transportation Research Record* 1233, pp. 28-33, 1989.

19 Hakkert, A.-S., and V. Gitelman. Consideration of Bollard Treatment at Exit Gore Areas. In *Transportation Research Record* 1635, 1998.

20 2013 UDOT Sign Manual, Part 5, Guide Signs, Section 5.C.18. Exit Gore Sign, Page 63. Access on April 2014 from http://www.udot.utah.gov/main/uconowner.gf?n=3000306255336296.

21 2011 Indiana Design Manual, Part 7 Traffic Design, Chapter 75. Accessed on April 2014 from http://www.in.gov/dot/div/contracts/standards/dm/2011/Part7/Ch75/ch75.htm

22 2011 Edition of the Maryland MUTCD, Section 2E.37 Exit Gore Signs (E5-1 Series), Page 235. Accessed on April 2014 from http://www.roads.maryland.gov/mmutcd/2011_Chapters_02E.pdf.

23 NMDOT Signing and Striping Manual, March 2008, Chapter 2—Signs, Page 2.5-10. Accessed on April 2014 from http://dot.state.nm.us/content/dam/nmdot/Infrastructure/SignandStripingManual.pdf.

24 NYS Supplement to the 2009 MUTCD, December 2010, Section 2E.31 Interchange Exit Numbering, Page 82 of 269. Accessed on April 2014 from https://www.dot.ny.gov/divisions/operating/oom/transportation-systems/repository/B-2011Supplement-adopted.pdf.

25 2008 Freeway Signing Handbook. Chapter 3—Application of Freeway Signs, Section 4—Recreational and Cultural Interest Area Signs (White on Brown), pp. 3-19. Accessed on April 2014 from http://onlinemanuals.txdot.gov/txdotmanuals/fsh/fsh.pdf.

26 2005 CODOT Roadway Design Guide, Chapter 10 Grade Separations and Interchanges, Section 10.6.3 Stopping Sight Distance, pp. 10-26, Section 10.7.4 Gores, pp. 10-34. Accessed on April 2014 from http://www.coloradodot.info/business/designsupport/bulletins_manuals/roadway-design-guide/dg05-ch-10-interchanges.pdf/at_download/file.

27 Connecticut Department of Transportation 2003 Highway Design Manual, Chapter 7, Sight Distance, pp. 7-2(2), pp. 12-2(9), pp. 13-7(2), pp. 13-7(4), and Figure 13-7B. Accessed on April 2014 from http://www.ct.gov/dot/lib/dot/documents/dpublications/highway/cover.pdf.

28 Traffic Manual Topic 7-02 (Clear Recovery Zone Concept), pp. 7-49, Topic 7-06 (Traffic Safety Systems), pp. 7-49. Accessed on April 2014 from http://www.dot.ca.gov/hq/traffops/engineering/safety-devices/docs/Clear-Recovery-Zone-

Concept.pdf and http://www.dot.ca.gov/hq/traffops/engineering/safety-devices/docs/Crash-Cushions.pdf.

29 VDOT Imperial Road Design Manual Revisions July 2013, (POLICY), Page 17. Accessed on April 2014 from http://www.virginiadot.org/business/resources/LocDes/RevisionsJuly_2013.pdf.

30 Maine Department of Transportation Highway Design Manual, December 2004, Section 9-3 Freeway/Ramp Junctions, pp. 9-18. Accessed on April 2014 from http://www.maine.gov/mdot/technicalpubs/documents/pdf/hwydg/vol1/chpt9.pdf.

31 2013 Traffic Engineering Manual, Markings, Section 4.2.3 Route Shield Pavement Markings, pp. 4-2-3. Accessed on April 2014 from http://www.dot.state.fl.us/trafficoperations/Operations/Studies/TEM/FDOT_Traffic_Engineering_Manual_revised_November_2013.pdf.

32 Commonwealth of Kentucky, Transportation Cabinet, *Traffic Operations Guidance Manual* (June 2005), Section 500 Pavement Marking and Delineation, Chapter 503 Striping, pp. 3. Accessed on April 2014 from http://transportation.ky.gov/Organizational-Resources/Policy%20Manuals%20Library/Traffic%20Operations.pdf.

33 Pennsylvania Department of Transportation. *Traffic Engineering Manual* (Pub. 46) February 2012, Chapter 3—Markings, Page 8. Accessed on April 2014 from ftp://ftp.dot.state.pa.us/public/PubsForms/Publications/PUB%2046.pdf.

34 MN MUTCD, Section 2E.37 Exit Gore Signs (E5-1 Series), pp. 2E-42. Accessed on April 2014 from http://www.dot.state.mn.us/trafficeng/publ/mutcd/mnmutcd2014/mnmutcd-2e.pdf.

35 MoDOT Engineering Policy Guide, Topic 903.8 Freeway and Expressway Guide Signs. Section 903.8.39 Exit Gore Signs (E5-1 Series) (same as MUTCD Section 2E.37). Accessed on April 2014 from http://epg.modot.mo.gov/index.php?title=903.8_Freeway_and_Expressway_Guide_Signs#903.8.39_Exit_Gore_Signs_.28E5-1_Series.29_.28MUTCD_Section_2E.37.29.

36 Iowa Design Manual, Chapter 8 (Roadside Safety) Section 8C-5 (Crash Cushions, Revised on 09-13-12), p. 6. Accessed on April 2014 from http://www.iowadot.gov/design/dmanual/08C-05.pdf#search="gore".

37 1961 Manual on Uniform Traffic Control Devices. Bureau of Public Roads, U.S. Department of Commerce, June 1961. Available at http://www.trafficsign.us/1961mutcd.html. Accessed August 4, 2014.

38 Authority of Transportation Commission to Alter Speed Limits. Texas Transportation Code, Section 545.353. Available at http://www.statutes.legis.state.tx.us/docs/tn/htm/tn.545.htm. Accessed August 4, 2014.

39 6(09)-5 (I)—Use of Pilot Car with Temporary Traffic Control Signals. Federal Highway Administration, U.S. Department of Transportation, August 31, 2010. Available at http://www.atssa.com/Resources/InterpretationLetters/2010InterpretationLetters.aspx. Accessed August 4, 2014.

40 6(09)-19 (E)—Pilot Vehicles Using Temporary Traffic Signals Instead of Flaggers—TxDOT. Federal Highway Administration, U.S. Department of Transportation, February 13, 2013.

41 Finley, M.D., B.R. Ullman, N.D. Trout, and E. Park. *Studies to Determine the Effectiveness of Automated Flagger Assistance Devices and School Crossing Devices*. Report FHWA/TX-12/0-6407-1, Texas A&M Transportation Institute, College Station, Texas, January 2012. Available at http://tti.tamu.edu/documents/0-6407-1.pdf. Accessed August 4, 2014.

42 Molina, C.J., Jr., C.J. Messer, and D.B. Fambro. *Passenger Car Equivalencies for Large Trucks at Signalized Intersections.* Report FHWA/TX-87/397-2, Texas A&M Transportation Institute, College Station, Texas, May 1987.

43 Daniels, G., S. Venglar, and D. Picha. *Guidelines for the Use of Portable Traffic Signals in Rural Two-Lane Maintenance Operations*. Report TX-00/3926-2, Texas A&M Transportation Institute, College Station, Texas, February 2000. Available at http://tti.tamu.edu/documents/3926-2.pdf. Accessed August 4, 2014.

APPENDIX A. GUIDANCE BY STATE

State	Content/Text	Reference Name	Link to webpage
Alabama	Not Found		
Alaska	Not Found		
Arizona	Not Found		
Arkansas	Not Available Online		
California	In February 2002, the California Department of Transportation announced that California will begin numbering exits on freeways across the Golden State. "Numbering exits will help travelers find their way in areas unfamiliar to them, determine distances and travel mileage. The new signs will be much more visible at night and thus increase highway safety," said Director Jeff Morales. To minimize costs, the new exit number signs will take advantage of existing roadside and overhead signs. Where possible, add-on plates will be used. In some cases, a new sign will be installed. Crash cushions are to be installed at fixed objects that cannot be economically removed or made breakaway and where other protective systems such as guardrail are not suitable, such as at the gore point on a separated structure. Relocate a fixed object in the median or gore to a location beyond the right CRZ (*30' for high speed highway and 20' conventional highway*), thereby reducing the risk of exposure to at least one direction of travel. California Department of Transportation Contract number 04270904 (2007) description: Remove gore area exit signs in	Caltrans Office of Traffic Engineering Traffic Control Devices Page Traffic Manual Topic 7-06 (Traffic Safety Systems), Pg. 7-49 Traffic Manual Topic 7-02 (Clear Recovery Zone Concept), Pg. 7-49	http://www.dot.ca.gov/hq/traffops/engineering/calnexus/index.htm http://www.dot.ca.gov/hq/traffops/engineering/safety-devices/docs/Crash-Cushions.pdf http://www.dot.ca.gov/hq/traffops/engineering/safety-devices/docs/Clear-Recovery-Zone-Concept.pdf http://www.dot.ca.gov/hq/asc/oap/payments/public/04270904.htm

	Santa Clara county at various locations (2SCL0017 0069 0072 2SCL0101 0405 0518 2SCL0237 0008 0044)	Caltrans Contract List	
	Background information for CA TCD committee meeting "Installation and repairs to exit gore signs are high-risk activity for Caltrans maintenance, and some preliminary work in Caltrans District 6 has been done to install larger, 2-post E5-1 FHWA specification signs downstream of the gore point to reduce knockdowns and allow for additional room to perform maintenance in a protected work zone environment. Other options being considered are to move the exit gore sign to the far right hand shoulder, or in the case of multi-lane exits in high-volume freeway corridors, delete the exit gore sign, completely, as a road-side sign and consider other locations or options. As a courtesy to the CTCDC, Caltrans is sharing its preliminary investigation, and will be in discussion with the FHWA to scope a request to experiment to add options to Section 2E.37 of the national MUTCD. Future recommendations will be based upon additional study, experimentation (if request to experiment is granted, and future outcomes currently unknown)	Agenda for Caltrans CA TCD Committee meeting Feb 19-20, 2014	http://www.dot.ca.gov/hq/traffops/engineering/ctcdc/agenda/agenda-02-19&20-2014.pdf
	CA TCD committee chairman Bahadori on alternative exit gore area sign placements "The one thought I have, Mr. Howe, is that moving the sign deeper in the gore, you may want to look at some criteria. Because a lot of -- because the gore area is technically like a use it if you want or if you miss the exit. I see a lot of people, and we all see them, that they use that gore area, especially if it's paved, to get into the ramp last minute. So you don't probably want to introduce another obstacle in that area. But if the gore, the pavement stops and then there is a slope usually or there's unpaved surface then I don't see a problem.	Minutes of Caltrans CA TCD Committee meeting Feb 20, 2014	http://www.dot.ca.gov/hq/traffops/engineering/ctcdc/minutes/2014-02-20-minutes.pdf

	But with the areas that are paved you may not want to have those obstacles introduced there.		
Colorado	There should be a clear view of the entire exit terminal, including the exit nose and a section of the ramp pavement beyond the gore. Heavy sign supports, street light standards, and roadway structure supports should be kept well out of the graded gore area. Yielding or breakaway type supports should be used for the standard exit sign, and concrete footings, where used, should be kept flush with adjoining ground level. If non-yielding obstructions are unavoidable in the gore area, impact attenuators should be considered.	2005 Roadway Design Guide Chapter 10 Grade Separations and Interchanges, Section 10.6.3 Stopping Sight Distance, Pg. 10-26 Section 10.7.4 Gores, Pg. 10-34	http://www.coloradodot.info/business/designsupport/bulletins_manuals/roadway-design-guide/dg05-ch-10-interchanges.pdf/at_download/file
Connecticut	As with SSD, the driver height of eye is 3.5 ft and the height of object is typically 2 ft. However, candidate sites for decision sight distance may also be candidate sites for assuming that the "object" is the pavement surface (e.g., freeway exit gores). Therefore, the designer may assume a 0.0-in height of object for application at some sites. A number of fixed objects may be located within interchanges, such as signs at exit gores or bridge piers. These should be removed where practical, made breakaway, or shielded with barriers or impact attenuators. Impact attenuators are most often installed to shield fixed-point hazards that are close to the traveled way. Examples include exit gore areas, bridge piers and non-breakaway sign	Connecticut Department of Transportation 2003 Highway Design Manual, Chapter 7, Sight Distance, Pg. 7-2(2) Pg 12-2(9) Pg. 13-7(2)	http://www.ct.gov/dot/lib/dot/documents/dpublications/highway/cover.pdf

	supports. There is some concern that the unanchored inertial systems may walk or crack due to the vibration of an elevated structure. This could adversely affect its performance. Therefore, designers should locate gore areas, etc., to avoid the use of impact attenuators on a structure. RESERVE AREA FOR IMPACT ATTENUATOR IN GORES	 Pg. 13-7(4) Figure 13-7B	
Delaware	Not Found		
District of Columbia	Not Found		
Florida	Route shield pavement markings are justified by each of the following: Increased crash history where high traffic volumes worsen complex lane assignments such as lane drops, double lane exits with optional lanes, and unusual geometries. High number of crashes at the gore or the Crash attenuator is hit frequently.	2013 Traffic Engineering Manual, Markings, Section 4.2.3 Route Shield Pavement Markings, Pg. 4-2-3.	http://www.dot.state.fl.us/trafficoperations/Operations/Studies/TEM/FDOT_Traffic_Engineering_Manual_revised_November_2013.pdf
Georgia	Not Found		
Hawaii	Not Found		
Idaho	Not Found		
Illinois	Not Found		
Indiana	An exit gore sign should be placed in each gore area of a freeway as shown on Figure 75-2C, Sign Gore Treatment.	2011 Indiana Design Manual, Part 7 Traffic Design, Chapter 75,	http://www.in.gov/dot/div/contracts/standards/dm/2011/Part7/Ch75/ch75.htm
Iowa	One of the most common installation locations for crash cushions is at gore areas. This is because two runs of concrete barrier (or bridge rail) often terminate here – one along the mainline and one along the ramp – and both of the approach ends need to be treated within a limited distance. Crash cushions are well-suited for use in gore areas, since they are narrow and relatively short. Because gore areas are usually high-crash locations, they should	Iowa Design Manual, chapter 8 (Roadside Safety) Section 8C-5 (Crash Cushions, Revised on 09-13-12), Pg. 6	http://www.iowadot.gov/design/dmanual/08C-05.pdf#search="gore"

	be protected with severe-use crash cushions.		
Kansas	Not Found		
Kentucky	Gore markings at interchanges with tapered ramps should be striped in conformance with Standard Drawing TPM-130. Gore markings at interchanges with parallel ramps should be striped in conformance with Standard Drawing TPM-135. Other types of interchanges or those with unusual geometry should be striped using similar principles to those shown in the Standard Drawings (TPM-130 and TPM-135) and the MUTCD. Chevron markings in the neutral area should not be used in most instances. They may be used if there is a specific need to provide additional guidance to motorists. Dotted extensions of the lane line or the right edge line should not be used in most instances. They may be used if there is a specific need to provide additional guidance to motorists. Lane reduction arrow markings should not be used in most instances. They may be used if there is a specific need to provide additional guidance to motorists. If used, they should be installed in conformance with Exhibit 6.	Commonwealth of Kentucky, Transportation Cabinet, Traffic Operations Guidance Manual (June 2005), Section 500 Pavement Marking and Delineation, Chapter 503 Striping, Pg. 3	http://transportation.ky.gov/Organizational-Resources/Policy%20Manuals%20Library/Traffic%20Operations.pdf
Louisiana	Not Found		
Maine	Highway Guidance on Crash Cushions: Category 3 - Low Maintenance and/or Self-Restoring Crash Cushions is a system designed to suffer little, if any, damage on impact and can be easily pulled back into full operating condition. No system is completely maintenance free. Devices in this category are not guaranteed to be both low maintenance and self-restoring. This system may be selected for gore areas. If practical, the area beyond the gore nose should be free of signs and luminaire supports for approximately 300 feet beyond the gore nose. If supports must be present, they must be yielding or	Maine Department of Transportation Highway Program Design Guidance on Crash Cushions Maine Department of Transportatio	http://www.maine.gov/mdot/technicalpubs/documents/ecdocs/HighwayGuidanceCrashCushions.doc http://www.maine.gov/mdot/technicalpubs/documents/pdf/hwydg/vol1/chpt9.pdf

	breakaway or shielded by guardrail or a crash cushion.	n Highway Design Manual, December 2004, Section 9-3 Freeway/Ramp Junctions, Pg. 9-18	
Maryland	Breakaway or yielding supports shall be used where protection is not provided. Standard: 09a Along State owned, operated, and maintained roadways, ramps leading from an expressway to an expressway shall have Exit Gore (E5-1(3), or E5-1(5)) signs that include a 36 inch (minimum) Route Marker Shield (See Figure 2E-28a), the appropriate cardinal direction, and an arrow oriented to the ramp direction. 09b For ramps that have numbers, an exit number panel shall be added to the top of the Gore sign. Guidance: 09c All other entrance ramps entering an expressway should be similarly signed. Standard: 09d Simple gores leading from an expressway to a divided highway or to a conventional highway shall have an Exit Gore sign E5-1a(1) where interchange exit numbers have been established for the expressway. 09e Independent route marker assemblies shall not be used in the gores. Guidance: 09f For all other expressway off ramps, where exit numbers are not established, a	2011 Edition of the Maryland MUTCD, Section 2E.37 Exit Gore Signs (E5-1 Series), Pg. 235	http://www.roads.maryland.gov/mmutcd/2011_Chapters_02E.pdf

	Exit Gore (E5-1(1)) sign should be used. 09g Ramps from a secondary roadway to an expressway or a divided highway should have a gore sign with a 24 inches (minimum) route marker shield and cardinal direction. An Exit Gore (E5-1(1)) sign should be used for on ramps to routes with no numbers designated. Guidance: 09h Gores at ramp splits should use a Gore sign with an arrow and cardinal direction on the top line, a 2/3 bar, a 36 inches (minimum) shield on the second line, a 2/3 bar, and an arrow and cardinal direction on the third line (E5-1(8)). Guidance: 09i This lateral clearance should always be measured from the edge of the sign face to the edge of the shoulder. When the shoulder is less than 10 feet wide, the gore sign should be moved further away from the edge of the shoulder, so that the minimum lateral clearance from the edge of the traveled roadway is 16 feet. Option: 09j The preferred spacing between the gore sign and physical gore is 50 feet. Deviations from the 50 feet preferred spacing may occur in two instances. The first case is where there is an extremely sharp turn off to the ramp, and 50 feet would be too far back from the actual point of exit. The second case is where there is an extremely smooth turn off to the ramp, and 50 feet would not allow for the proper lateral clearance from the shoulder. Standard: 09k Along State owned, operated and maintained roadways, when the advisory speed posted on the Optional Advisory Speed Panel is less than or equal to 25 mph, the associated Exit Gore signshall display a turn arrow. Guidance:		

	09l The Optional Advisory Speed Panel should be mounted below the Exit Gore sign. 09m The Optional Advisory Speed Panel should not be used for a ramp movement from a low speed roadway when the advisory speed is greater than the secondary road. Option: 09n Along State owned, operated and maintained roadways, an Optional Advisory Speed Panel may be used where the advisory ramp speed is identified as less than or equal to 30 mph. Guidance: 09o If the Exit Gore Sign is greater than 50 feet back from the physical gore or greater than (300 feet back from the theoretical gore, an Object Marker (OM) should be placed in front of the Exit Gore Sign. 09p The OM should be placed 4 feet back from the physical gore. If the roadway has a speed limit of 55 mph or greater, a modified Type 3 OM should be used. 09q A Type 1 OM should be used for all other roadways.		
Massachusetts	Not Found		
Michigan	Not Found		
Minnesota	Breakaway or yielding supports shall be used.	MN MUTCD, Section 2E.37 Exit Gore Signs (E5-1 Series), Pg. 2E-42	http://www.dot.state.mn.us/trafficeng/publ/mutcd/mnmutcd2014/mnmutcd-2e.pdf
Mississippi	Not Available Online		
Missouri	Breakaway or yielding supports shall be used.	MoDOT Engineering Policy Guide, Topic 903.8 Freeway and Expressway Guide Signs. Section 903.8.39 Exit Gore Signs (E5-1 Series)	http://epg.modot.mo.gov/index.php?title=903.8_Freeway_and_Expressway_Guide_Signs#903.8.39_Exit_Gore_Signs_.28E5-1_Series.29_.28MUTCD_Section_2E.37.29

		(same as MUTCD Section 2E.37)	
Montana	Not Available Online		
Nebraska	Not Found		
Nevada	Not Found		
New Hampshire	Not Found		
New Jersey	Not Found		
New Mexico	NMDOT uses the Exit Gore Sign (E5-1a), with the exit number within the sign area.	Signing and Striping Manual, March 2008, Chapter 2 – Signs Page 2.5-10	http://dot.state.nm.us/content/dam/nmdot/Infrastructure/SignandStripingManual.pdf
New York	An E5-1bP exit number plaque shall be used only in conjunction with the E5-1 Exit Gore sign (see Section 2E.37).	NYS Supplement to the 2009 MUTCD, December 2010, Section 2E.31 Interchange Exit Numbering, Page 82 of 269	https://www.dot.ny.gov/divisions/operating/oom/transportation-systems/repository/B-2011Supplement-adopted.pdf
North Carolina	Not Found		
North Dakota	Not Found		
Ohio	Same as MUTCD section 2E.37	Ohio Manual of Uniform Traffic Control Devices 2012 Edition	http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/traffic/OhioMUTCD/Documents/2012_Part02_complete_Final_011312_bookmarked_011712_ReorganizedsomeBookmarks.pdf

Oklahoma	Not Found		
Oregon	Not Found		
Pennsylvania	Install RPMs on the lane lines and within exit-ramp gore areas of all Interstate highways, freeways, and expressways. (An exception may occur if the pavement is in poor condition and will not accommodate RPMs, or if the Department plans to resurface the pavement within 4 years.)	Pennsylvania Department of Transportation. Traffic Engineering Manual (Pub. 46) February 2012, Chapter 3 – Markings, Page 8	ftp://ftp.dot.state.pa.us/public/PubsForms/Publications/PUB%2046.pdf
Puerto Rico	Not Available Online		
Rhode Island	Not Found		
South Carolina	Not Found		
South Dakota	Not Found		
Tennessee	Not Found		
Texas	Same as MUTCD All Exit Gore signs must remain white on green.	TMUTCD 2008 Freeway Signing Handbook. Chapter 3 — Application of Freeway Signs, Section 4 — Recreational and Cultural Interest Area Signs (White on Brown), Pg. 3-19	http://onlinemanuals.txdot.gov/txdotmanuals/fsh/fsh.pdf
Utah	Reference to MUTCD section 2E.37 Consistent application of this sign (Exit Gore Sign) at each exit is important.	2013 UDOT Sign Manual, Part 5, Guide Signs, Section 5.C.18. Exit Gore Sign, Page 63	http://www.udot.utah.gov/main/uconowner.gf?n=300030625536296
Vermont	Not Available Online		
Virginia	The rate of accidents in gore areas is typically greater than that for run-off-the road accidents at other locations. For this reason, the gore area and the unpaved area	IMPERIAL ROAD DESIGN MANUAL	http://www.virginiadot.org/business/resources/LocDes/RevisionsJul

	beyond should be kept as free of obstructions as practicable to provide a clear recovery area. Heavy sign supports, street light standards, and roadway structure supports should be kept well out of the graded gore area. Yielding or breakaway-type supports should be employed for the standard exit sign, and concrete footings, where used, should be kept flush with adjoining ground level. Cushioning or energy-dissipating devices shall be provided in front of hazardous fixed objects.	REVISIONS July, 2013 , (POLICY), Page 17	y_2013.pdf
Washington	Same as MUTCD	WSMUTCD	http://www.wsdot.wa.gov/Operations/Traffic/mutcd.htm
West Virginia	Not Found		
Wisconsin	Not Found		
Wyoming	Not Found		

APPENDIX B. CONSENT FORM

CONSENT FORM
9-1001-14 Traffic Control Device Evaluation Program – Exit Gore Simulator Study

Introduction
The purpose of this form is to provide you information that may affect your decision as to whether or not to participate in this research study. If you decide to participate in this study, this form will also be used to record your consent.

You have been asked to participate in a research project studying signs and devices seen at freeway exits. The purpose of this study is to assess driver understanding and evaluation of the various treatment alternatives. You were selected to be a possible participant because you are a current driver and are 18 or above. This study is being sponsored/funded by the Texas Department of Transportation.

What will I be asked to do?
If you agree to participate in this study, you will be asked to complete a short survey, one practice drive and a maximum of 10 test drives in Texas A&M Transportation Institute's driving simulator, which is a desktop computer system with an attached steering wheel and pedals. In each of the simulated scenarios, you will be able to view and control your speed and lane position on the roadways you will see on the computer display. The researcher will begin each scenario by giving you some details about the drive you are about to make and where you should go. Your driving data, including your lane selections, will be recorded by the simulator computers. Following each scenario, the researcher will ask you up to five follow-up questions about the signs and devices you saw and the decisions you made. The study will take no longer than 1.5 hours.

What are the risks involved in this study?
The risks associated in this study are minimal. Some individuals may encounter simulator induced sickness which feels similar to motion sickness. Please tell the researcher if you are feeling uncomfortable at all and they will stop the simulation.

What are the possible benefits of this study?
You will receive no direct benefit from participating in this study; however, TTI will submit the results of this research for review to improve future low-bridge warning signing.

Do I have to participate?
No. Your participation is voluntary. You may decide not to participate or to withdraw at any time without your current or future relations with Texas A&M University or the Texas Department of Transportation being affected.

Will I be compensated?
You will receive $50 for your participation. Disbursement will occur at the end of the study. You must remain for the entire study to receive compensation. If you experience simulator sickness and must stop, you will be compensated the full amount. If the research study must be cancelled due to equipment problems, in the first 15 minutes, you will be compensated $20, after that you will be compensated at least $30.

Who will know about my participation in this research study?

This study is confidential and your data will be identified by a number, not by your name. The records of this study will be kept private. Information about you will be kept confidential to the extent permitted or required by law. No identifiers linking you to this study will be included in any sort of report that might be published. Research records will be stored securely and only Laura Higgins will have access to the records.

Whom do I contact with questions about the research?
If you have questions regarding this study, you may contact Laura Higgins at l-higgins@tamu.edu or (979) 845-8109.

Whom do I contact about my rights as a research participant?
This research study has been reviewed by the Human Subjects' Protection Program and/or the Institutional Review Board at Texas A&M University. For research-related problems or questions regarding your rights as a research participant, you can contact these offices at (979) 458-4067 or irb@tamu.edu.

Signature
Please be sure you have read the above information, asked questions and received answers to your satisfaction. You will be given a copy of the consent form for your records. By signing this document, you consent to participate in this study.

Signature of Participant: ____ **Date:** _____________

Printed Name: ____

Signature of Person Obtaining Consent: ___________________________ **Date:** _____________

Printed Name: ____

IRB NUMBER: IRB2013-0840D
IRB APPROVAL DATE: 05/21/2014
IRB EXPIRATION DATE: 01/15/2015

APPENDIX C. PARTICIPANT COMMENTS FOR WHICH TREATMENTS THEY THOUGHT WORKED THE BEST AND LEAST

Reasons why M Works Best (20.0%)	Reasons why M Works Least (42.5%)
I like the lines	Doesn't tell you what it's doing at all
Clear separation that there's a divide in the road	It's very slight; no signage
Cross-hatched lines provide more presence to the gore	Because nothing is above the ground
Bolder, lets you know where the exit is	Other than the white on the ground, there is nothing to confirm what it is
White striping on pavement is more obvious	Because there is nothing vertical, only on the ground
Easier to see than sign alone	No sign
Good at night	Better than yellow and black which could mean anything, but needs more
Stripes are easier to see	You don't see it until you're right on top of it
	Least amount of warning
	It's the hardest to see at night; not reflective or sticking up
	Doesn't have a sign, or something telling you to exit
	There's nothing there except for the stripes
	Doesn't stand out or grab your attention
	Nothing above the road
	No visible sign higher than the markings
	Because it doesn't tell you anything and might not see it until it was too late if driving at night
	When the paint starts fading, it's terrible
Reasons why C1 Works Best (5.0%)	**Reasons why C1 Works Least (22.5%)**
Just the yellow marker, no white stripes	Not as visible as the others
Stands out more	Don't understand what the sign is saying
	No signaling right there, just veers off. Don't know what's splitting off; just looks like a lane splitting
	Looks short
	The road is telling me there is an exit, the sign is not
	Yellow barrier not very informative
	Seems like it's directing you toward the middle/gore
	Doesn't tell me anything I need to know
	A little iffy
Reasons why C2 Works Best (2.5%)	**Reasons why C2 Works Least (30.0%)**
Like the outward pointing arrows	Doesn’t stand out as much
	Arrows look like they're going in 2 directions
	Don't understand what the sign is saying
	Strange looking marker
	No signaling right there, just veers off. Don't know what's splitting off; just looks like a lane splitting

	It seems the most minimalist of options; pattern is less bold and seems thinner
	Doesn't make any sense with arrows pointing out; need more processing time
	Looks like it's saying the roadway is splitting around something, not that it's an exit
	Looks short
	Yellow barrier not very informative
	Can't tell what that is, looks like a construction zone
	A little iffy
Reasons why S Works Best (32.5%)	**Reasons why S Works Least (25.0%)**
Familiar; looks similar to advance guide signs	Not fond of absence of pavement markings
Because I'm used to it	By the time you get there and see the sign, you might already have passed the exit or there might be someone in the exit lane you'd conflict with
Has words	Because the sign is too far away. I think I would see it and think the exit was after the sign
Elevated sign; used to seeing it	Seems smaller
I like the sign because it's taller and more reflective at night	Least amount of warning
Signage is different than other signs	Not really anything done to it (may not be able to see the sign)
I like the green sign	You're already there, too late to make a decision
It tells you there's an exit	Green fades away
Consistency as far as road signs, vs. the yellow that is usually associated with warnings	Hard to see green sign
Recognizable and it uses words	The sign is too far past the exit point
Used to it	
Because I'm used to it	
Because I've seen it so often	
Reasons why MC1 Works Best (50.0%)	**Reasons why MC1 Works Least (7.5%)**
Has color; it shows up more. Shows you where not to go	Don't understand what the sign is saying
Stands out the most; most contrast	Too busy
Because you have striping and signage it catches your attention	Doesn't tell me anything I need to know
Stripe and yellow chevron have good "target value" for yellow chevron	
The color and lines on ground are hard not to miss; markings tell you where not to go	
Easier to see than green sign; best of the yellow markers	
Stripes plus the yellow sign is easier to see; like the vertical chevrons over the horizontal	
Delineates lanes well. The barrier sign is extra help	
Has the stripes on the road and sign	
White lines catch my attention with the added vertical component	
Cross-hatched lines provide more presence to the gore	

Has something on the roadway and also sticking up from the roadway	
Has the sign plus markings	
Easier to see than sign alone	
Composite of lane markings and a vertical component; would prefer the "C" chevron pattern	
I like the paint plus "physical" component	
(in conjunction with F) Road marking alone might be missed in the rain or snow, but yellow and black marker is visible and the gore striping clearly delineates gore	
I like the yellow with white stripes; arrows point up to where you exit	
Stripes are easier to see	
The yellow and black immediately alerts me even if the paint is fading	
Reasons why HM Works Best (55.0%)	**Reasons why HM Works Least (25.0%)**
Bolder, can be seen as you approach it	Could miss the letters, can't see it far ahead
Because it has words you can read	If traffic is backed up, a car can cover it
Stands out, obvious	Not fond of the "EXIT" word in the lane
Big text is harder to miss	Is dangerous; looks like an exit only. I might make a quick swerve
It seems to be easier to see	It doesn't have lines at the exit
Very large, gives you advance warning and arrow points you into the divide	Current design is kind of a last minute exit
Good for night time	Nothing above the road
Pavement markings are easy to see; might now be great in bad weather	All info is on the road and not up in your face
Telling you the exit is there verbally	Would get nervous that the lane doesn't continue
Big, you can see it	
When you see the "EXIT" marking you know you're in the correct lane	
Gives you warning in advance, but it's kind of right there; sharp exit	
It warns you before you get to it	
Says "exit"	
I want something that catches my attention	
Arrow provides good guidance	
Most visible, give you more warning	
Large and sooner on the road than A (exit guide sign only)	
Can see before I exit	
(in conjunction with E) Road marking alone might be missed in the rain or snow, but yellow and black marker is visible and the gore striping clearly delineates gore	
I like it, but it needs something extra	
You know you're going to exit	
Because it's in the area of the exit	

APPENDIX D. RATINGS DATA – STATISTICAL RESULTS

Paired t-test: P-values

The p-values shown in the tables below are for the differences in mean ratings among the exit gore treatments under each of the three viewing distances, across 40 participants. Two-tailed p-values less than or equal to 0.01 are statistically significant.

Long Viewing Distance

	M	C1	C2	S	MC1
M		p=.14045	p=.66043	p=.24854	**p=1.252E-07**
C1			p= .14098	p=.82186	**p=.00166**
C2				p= .47490	**p=.00158**
S					**p=.00297**

Short Viewing Distance

	M	C1	C2	S	MC1
M		p=.14045	p=.15991	**p=.00035**	**p=7.19E-08**
C1			P=.15991	**p=6.54E-05**	**p=2.77E-08**
C2				**p=.00576**	**p=2.42E-05**
S					p=.24619

Blocked Viewing Distance

	M	C1	C2	S	MC1	HM
M		p=.05563	p=.90979	**p=.00460**	**p=.00383**	**p=.00074**
C1			p=.03562	p=.24308	p=.28186	p=.04261
C2				**p=.00790**	**p=.00649**	**p=.00042**
S					p=.71482	p=.45469
MC1						p=.26273

Wilcoxon Signed-Ranks Test: P-values

The p-values shown in the tables below are for the signed-rank comparisons between each of the exit gore treatments under each of the three viewing distances, across 40 participants. P-values less than or equal to 0.05 are statistically significant.

Long Viewing Distance

	M	C1	C2	S	MC1
M		p=.14706	p=.4965	p=.238	**p=0**
C1			p= .13888	p=.67448	**p=.00424**
C2				p= .50286	**p=.00068**
S					**p=.0096**

Short Viewing Distance

	M	C1	C2	S	MC1
M		p=.90448	p=.12114	**p=.0009**	**p=0**
C1			p=.08186	**p=.0003**	**p=0**
C2				**p=.0088**	**p=.00014**
S					p=.33204

Blocked Viewing Distance

	M	C1	C2	S	MC1	HM
M		p=.06148	p=1	**p=.00578**	**p=.00614**	**p=.00262**
C1			**p=.03156**	p=.267	p=.26272	p=.07346
C2				**p=.01278**	**p=.00988**	**p=.001**
S					p=.68916	p=.4413
MC1						p=.36282

Differences in Means – Paired T-test P-values

Long Viewing Distance

	M	C1	C2	S	MC1
M		p=0.14045	p=	p= 0.24854	**p=1.252E-07**
C1			p=	p=	**p= 0.00166**
C2				p=	**p= 0.00158**
S					**p= 0.00297**

Short Viewing Distance

	M	C1	C2	S	MC1
M		p=	p= 0.15991	p=	p=
C1			p=0.15991	p=	p=
C2				p= 0.00576	p=
S					p= 0.24619

Blocked Viewing Distance

	M	C1	C2	S	MC1	HM
M		p=0.05563	p=	**p=0.00460**	**p=0.00383**	p=
C1			**p=0.03562**	p=0.24308	p=0.28186	p=
C2				**p=0.00789**	**p=0.00649**	**p=0.00042**
S					p=	p=0.45469
MC1						p=0.26273