TREATMENTS FOR CRASHES ON RURAL TWO-LANE HIGHWAYS IN TEXAS

for
Texas
Department of
Transportation

by
Texas
Transportation
Institute

April 2002
Report 4048-2

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-02/4048-2		

4. Title and Subtitle	5. Report Date
TREATMENTS FOR CRASHES ON RURAL TWO-LANE HIGHWAYS IN TEXAS	April 2002
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Kay Fitzpatrick, Angelia H. Parham, and Marcus A. Brewer	Report 4048-2
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	
	11. Contract or Grant No.
	Project No. 0-4048
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin Texas 78763-5080	Research: September 2000-April 2002
	14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.
Research Project Title: Low-Cost Design Safety Improvements for Rural Highways

16. Abstract

Most of the crashes in rural areas occur away from intersections and driveways (60 percent), while most urban crashes occur at or are related to either intersections or driveways (57 percent). The distribution of crashes by first harmful event also clearly shows an urban versus rural division. In urban areas, most of the crashes involve another vehicle (81 percent) while only about half in the rural area involve another vehicle (51 percent). Striking a fixed object is more common in rural areas (25 percent) than in urban areas (14 percent). This document provides transportation practitioners with information on crash characteristics for rural roads in Texas. It also presents discussion on low-cost safety treatments used on highways and at intersections along with their known effectiveness. Treatments discussed for highways include: rumble strips, passing improvements, two-way left-turn lanes, lane or shoulder widening, pavement edge drop-off improvements, pavement markings, mowing, skid resistance improvements, side slope flattening, recovery distance improvements, tree mitigation, culvert modifications, advance warning for horizontal curves, delineation, barrier reflectors, and animal countermeasures. Treatments discussed for intersections include: advance warning for intersections, approach rumble strips, left-turn bays, shoulder bypass lanes, intersection flashing beacons, signalization, high-intensity strobe lights, backplates on traffic signals, illumination, and sight obstruction reduction. Experiences with selected treatments in Texas, including whether the treatment would be considered elsewhere, are also included in the report.

17. Key Words	18. Distribution Statement		
Rural Two-Lane Highways, Crashes, Treatments, Effectiveness, Intersections	No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161		
19. Security Classif.(of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	182	

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

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Project Number 0-4048
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Sponsored by the
Texas Department of Transportation
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

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TEXAS TRANSPORTATION INSTITUTE
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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The report was prepared by Kay Fitzpatrick, P.E. (TX-86762), Angelia Parham, P.E. (TX-87210), and Marcus A. Brewer. The engineer in charge of the project was Kay Fitzpatrick.

ACKNOWLEDGMENTS

The research team recognizes Danny Brown, the project director; Lynn Passmore, the program coordinator; and technical panel members Robert Neel, Margaret (Meg) Moore, Aurora (Rory) Meza, and David Bartz for their time in providing direction and comments for this study. They were instrumental in producing this document, and their assistance was appreciated.

The research team would also like to recognize the more than 125 individuals who provided information on treatments by responding to our mailout survey. Additionally, we would like to thank the following district representatives for meeting with members of the research team during interviews conducted as part of the research: Robert Neel, Herbert Binkley, Richard Ivey, Carlos Chavez, Edgar Fino, Patricia Dalbin, Matt Carr, Daniel L. Dalager, and Imelda Barrett.

The research reported herein was performed by the Texas Transportation Institute as part of a study entitled “Low-Cost Design Safety Improvements for Rural Highways.” The study was sponsored by the Texas Department of Transportation in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

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INTRODUCTION

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A Overview

In 1999, the state of Texas reported a total of 172,730 crashes for the on-system roadways. Of this total, 31 percent occurred in rural areas (see Table 1-1). Near a 30 percent distribution of crashes in rural areas has been constant for the previous five years.

Table 1-1. Distribution of Texas On-System Crashes by Population Group.

Population	1995		1996		1997		1998		1999	
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
Under 5000	53,307	30	51,928	32	53,537	32	52,515	31	53,570	31
5000-10,000	7347	4	6022	4	6101	4	5993	3	6408	4
10,000-25,000	17,808	10	14,873	9	14,818	9	14,169	8	13,695	8
25,000-50,000	14,088	8	11,375	7	11,683	7	12,158	7	13,031	8
50,000-100,000	15,659	9	12,801	8	13,336	8	14,140	8	13,460	8
100,000-250,000	10,435	6	9106	6	11,424	7	13,204	8	13,601	8
over 250,000	61,883	34	55,886	34	58,621	35	59,066	34	58,965	34
Total	**180,527**	**100**	**161,991**	**100**	**169,520**	**100**	**171,245**	**100**	**172,730**	**100**

A Rural Versus Urban Crashes

The types of crashes that are occurring in rural areas in Texas as compared to urban areas in Texas do differ. As shown in Table 1-2, most of the crashes in rural areas occur away from intersections and driveways (60 percent) while most urban crashes occur at or are related to either intersections or driveways (57 percent). This split is also reflected in the number of vehicles involved in the crash. In rural areas about half of the crashes involve only one vehicle while only 17 percent of the urban crashes involve only one vehicle. The distribution of crashes by first harmful event also clearly shows an urban versus rural division. In urban areas most of the crashes involve another vehicle (81 percent) while only about half in the rural area involve another vehicle (51 percent). Striking a fixed object is more common in rural areas (25 percent) than in urban areas (14 percent).

The distribution for injury severity shows some differences between rural and urban crashes. The percentage of fatal crashes is higher in rural areas (3 percent to 1 percent) as well as the percentage of incapacitating crashes (10 percent to 5 percent). The percent of not injured crashes is slightly higher in rural areas (37 percent compared to 31 percent). Most of the crashes in both urban and rural environment occur during daylight (69 and 63 percent, respectively). A higher percent of the rural crashes, however, occur during dark-no lights condition – 27 percent in rural areas and 6 percent in urban areas. Distributions for surface conditions and weather conditions are similar between rural and urban – over 80 percent occur on dry pavement and in clear weather.

Table 1-2. Distribution of Urban and Rural Crashes by Selected Variables.

	URBAN 1997-1999		RURAL 1997-1999	
	Frequency	%	Frequency	%
	353,833		159,622	
INTERSECTION				
Intersection	95,140	27	26,920	17
Intersection-Related	75,541	21	20,127	13
Driveway Access	30,228	9	16,995	11
Non-Intersection	152,964	43	95,580	60
LIGHT				
Daylight	244,757	69	99,999	63
Dawn	4608	1	3124	2
Dark-No Lights	22,869	6	43,658	27
Dark-Street Lights	75,653	21	100,006	6
Dusk	5986	2	2835	2

Table 1-2. Distribution of Urban and Rural Crashes by Selected Variables (continued).

	URBAN 1997-1999		RURAL 1997-1999	
	Frequency	**%**	**Frequency**	**%**
	353,833		**159,622**	
FIRST HARM EVENT				
Overturned	8197	2	23,442	15
Other Non-Collision	1624	0	2268	1
Pedestrian	3197	1	983	1
Another Vehicle in Transport	285,650	81	82,030	51
Railroad Train	77	0	138	0
Parked Car	2778	1	1738	1
Pedal Cyclist	1440	0	386	0
Animal	717	0	7518	5
Fixed Object	48,973	14	40,203	25
Other Object	1220	0	916	1
SEVERITY				
Incapacitating	16,351	5	15,558	10
Non-Incapacitating	59,241	17	34,739	22
Possible Injury	162,603	46	44,968	28
Fatal	2372	1	4511	3
Not Injured	108,016	31	59,846	37
WEATHER				
Clear	308,327	87	136,304	85
Raining	41,272	12	18,135	11
Snow	743	0	818	1
Fog	2043	1	3113	2
Blowing Dust	92	0	48	0
Smoke	47	0	46	0
Other	160	0	139	0
Sleeting	1189	0	1019	1
SURFACE CONDITION				
Dry	292,998	83	129,158	81
Wet	57,515	16	26,649	17
Muddy	82	0	69	0
Snowy/Icy	3278	1	3746	2
TOTAL VEHICLES				
1	61,018	17	74,417	47
2	240,644	68	75,392	47
3	10,857	12	7992	5
More than 3	11,348	3	1821	1

A TxDOT Project 0-4048

TxDOT Project 0-4048 investigated characteristics of low-volume, rural two-lane highway crashes. Because of concerns over the quality of non-injury and property-damage-only (PDO) crash data, especially high non-reporting rates, the analysis into characteristics of crashes on low-volume rural roads used only KAB crashes. KAB crashes include fatal (K), incapacitating injury (A), or non-incapacitating injury (B) crashes. Low-volume has been defined as being highways with less than 2000 average daily traffic (ADT).

The state of Texas maintains nearly 80,000 centerline-miles of paved roadways serving about 400 million vehicle miles per day. Over 62 percent of the centerline-miles are rural two-lane roads that, on average, have less than 2000 ADT. These low-volume rural roadways carry less than 8 percent of the total vehicle miles on state-maintained (or on-system) highways but have approximately 11 percent of the total on-system vehicle crashes. When only two-lane highways are considered, almost three-fourths of the crashes occur in the rural environment with 30 percent of the crashes occurring on the low-volume roads (see Figure 1-1).

Due to the low volume and relatively low crash frequency on these roads, it is often not cost-effective to upgrade the roads. However, vehicles traveling on these roadways generally have high speeds and, thus, tend to have relatively more severe injuries when vehicle crashes do occur. For example in 1999, 26 percent of the Texas on-system crashes were KAB crashes (i.e., fatal, incapacitating injury, or non-incapacitating injury crashes), while 40 percent of the crashes on low-volume on-system roads in 1999 were KAB crashes (see Table 1-3).

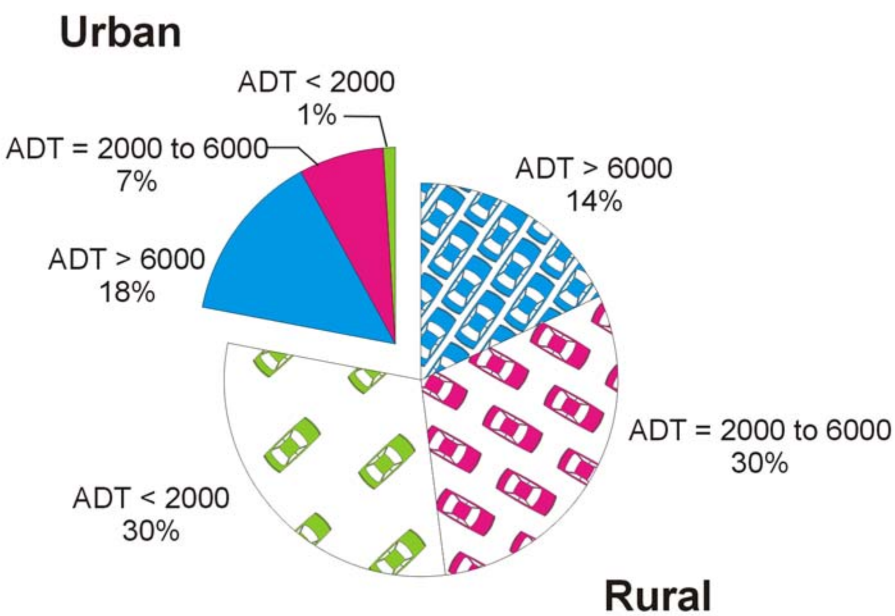

Figure 1-1. Distribution of Crashes by ADT on Two-Lane Highways in Texas (*1*).

Table 1-3. Low-Volume (≤ 2000 ADT), Rural Two-Lane Highway Crashes for 1999 for On-System Texas Roads (1).

	On-System, Low-Volume, Rural Two-Lane Highway Crashes		All On-System Crashes	
	Frequency	**Percent**	**Frequency**	**Percent**
PDO: Non-Injury	4407	36	58,288	34
C Crashes: Possible Injury	2959	24	69,836	40
B Crashes: Non-Incapacitating	2946	24	31,902	19
A Crashes: Incapacitating Injury	1418	12	10,331	6
K Crashes: Fatal	460	4	2373	1
TOTAL	**12,190**	**100**	**172,730**	**100**
KAB Crashes	4824	40	44,606	26
Intersection	1734	14	41,112	24
Intersection-Related	1331	11	32,798	19
Driveway Access Related	1092	9	16,296	9
Non-Intersection	8033	66	82,524	48
TOTAL	**12,190**	**100**	**172,730**	**100**

A Organization

This document provides transportation practitioners with information on crash characteristics for rural roads in Texas. It also presents discussion on low-cost safety treatments used and their known effectiveness.

This document is divided into the following chapters:

A **Chapter 1** contains an introduction concerning crashes on low-volume, rural two-lane highways.

A **Chapter 2** provides information on how to conduct a crash study in Texas.

A **Chapter 3** presents information on the characteristics of vehicle crashes for on-system, low-volume, rural two-lane highways in Texas. It provides answers to three questions: how often do crashes occur, where do crashes occur, and what types of crashes occur more often.

A **Chapter 4** identifies the types of treatments being used on rural two-lane highways.

A **Chapter 5** presents an overview and summarizes effectiveness information available for various treatments for rural roadways.

A **Chapter 6** presents an overview and summarizes effectiveness information available for various treatments for rural intersections.

A **Chapter 7** presents information on experiences with selected safety treatments at several locations in Texas.

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CHAPTER 2
CONDUCTING A CRASH STUDY IN TEXAS

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A Introduction

This chapter contains steps to follow when performing a crash study in Texas. It is the goal of the chapter to provide information on the steps that can be used to identify sites and treatments for intersections or roadway sections that are experiencing an undesired level of crashes.

Key elements in conducting a safety study include the following:

A Identify Sites and Crash Characteristics,

A Gather Existing Conditions,

A Collect Additional Field Data,

A Assess Situation and Select Treatments, and

A Implement and Evaluate.

Steps within each of the above elements are discussed in the following sections.

AIdentify Sites and Crash Characteristics

The initial effort in a safety study is to identify which sites may need safety treatments. Calls to the department, requests for information on an intersection or roadway segment by the media, or the department employee's knowledge are typical techniques used to identify sites. Sites with potential safety concerns can also be identified by using historical data on previous crashes contained in the TxDOT crash database.

Resources needed:

A Texas crash database data (available from the District Traffic Section),

A List of sites identified from phone calls or correspondence,

A List of sites identified from maintenance crews or other department employees,

A Control section maps,

A ADT maps, and

A Crash narratives (ordered from Department of Public Safety [DPS] after crashes and sites are identified or may be available from local law enforcement).

Documents that could assist with the study include the following:

A National Cooperative Highway Research Program (NCHRP) Report 440: *Accident Mitigation Guide for Congested Rural Two-Lane Highways* (*2*) (summaries of the material in the NCHRP Report 440 resource are listed in Table 2-1),

A Institute of Traffic Engineers (ITE) *Traffic Engineering Handbook* (*3*),

A ITE "Traffic Accident Studies" chapter of the *Manual of Transportation Engineering Studies* (*4*),

A *Texas Manual on Uniform Traffic Control Devices (Texas MUTCD)* (*5*),

A *Manual on Uniform Traffic Control Devices (MUTCD)* (*6*),

A American Association of State Highway and Transportation Officials (AASHTO) *Green Book* (*7*),

- TxDOT *Roadway Design Manual* (available on the web)(*8*),

- AASHTO *Roadside Design Guide* (*9*), and

- NCHRP Synthesis 295: *Statistical Methods in Highway Safety Analysis (10)*.

Table 2-1. Synopsis of Material in the *Accident Mitigation Guide for Congested Rural Two-Lane Highways* (*2*).

Chapter 1: Introduction. This chapter discusses the need for the *Accident Mitigation Guide* along with information on accident characteristics and the role of congestion on rural two-lane highways. **Chapter 2: Accident Mitigation Process.** The accident mitigation process was divided into six steps: identify sites with potential safety problems, characterize accident experience, characterize field conditions, identify contributing factors and appropriate countermeasures, assess countermeasures and select most appropriate, and implement countermeasure and evaluate effectiveness. **Chapter 3: Roadway Countermeasures.** The roadway chapter discusses the following two-lane rural roadway cross section elements: lanes and shoulders, passing improvements, two-way left-turn lane improvements, and bridges. Alignment is discussed within the following sections: horizontal alignment, vertical alignment, and combined alignment. Devices that can impact the operations and safety along a two-lane roadway are discussed in the following sections: traffic control devices and rumble strips. **Chapter 4: Roadside Countermeasures.** The condition of the roadside can affect crash frequency and severity, especially when considering the high percentage of crashes, particularly on rural two-lane roads, which involve a run-off-road vehicle. The roadside chapter provides information on: recovery distance, side slopes, obstacles, and utility poles. **Chapter 5: Intersection Countermeasures.** The sections within the intersection chapter discuss countermeasures related to intersection configuration and geometry (such as type of intersection, severe grades, and angle of intersection), sight obstructions, turning improvements, and traffic control devices.	**Chapter 6: Other Countermeasures.** The previous three chapters focus on different physical areas (roadway, roadside, or intersection). Factors other than the physical area of a highway also relate to accidents and, in many cases, can provide the key to reducing accidents at a location or along a section of highway. This chapter describes the accidents and related countermeasures for these *other* factors associated with different types of accidents. Discussions occur on the following: speed enforcement, technology-based improvements, work zones, special events, public information and education, access management, older drivers, pedestrians, animals, and lighting. **Chapter 7: Examples of Safety Improvements.** This chapter contains information on 13 implemented improvements: Rural Advance Traveler Information System; Innovative Electronic Advance Warning System; Centerline Rumble Strips and Inverted Profile Thermoplastic Edge Lines; Inverted Centerline Rumble Strips and Right- and Left-Turn Channelization; Rumble Strips; Rumble Strips, Lane Striping, and Guardrail Installations; Open-Graded Asphalt Concrete Overlay; Flashing Advance Warning Beacons for an All-Way Stop Controlled Intersection; Cooperative Safety Program; Left-Turn Channelization and Pavement Rehabilitation; Left-Turn Channelization; Climbing Lanes; and Addition of Paved Shoulder and Left-Turn Channelization to Increase Roadway Width. **Chapter 8: Suggested Readings.** This chapter presents an annotated list of material that can supplement the discussions in Chapters 3 to 6 on countermeasures. It is subdivided into reference materials and research reports and/or papers.

Steps:

A **Criteria.** Set criteria for the study. The criteria could include the following:

- Identify areas of interest (e.g., wet pavement crashes only, intersections, roadway segments, driving under influence, etc.).
- Identify region (e.g., urban versus rural area, selected counties, etc.).
- Set minimum number of crashes in a three-year time period.
- Limit to specific roadway type (e.g., interstate only, two-lane highway only, etc.).

A **Crash Data.** Obtain crash data that satisfy the criteria. Three years is the most common time frame. Time frames of less than two years may be necessary, but the smaller sample size may not be representative of conditions at the location and the user may need to adjust for the regression-to-the-mean condition (see NCHRP Synthesis 295 [*10]* for additional information on regression to-the-mean). Several factors are associated with each crash in the database. The analyst may not be interested in all the factors and may want to limit which data fields are pulled. For example, the database includes ADT for several years, and the analyst may only be interested in the ADTs for the years under study. Examples of factors that may be of interest include: collision type, severity of injury, road surface conditions, weather, object struck, traffic control, month, day of week, time of day, light conditions, first harmful event, roadway condition, alignment, curve, number of vehicles involved, other factors, and direction of travel.

A **Summary Report.** Prepare a summary report of the crashes. This report will assist in evaluating whether the crash data satisfy expectations. For example, criteria of 15 minimum crashes in three years may have overly restricted the search and identified less than a desired number of intersections from the crash database. Reducing the minimum number of crashes to a lower value will permit more intersections to be identified as needing treatments.

A **Collision Diagram.** Prepare a collision diagram to identify patterns of crashes. Examples of collision diagrams are contained in several documents including NCHRP Report 440: *Accident Mitigation Guide for Congested Rural Two-Lane Highways* (*2*) and ITE "Traffic Accident Studies" chapter of the *Manual of Transportation Engineering Studies* (*4*).

A **ADT.** Obtain ADT for the roadway segment or the approach volumes for each roadway for the intersections. Calculate crash rates for the roadway segment or intersection.

A **Site.** Select sites for study. The total number of crashes for a roadway section or spot location has been used. In some cases these values are adjusted for volume or compared to the crash data for other related areas (e.g., the entire state, similar size cities, and so forth). Other approaches include: crash severity, number rate, rate quality control, and crash index. Methods for identifying "critical" locations are discussed in the *Accident Mitigation Guide for Congested Rural Two-Lane Highways* (*2*). Related issues are discussed in NCHRP Synthesis 295 (*10*).

A **Crash Narratives.** Request crash narratives from the Department of Public Safety. Compare information from crash database used to produce the summary and collision diagrams with information contained in the narratives. Update as needed.

A Gather Existing Conditions

The initial efforts resulted in a list of preliminary sites. For each site, general information was extracted from the crash database and preliminary collision diagrams were produced. The next step in the process is to gather information on the in-field condition of the sites. Following are suggested steps that can be followed:

Steps:

A **Field Methodology.** Develop a methodology for the field visits. At each location, the review team should perform the following:

- Film a drive-through video of all approaches to record existing conditions from a driver perspective at 85th percentile speeds and during the time of day when crashes are occurring (e.g., nighttime, sunset, when school releases, etc.)
- Draw a condition diagram,
- Take pictures,
- Observe traffic, and
- Note driver behavior.

A **Checklists.** To assist with field operations, three groups of questions or checklists can be used at each site (see Tables 2-2, 2-3, and 2-4).

Table 2-2. Basic Field Observations (2).

Operational Problem Symptoms	Physical Inventory Parameters (supplement construction plans)
A Length of vehicle queues A Erratic vehicle maneuvers A Vehicles experiencing difficulty in making turning movements A Vehicles experiencing difficulty in making merging or weaving movements A Evidence of unreported crashes such as damaged guardrail, skid marks, or tire tracks off of the pavement A Pedestrians on roadway A Pedestrian-vehicle conflicts	A Sight distance restrictions A Pavement and shoulder conditions A Signal visibility A Signs, including speed limits A Curb radii A Pavement markings A Lighting A Driveway locations A Fixed objects and roadside design

Table 2-3. Questions to Consider During the Field Observation (2).

1. Are the crashes caused by physical conditions of the road or adjacent property, and can the condition be eliminated or corrected?
2. Is a blind corner responsible? Can it be eliminated? If not, can adequate measures be taken to warn the motorists?
3. Are the existing signs and pavement markings doing the job for which they were intended? Is it possible they are, in any way, contributing to causes of crashes, rather than contributing to crash prevention?
4. Is traffic properly channelized to minimize the occurrence of crashes?
5. Would crashes be prevented by the prohibition of any single traffic movement, such as a minor left-turn movement?
6. Can part of the traffic be diverted to other thoroughfares where the crash potentialities are not as great?
7. Are night crashes out of proportion to daytime crashes, based on traffic volume, indicating need for special nighttime protection, such as street lighting, signal control, or reflectorized signs or marking?
8. Do conditions show that additional traffic laws or selective enforcement are required?
9. Is there a need for supplemental studies of traffic movement, such as driver observance of existing control devices, speed studies of vehicles approaching the crash location, and others?
10. Is parking in the area contributing to crashes? If so, perhaps reduction of the width of approach lanes or sight obstructions in advance of the intersection resulting from the parking are causing the crashes.
11. Are there adequate advance warning signs of route changes so that the proper lanes may be chosen by approaching motorists well in advance of the area, thus minimizing the need for lane changing near the crash location?

Table 2-4. On-Site Observation Report (2).

ON-SITE OBSERVATION REPORT

LOCATION____ CONTROL________

DATE_________________________ TIME_____________

OPERATIONAL CHECKLIST:

	NO	YES
1. Do obstructions block the drivers' view of opposing vehicles?	___	___
2. Do drivers respond incorrectly to signals, signs, or other traffic control devices?	___	___
3. Do drivers have trouble finding the correct path through the locations?	___	___
4. Are vehicle speeds too high? Too low?	___	___
5. Are there violations of parking or other traffic regulations?	___	___
6. Are drivers confused about routes, street names, or other guidance information?	___	___
7. Can vehicle delay be reduced?	___	___
8. Are there traffic flow deficiencies or traffic conflict patterns associated with turning movements?	___	___
9. Would one-way operation make the location safer?	___	___
10. Is this volume of traffic causing problems?	___	___
11. Do pedestrian movements through the location cause conflicts?	___	___
12. Are there other traffic flow deficiencies or traffic conflict patterns?	___	___

PHYSICAL CHECKLIST:

	NO	YES
1. Can sight obstructions be removed or lessened?	___	___
2. Are the street alignment or widths inadequate?	___	___
3. Are curb radii too small?	___	___
4. Should pedestrian crosswalks be relocated? Repainted?	___	___
5. Are signs inadequate as to usefulness, message, size, conformity, and placement? (See *MUTCD*)	___	___
6. Are signals inadequate as to placement, conformity, number of signal heads, or timing? (See *MUTCD*)	___	___
7. Are pavement markings inadequate as to their clearness or location?	___	___
8. Is channelization (island or paint markings) inadequate for reducing conflict areas, separating traffic flows, and defining movements?	___	___
9. Does the legal parking layout affect sight distance, through or turning vehicle paths, or traffic flow?	___	___
10. Do speed limits appear to be unsafe or unreasonable?	___	___
11. Is the number of lanes insufficient?	___	___
12. Is street lighting inadequate?	___	___
13. Are driveways inadequately designed or located?	___	___
14. Does the pavement condition (potholes, washboard, or slick surface) contribute to crashes?	___	___

Comments____

A **Consolidation.** Consolidate information gathered from different techniques. Request additional information as needed. For example, the date that a driveway to a high-volume convenience store was open or the date a signal was installed may be needed to determine if one of those events could have had an impact on a crash trend at a location.

A **Findings.** Compare findings from the field, information in the crash narratives obtained from the Department of Public Safety, and information from the crash database used to produce the summary and collision diagrams. Update collision diagram as needed.

A **Additional Field Studies.** Determine if additional field studies are needed.

A Collect Additional Field Data

The previous efforts have identified potential trends; however, additional information may be needed to better define the condition at the site. Table 2-5 lists supplemental traffic studies that would further define the nature of operational or safety problems, isolate the cause of the problem, and help identify appropriate solutions.

Steps:

A Identify field studies that could aid in understanding the conditions at the locations. Suggestions on supplementary studies are listed in Table 2-5.

A Collect the necessary data.

A Reduce data from data collection field visits.

A Add any field measurements or sight distance restrictions to the condition diagrams.

A Potential calculations:

- **Intersection Sight Distance**. The TxDOT *Roadway Design Manual* (*8*) recommends following the procedure presented in the AASHTO *Green Book* (*7*).
- **Stopping Sight Distance**. Follow the appropriate procedure as listed in the TxDOT *Roadway Design Manual* (*8*). The stopping sight distances in the 2001 *Green Book* and the TxDOT *Roadway Design Manual* have recently been revised using findings from NCHRP Report 400 (*11*).
- **Multiway Stop Warrant**. The 2003 *Texas MUTCD* (*5*) and the 2000 *MUTCD* (*6*) have procedures for multiway stop warrants.
- **Traffic Control Signal Warrant**. The 2003 *Texas MUTCD* (*5*) and the 2000 *MUTCD* (*6*) include procedures for traffic signal warrants.
- **Left-Turn Bays**. The TxDOT *Roadside Design Manual* contains information on left-turn bay design (*8*).

Table 2-5. Supplementary Engineering Studies (2).

Supplementary Study	Purpose of Study	Symptom of Operational Study Problem That Indicates Study Needed
Capacity Studies	To determine operating condition and pinpoint bottlenecks	A Congestion and delays
Travel Time and Delay Studies	To determine location and extent of delay and average travel speeds	A Intersection congestion A Other congestion along roadway A Rear-end crashes during peak periods
Speed Studies	To determine actual vehicle speeds, actual speed profiles, and adequacy of legal and advisory speed limits	A Extremely high or low speeds observed during on-site visits A Run-off-road crashes A Rear-end crashes near intersections
Traffic Conflict and Erratic Maneuver Studies	To supplement traffic crash data and identify potential crash problems	A Hazardous driver actions observed during on-site visits A Public complaints of safety problems not evident in crash data
Traffic Signal Studies	To determine need for and design of traffic signals, to identify improper phasing, timing, or interconnect strategy, and to identify unwarranted signals	A Right-angle crashes at unsignalized intersections A Excessive delay at Stop sign controlled intersections A Excessive delay at existing signalized intersections
Sight Distance Studies	To determine adequacy of the length of highway visible to the driver	A Rear-end crashes at horizontal curves, crest vertical curves, or decision points A Right-angle crashes at uncontrolled intersections A Turning crashes at intersections
Turning Radius Studies	To determine adequacy of existing curb radii	A Sideswipe crashes involving vehicles traveling in opposite directions A Rear-end crashes in right-turn lanes A Evidence of large vehicles encroachment on curb or shoulder
Skid Resistance Studies	To determine the coefficient of tire-pavement friction	A Run-off-road or skidding crashes under wet-pavement conditions

A Assess Situation and Select Treatments

The next series of steps assesses the condition at the site and selects appropriate safety treatment(s). The following steps outline the process.

Steps:

- A Identify crash patterns and conditions present at the site.
- A Identify potential mitigation measures. Suggested measures for various patterns are contained in Tables 2-6 to 2-9. A safety review team that includes individuals with many different backgrounds is also a common technique used to identify potential safety treatments. The safety review team identifies multiple approaches to address a concern such as both engineering and enforcement, and often involves more than one agency.
- A Select safety treatment(s) for site.
- A If the selected treatment is not included in the *Texas MUTCD* or is not part of TxDOT standards, then a request for experimentation to the TxDOT Traffic Operations Division in accordance with the *Texas MUTCD* is required in order to install the treatment.
- A Complete the Safety Evaluation Report (SER) form and develop attachments if requesting Hazard Elimination (HES) Program funds. The SER form is available in the TxDOT *Traffic Operations Manual* in the Traffic Accident Information and Hazard Elimination Program.

Table 2-6. Potential Countermeasures for Roadway Crashes (2).

TYPE OF ROADWAY CRASH **Contributing Factor** Potential Countermeasure	
LEFT TURNS **Large Volume of Left Turns** Add two-way left-turn lane Add turn bays at selected locations **Restricted Sight Distance** Remove sight obstruction Install or improve warning signs Reduce speed limit if justified by a study Provide turn lane **Excessive Speed** Reduce speed limit if justified by a study **Lack of Adequate Gaps** Provide Stop sign (see *MUTCD*) Improve roadway lighting Provide traffic signal (see *MUTCD*) **RIGHT TURNS** **High Approach Speed** Reduce speed limit if justified by a study Install rumble strips **Roadway Design** Increase curb radii Install acceleration or deceleration lane **REAR END** **Driver Not Aware of Intersection** Install/improve warning signs Reduce speed limit if justified by a study **Large Numbers of Turning Vehicles** Create left- or right-turn lanes Prohibit turns Increase curb radii Install acceleration or deceleration lane **Excessive Speed** Reduce speed limit if justified by a study **Inadequate Roadway Lighting** Improve roadway lighting	**SIDESWIPE CRASHES** **(INCLUDING OPPOSITE- AND SAME-DIRECTION SIDESWIPE CRASHES)** **Roadway Design** Widen lanes Provide turn bays Install advance route or street signs Install/improve pavement lane lines Prohibit parking Install median barrier Install rumble strips Upgrade or widen roadway shoulder Provide turn lane Install acceleration or deceleration lane Repair road surface **Inadequate Signing/Marking** Install illuminated street name sign Install advance guide sign Improve or install pavement markings **HEAD-ON CRASHES** **Roadway Design** Widen lanes Provide turn bays Install/improve pavement lane lines Remove parking Install median barrier/rumble strips

Table 2-7. Potential Countermeasures for Roadside Crashes (2).

TYPE OF ROADSIDE CRASH **Contributing Factor** Potential Countermeasure	
RUN-OFF-ROAD CRASHES (INCLUDING FIXED OBJECT, ROLLOVER, AND OTHER RUN-OFF-ROAD CRASHES) **Objects near Traveled Way** Remove obstacles Relocate obstacle away from roadway Install breakaway feature to light poles, signposts, etc. Install guardrail or crash cushioning device Reduce number of utility poles **Roadway Design** Increase recovery distance Flatten sideslopes Install rumble strips Provide proper superelevation Widen lanes Repair road surface Reshape ditch Convert ditch to a closed drainage system Design drainage facility flush with roadside terrain Install or improve warning signs **Shoulder Drop-off** Upgrade shoulder Repair shoulder	**Slippery Pavement** Overlay existing pavement/improve skid resistance Provide adequate drainage Groove existing pavement Reduce speed limit if justified by a study Provide Slippery When Wet signs Widen lane or shoulders **Poor Delineation** Improve/install pavement markings Install roadside delineators Install advance warning signs (e.g., Curves) Install raised pavement markers **Excessive Speed** Reduce speed limit if justified by a study **Inadequate Roadway Lighting** Improve roadway lighting **Poor Traffic Control Device Visibility** Increase sign size Install reflectors on obstruction Use larger letters on sign Illuminate sign Use brighter grade material Add beacons on advance warning signs

Table 2-8. Potential Countermeasures for Intersection Crashes *(2)*.

TYPE OF INTERSECTION CRASH **Contributing Factor** Potential Countermeasure	
<u>**LEFT TURNS**</u> **Restricted Sight Distance** Remove sight obstruction Provide turn lane Prohibit left turns Install or improve warning signs Reduce speed limit if justified by a study **Large Volume of Left Turns at Unsignalized Intersection** Prohibit left turns Reroute left-turn traffic Add turn lane Install Stop signs (see *MUTCD*) Provide traffic signal Provide left-turn signal Increase left-turn bay length or taper length **Large Volume of Left Turns at Signalized Intersection** Prohibit left turns Reroute left-turn traffic Add turn lane Provide left-turn signal Provide adequate channelization Revise signal timing (length, phase sequence, etc.) Provide turning guidelines (if there is a dual left-turn lane) Increase left-turn bay length or taper length **Amber Phase Too Short at Signalized Intersection** Adjust amber phase Provide all-red phase Increase amber phase if signal is located after a downgrade and there is a high percentage of trucks **Absence of Left-Turn Phase at Signalized Intersection** Provide left-turn signal phase Prohibit turns Split phase	<u>**RIGHT TURNS**</u> **Restricted Sight Distance** Remove sight obstruction Restrict parking near corners Install Stop signs (see *MUTCD*) Install/improve street lighting Reduce speed limit if justified by a study Install Yield signs (see *MUTCD*) Provide adequate channelization Provide traffic signal Install or improve warning sign Install or improve pedestrian crosswalk Install stop bars **Short Turning Radii for a Right Turn** Increase curb radii Prohibit right turn on reds Add right-turn indication to signal **Large Total Intersection Volume** Install signals (see *MUTCD*) Add lane Retime signal if signal is present **Inadequate Roadway Lighting** Improve or add roadway lighting **Advance Intersection Warning Signs** Install or improve warning signs Install hazard beacons **High Approach Speed** Reduce speed limit if justified by a study Install rumble strips Adjust amber phase **Signal Timing** Adjust amber phase Provide all-red clearance phases Add multi-dial controller Install signal actuation Retime signals Provide progression through a set of signalized intersections

Table 2-8. Potential Countermeasures for Intersection Crashes (continued) (*2*).

<table>
<tr><th colspan="2"><u>TYPE OF INTERSECTION CRASH</u>
Contributing Factor
Potential Countermeasure</th></tr>
<tr><td><u>REAR END</u>
Pedestrian Crossing
Install/improve signing or marking of pedestrian crosswalks
Relocate crosswalk
Install traffic signal (see MUTCD)
Provide pedestrian “WALK” phase if signal is present
Driver Not Aware of Intersection
Install/improve warning signs
Reduce speed limit if justified by a study
Install hazard beacons
Large Numbers of Turning Vehicles
Create left- or right-turn lanes
Prohibit turns
Increase curb radii
Provide left-turn signal phase if signal is present
Inadequate Roadway Lighting
Improve roadway lighting
Poor Visibility of Signals
Install/improve advance warning devices
Install 12 inch signal lenses (see MUTCD)
Install visors
Install back plates
Improve location of signal heads
Add additional signal heads
Reduce speed limit if justified by a study
Remove sight obstruction
Install overhead signal
Relocate signal
Increase amber phase</td>
<td>Slippery Surface
Overlay pavement
Provide adequate drainage
Groove pavement
Reduce speed limit if justified by a study
Provide Slippery When Wet signs
Improve roadway lighting
Excessive Speed
Reduce speed limit if justified by a study
Inadequate Signal Timing
Adjust amber phase
Provide progression through a set of signalized intersections
Provide all-red phase
Unwarranted Signals
Remove signals (see MUTCD)

<u>RIGHT ANGLE</u>
Inadequate Signal Timing
Adjust amber phase
Provide all-red clearance phases
Add multi-dial controller
Install signal actuation
Retime signals
Provide protective movement phases
Restricted Sight Distance
Provide adequate channelization
Remove sight obstruction
Install or improve warning sign
Install hazard beacons
Prohibit parking
Provide markings to supplement signs</td></tr>
</table>

Table 2-9. Potential Countermeasures for Other Crashes (2).

TYPE OF OTHER CRASH **Contributing Factor** Potential Countermeasure	
PEDESTRIAN **Pedestrians Walking on Roadways** Install sidewalks **Driver Has Inadequate Warning of Frequent Midblock Crossings** Prohibit parking Install or improve warning signs Reduce speed limit if justified by a study Install pedestrian barriers **Excessive Speed** Install or improve warning signs Reduce speed limit if justified by a study Increase enforcement Install pedestrian barrier **Inadequate or Improper Pavement Markings** Install thermoplastic markings Provide signs to supplement markings Improve or install pavement markings **Inadequate Roadways Lighting** Improve roadway lighting **Lack of Adequate Gaps** Provide traffic signal Install or improve pedestrian crosswalk Provide pedestrian signal **Large Turning Volumes** Create left- or right-turn lanes Prohibit turns Increase curb radii Provide pedestrian-only phase if signal is present **Restricted Sight Distance** Remove sight obstructions Install pedestrian crossings Improve/install pedestrian crossing signs Reroute pedestrian paths Restrict parking **Inadequate Protection for Pedestrians** Add pedestrian refuge islands Install pedestrian barrier to channelize pedestrians to a better crossing point	**Inadequate Signals** Install pedestrian signals (see *MUTCD*) **Inadequate Signal Phasing** Add pedestrian “WALK” phase Change timing of pedestrian phase **School Crossing Area** Use school crossing guards **Sidewalk Too Close to Traveled Way** Move sidewalk laterally away from highway **ANIMAL** **High Number of Animal Crashes** Install advance warning sign Install fencing and underpasses to control animals crossing the roadway Install warning reflectors Encourage driver education about local animal behavior **NIGHT** **Poor Traffic Control Device Visibility** Install or improve warning sign Improve roadway lighting Improve or install delineation Install hazard beacons **Inadequate Delineation** Install or improve warning sign Improve or install delineation Provide raised markings **Inadequate Channelization** Install or improve warning signs Improve or install pavement markings Improve or install delineation Provide raised markings **Inadequate Signing** Upgrade traffic control devices Provide illuminated sign

Table 2-9. Potential Countermeasures for Other Crashes (continued) *(2)*.

TYPE OF OTHER CRASH **Contributing Factor** Potential Countermeasure	
DRIVEWAY/ACCESS CRASHES **Left-Turning Vehicles** Provide turn lane barrier Install median Install two-way left-turn lanes Prohibit turn **Improperly Located Driveway** Regulate minimum spacing of driveways Regulate minimum corner clearance Move driveway to side street Install curb to define driveway location Consolidate adjacent driveways **Large Volume of Main Street Traffic** Move driveway to side street Construct a local service road Reroute through traffic Add traffic signal (see MUTCD) **Right-Turning Vehicles** Provide right-turn lanes Restrict parking near driveways Increase the width of the driveway Widen through lanes Increase curb radii Prohibit turn Add acceleration lane **Large Volume of Driveway Traffic** Provide traffic signal Provide acceleration and deceleration lanes Provide adequate channelization **Restricted Sight Distance** Remove sight obstruction Restrict parking near driveway Install/improve street lighting Reduce speed limit if justified by a study Install hazard beacons	**Excessive Speed** Reduce speed limit if justified by a study **Inadequate Roadway Lighting** Improve roadway lighting Regulate minimum driveway spacing **EXCESSIVE SPEED** **High Speeds** Increase conventional enforcement Target specific locations or vehicle types Use speed radar trailers or speed display boards Begin automated enforcement program Implement public relation campaign (perhaps using National Highway Traffic Safety Administration (NHTSA) materials) **High Speeds at Intersections** Install Intersection Ahead warning signs Install Signal Ahead warning signs Install rumble strips on intersection approach **WET PAVEMENT** **Slippery Pavement** Overlay with skid-resistant surface Provide adequate drainage Groove existing pavement Reduce speed limit if justified by a study Provide Slippery When Wet signs **Inadequate or Improper Pavement Markings** Improve or install pavement markings **BICYCLE CRASHES** **Inadequate or Improper Pavement Markings** Improve or install pavement markings Provide signs to supplement markings **Inadequate Roadway Lighting** Improve roadway lighting

Table 2-9. Potential Countermeasures for Other Crashes (continued) (2).

TYPE OF OTHER CRASH **Contributing Factor** Potential Countermeasure	
<u>**WORK ZONE**</u> **Narrow Work Zone Roadway** Widen roadway by moving channelizing device or by using narrower devices Improve reflectivity and delineation of devices Illuminate or reflectorize channelizing devices Increase roadway width by routing traffic onto the shoulder **Insufficient Advance Warning** Move taper upstream to increase sight distance Add arrow board **Drums Rolling into Travel Lane** Replace drums with barricades Increase traffic control device inspection frequency **Too Many Traffic Control Devices in or near Roadway** Provide portable concrete median barriers Increase spacing between devices **Speeds Too High or High Variance in Speeds** Increase design speeds Provide speed enforcement patrols Add advisory speed plates Add rumble strips Use variable message signs **Large Vehicles** Provide truck detours Widen work zone roadway Provide truck detours Increase pavement strength Provide climbing lanes Provide truck detours	**Insufficient Work Zone Traffic Capacity** Provide alternative routes Change work schedule to exclude peak traffic periods Increase capacity by routing traffic onto shoulder Reduce length of work area Install warning area **Poor Work Vehicle Access or Egress to Traffic Stream** Change work vehicle access or egress points Provide flaggers **Improper Flagging Technique** Train flaggers Move flaggers upstream Replace flaggers with signal Provide extra flaggers positioned near the upstream end of vehicle queue **Insufficient Taper Length** Lengthen taper Add arrow board Position arrow board near start of taper Move taper upstream to increase sight distance **Insufficient Acceleration Lane Length** Lengthen taper Install Yield or Stop sign on on-ramp Close on-ramp Build temporary ramp downstream

A Implement and Evaluate

The final element in the process is to implement the selected improvement project and, subsequently, to evaluate its effectiveness. The objective of an effectiveness evaluation is to compare the actual effects of the project with its predicted effects. Feedback from the evaluation of completed projects will enable the anticipated effects of planned projects to be more accurately quantified in the future.

Steps:

A Install treatment(s).

A Evaluate effectiveness. Several sources provide information on conducting evaluation studies including the following:

- NCHRP Report 440: *Accident Mitigation Guide for Congested Rural Two-Lane Highways* (*2*).
- ITE "Traffic Accident Studies" chapter of the *Manual of Transportation Engineering Studies* (*4*).
- *FHWA Highway Safety Evaluation – Procedural Guide* (*12*).
- *FHWA Accident Research Manual* (*13*).
- FHWA Griffin, L. I., and Flowers, R. J. *A Discussion of Six Procedures for Evaluating Highway Safety Projects.* (Unpublished) (*14*).
- Hauer, E. *Observational Before-After Studies in Road Safety* (*15*).
- NCHRP Synthesis 295 (*10*).

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CHAPTER 3
CRASHES ON RURAL TWO-LANE HIGHWAYS

A A A

A Overview

The occurrences of vehicle crashes are quite random and sporadic across the road network. Previous experience suggests that although it is almost impossible to predict when and where on the network a vehicle crash will occur, it is, however, quite predictable as to how many crashes will occur on the entire network in a large area for a relatively long period of time (e.g., one to three years). Borrowing from this experience, in TxDOT Project 0-4048, vehicle crashes were examined at three levels of aggregations: state level, district/county level, and site level.

Before presenting the results of the crash data analysis, it is worth noting that there are concerns over the quality of non-injury and property-damage-only (PDO) crash data, especially high non-reporting rates. Because of these concerns, most analyses in this study were conducted with KAB crashes only. KAB crashes include fatal (K), incapacitating injury (A), or non-incapacitating injury (B) crashes.

In the evaluations, the following questions were explored:

A How often do crashes occur?

A Where do crashes occur?

A What types of crashes occur more often?

A State-Level Analysis

The purpose of the state-level analysis was to understand how low-volume, rural two-lane highways as a type of roadway differ from other types of two-lane roadways in terms of their vehicle crash rates and crash characteristics. Specifically, in this analysis, crashes on six types of two-lane roads were examined. These roads were categorized based on their annual ADT volumes and area type (i.e., rural versus urban). They are:

A Rural two-lane with ADT less than or equal to 2000 (2K) vehicles per day,

A Rural two-lane with ADT between 2001 and 6000 vehicles per day,

A Rural two-lane with ADT greater than 6000 vehicles per day,

A Urban two-lane with ADT less than or equal to 2000 vehicles per day,

A Urban two-lane with ADT between 2001 and 6000 vehicles per day, and

A Urban two-lane with ADT greater than 6000 vehicles per day.

While working with the crash database, researchers determined that crashes at an intersection are **only** assigned to the higher class or higher volume road within the state's database. Therefore, the number of crashes along a long stretch of rural two-lane highway could be undercounted because the crashes at some intersections may not be counted. For this project, crashes were counted once if both roads belong to the same ADT group and counted twice if the intersecting roads belong to different ADT groups (once within each group).

Two-Lane Highway Crash Rates

The KAB crash frequencies, million vehicle miles traveled (MVMT), KAB crash rates, and centerline miles for the six ADT/area type groups are presented in Table 3-1 for the three years from 1997 to 1999. Observations that can be made from the table follow:

A While many more KAB crashes occur on rural two-lane roadways, the crash rates (measured in KAB crashes per million vehicle miles traveled, KAB/MVMT) are higher for the urban groups. The urban groups have a much lower number of centerline miles. For 1999, of the 44,606 KAB crashes in Texas, 31 percent occurred on two-lane highways (13,909) with approximately 75 percent of those crashes occurring in rural areas. The remaining KAB crashes (30,697) occurred on roads with more than two lanes.

Table 3-1. Texas On-System, Two-Lane Highways.

ADT Group		KAB Crashes	MVMT	KAB/100 MVMT	Centerline Miles
1999					
Rural	ADT # 2000	4824	10,561	45.7	45,674
	ADT = 2001 to 6000	4902	12,967	37.8	10,268
	ADT > 6000	2356	6496	36.3	2031
Urban	ADT # 2000	205	197	104.1	446
	ADT = 2001 to 6000	1046	1420	73.7	976
	ADT > 6000	2697	5086	53.0	1114
	All Two-Lane (w/ Crashes Double Count)	16,030	36,727	43.6	60,509
	All Two-Lane (No Crashes Double Count)	13,909			
	All On-System	44,606	141,450	31.5	73,772
1998					
Rural	ADT # 2000	4822	10,587	45.5	45,865
	ADT = 2001 to 6000	4675	12,838	36.4	10,209
	ADT > 6000	2202	6015	36.6	1906
Urban	ADT # 2000	195	211	92.4	478
	ADT = 2001 to 6000	1044	1465	71.3	998
	ADT > 6000	2872	5159	55.7	1112
	All Two-Lane (w/ Crashes Double Count)	15,810	36,275	43.6	60,568
	All Two-Lane (No Crashes Double Count)	13,777			
	All On-System	44,355	138,927	31.9	73,724
1997					
Rural	ADT # 2000	4976	10,744	46.3	46,629
	ADT = 2001 to 6000	4622	12,192	37.9	9711
	ADT > 6000	2210	6008	36.8	1917
Urban	ADT # 2000	202	227	89.0	524
	ADT = 2001 to 6000	1210	1615	74.9	1117
	ADT > 6000	3069	5557	55.2	1218
	All Two-Lane (w/ Crashes Double Count)	16,173	36,343	44.5	61,116
	All Two-Lane (No Crashes Double Count)	14,111			
	All On-System	45,050	131,312	34.3	72,792

- A Each two-lane ADT group in both rural and urban areas in 1999 had KAB crash rates (between 36.3 and 45.7 KAB/100 MVMT for rural and 53.0 and 104.1 KAB/100 MVMT for urban) that were greater than the crash rate for all on-system roadways (31.5 KAB/100 MVMT). An interpretation of the data is to note that a vehicle traveling on two-lane roadways, whether in an urban or rural environment, has a greater likelihood of being involved in a KAB crash per vehicle miles traveled (VMT) than one traveling on a multilane roadway.

- A In terms of centerline miles, rural low-volume roads constitute over 79 percent of the on-system two-lane roads.

- A Within each area type, higher volume roads tend to have lower KAB crash rates due, presumably, to better roadway design. As will be discussed later, higher volume roads have lower percentages of KAB crashes occurring on curves.

- A Urban two-lane roads have significantly higher KAB crash rates than rural two-lane roads. As will be discussed later, this higher crash rate is due, most likely, to a higher number of intersection or intersection-related crashes on higher volume roads.

Two-Lane Highway Crash Characteristics

The characteristics of the KAB crashes for each of the ADT groups were identified for injury severity, and whether they are related to intersection, roadway alignment, horizontal curvature, weather conditions, lighting conditions, pavement wetness conditions, month-of-year, day-of-week, time-of-day, manner of collision, first harmful event, or object struck. These statistics are based on three years of crash records from 1997 to 1999. Following are observations from these distributions:

- A **Injury Severity.** For the KAB crashes, within each area type, higher volume roads tend to have lower percentages of fatal crashes. Rural two-lane roads have significantly higher percentages of fatal crashes than the urban two-lane roads.

A **Intersection, Intersection-Related, and Driveway-Related Crashes.** Urban two-lane roads have considerably higher percentages of intersection, driveway-related, or intersection-related crashes than the rural two-lane roads. For example, urban #2000 ADT had 62 percent while rural #2000 ADT only had 33 percent of intersection, driveway- or intersection-related crashes. High ADT groups have higher percentages of intersection, intersection-related, and driveway-related crashes than the 2K group (e.g., the rural > 6000 ADT had 55 percent intersection, driveway- or intersection-related crashes).

A **Alignment.** Most crashes occurred on straight, level sections (66 to 95 percent of the KAB crashes). The percentages of KAB crashes that occurred on curved, level road sections for each of the ADT groups are: 32, 18, and 9 percent for rural roads and 15, 11, and 5 percent for urban roads. This suggests that the presence and/or the design of horizontal curves is a major roadway factor associated with low-volume roads having significantly higher KAB crash percentages as compared to the higher volume roads. In addition, it suggests that horizontal curves are a major factor that contributes to the higher frequencies of curve-related crashes for rural roads than for the urban roads.

A **Horizontal Curvature.** A larger percentage of KAB crashes occurred on tight horizontal curves (defined as being greater than or equal to 4 degrees) than on larger radius curves. The percentages of KAB for each ADT group for crashes on curves with a degree of curvature of 4 degrees or more were 21, 10, and 5 percent for the rural ADT groups and 11, 9, and 4 percent for the urban ADT groups. This further indicates that the existence of sharp curves on rural low-volume roads is a major factor responsible for the higher KAB crash rates. Previous research has also found that horizontal curves experience a higher crash rate than tangents on rural two-lane highways (*16*).

A **Weather.** For rural roads, higher ADT groups had a slightly higher percentage of crashes that occurred on rainy days (9.5 and 9.4 percent versus 7.2 percent).

A **Lighting Conditions.** Considerably higher percentages of the KAB crashes occurred on dark-no lights roads for rural and for low-volume roads. For roads in rural areas with less than 2000 ADT, 37 percent of the KAB crashes occurred during dark-no lights conditions while only 27 percent of the KAB crashes in the urban low-volume areas occurred under similar lighting conditions.

A **Surface Conditions.** About 14 to 16 percent of all KAB crashes regardless of area type or ADT occurred under wet/muddy/snowy conditions.

A **Month-of-Year.** Crashes occurred quite uniformly throughout the year with May, July, and October having slightly higher percentages of crashes.

A **Day-of-Week.** For rural roads regardless of the ADT groups, more crashes occurred on Friday, Saturday, and Sunday, with Saturday having the highest percentage (about 19 percent). Urban roads are, however, different. Their highest percentage occurs on Friday, lowest generally on Sunday, and the rate is uniform for the rest of the days.

A **Time-of-Day.** The higher percentages of KAB crashes occurred between 3 pm and 7 pm for all development/ADT groups.

A **Manner of Collision/Vehicle Movement.** Low-volume roads have considerably higher percentages of single-vehicle crashes than high-volume roads, and rural two-lane roads have significantly higher percentages of single-vehicle crashes than urban two-lane roads. On rural low-volume two-lane roads, 68 percent of crashes involve a single vehicle while only 40 percent of crashes involve a single vehicle on urban low-volume two-lane roads. At higher ADTs, the percentage for single vehicle drops to 31 percent for rural and 19 percent for urban (two-lane roads with ADT over 6000).

- **First Harmful Event.** For the rural 2K group, about 61 percent of the crashes are either overturned or fixed-object crashes, and the percentages decrease as ADT increases (42 percent for 2001-6000 group and 26 percent for 6000+ group). These percentages are considerably higher than the urban roads in their respective ADT categories (which are 37, 26, and 15 percent, respectively). For urban roadways and higher volume rural roadways (> 2000), the majority of the crashes involved striking another moving vehicle. Only 31 percent of the crashes on rural 2K roads involved striking another moving vehicle.

- **Object Struck.** Rural roads and low-volume urban roads have much higher percentages of tree/shrub, fence, and culvert/headwall crashes. Low-volume urban roads also have a high percentage of utility-pole crashes. For low-volume rural two-lane roads the type of object struck is: no code applicable (50 percent), fence (13.5 percent), tree/shrub (9.7 percent), culvert/headwall (5.0 percent), highway sign (3.7 percent), embankment (2.5 percent), ditch (2.5 percent), other fixed object (2.3 percent), and utility pole (2.1 percent). All other objects had percentages less than 2.

- **Other Factor.** Only 29 percent of the crashes had an "other factor" code used. Codes used were attention diverted (4.1 percent), swerves due to animal (4 percent), moving vehicle entering driveway (3.1 percent), moving vehicle pass on left (2.1 percent), and highway under construction (2.1 percent).

A District/County-Level Analysis

The purpose of the district/county-level analysis was to show spatial patterns of vehicle crashes on the rural low-volume roads. In addition, the statistical characteristics of vehicle crashes were compared between districts that have high crash rates and those that have low crash rates. This district/county-level analysis provided some insights on which types of crashes occurred relatively more often than others and what contributing factors potentially made some districts have higher crash rates than other districts.

Based on the KAB crash rates for on-system, low-volume (less than or equal to 2000 ADT), rural two-lane highways (1992 to 1999), the TxDOT districts were combined into three "rate groups."

A **High-Rate Group:** Atlanta, Austin, Bryan, Dallas, Ft. Worth, Houston, Lufkin, and Tyler;

A **Mid-Rate Group:** Beaumont, Brownwood, Corpus Christi, Paris, Pharr, San Antonio, Waco, Wichita Falls, and Yoakum; and

A **Low-Rate Group:** Abilene, Amarillo, Childress, El Paso, Laredo, Lubbock, Odessa, and San Angelo.

Figure 3-1 shows the location of the rate groups in the state. Observations that can be made with regard to the crash-rate time series include:

A The eight districts in the high-rate group have higher than average crash rates consistently throughout each of the nine years while the eight low-rate districts consistently have below-average rates throughout the same period.

A The high-rate group has crash rates between 0.5 and 0.82 crashes/MVMT. The low-rate group has crash rates between 0.16 and 0.39 crashes/MVMT.

A The overall KAB crash rate was about 0.4 crashes/MVMT. The high-rate group has an average rate of about 2.5 times higher than that of the low-rate group.

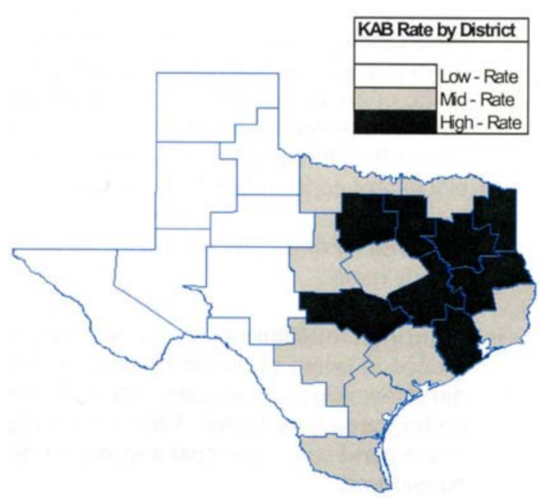


Figure 3-1. Location of Crash Rate Groups in Texas.

Characteristics of Crashes by District Groups

Characteristics of vehicle crashes for the three district groups were identified. These statistics are based on three years of crash records from 1997 to 1999, two-lane, rural, and ADT less than or equal to 2000. Following are the observations from these distributions:

- **Injury Severity.** The low-rate group has a slightly higher percentage of fatal crashes (10.6 percent) than the high-rate group (8.7 percent) and the mid-rate group (9.1 percent).

- **Intersection, Intersection-Related, and Driveway-Related Crashes.** More of the crashes in the low-rate districts were not related to an intersection (73 percent) than in the mid-rate districts (65 percent) and the high-rate districts (65 percent). The high-rate districts have more driveway-related crashes (10 percent) than the mid-rate districts (8 percent) and the low-rate districts (5 percent).

- **Alignment.** Approximately 37 percent of the crashes in the high-rate group occurred on level, horizontal curves. This percentage is much higher than the low-rate group (24 percent) and mid-rate group (31 percent) which indicates that horizontal curves are a major contributing factor to crashes on sites within the high-rate group.

- **Horizontal Curvature.** The majority of crashes **on curves** are occurring on tight curves (greater than or equal to 4 degrees). For the high-rate districts, 25 percent occurred on 4 degree or more curves, 16 percent were on curves of less than 4 degrees, and the remainder were on no curve or unknown. The mid-rate districts also had a similar pattern with 20 percent occurring on 4 degree or more curves, 14 percent on curves of less than 4 degrees, and the remainder on no curve or unknown. The low-rate districts had similar percentages of curves for more than 4 degrees (13 percent) and less than 4 degrees (12 percent). These findings further suggest that the existence of sharp curves is a significant contributing factor on two-lane rural highways.

- **Weather.** For all groups, about 89 percent of the crashes occurred on clear or cloudy days.

- **Lighting Conditions.** There is a very small difference between the different groups in terms of the percentage of crashes that occurred under dark/dawn/dusk conditions. Overall, about 43 percent of the crashes occurred under these conditions. With such a high percentage of crashes occurring in these conditions, low-cost improvements to reduce nighttime crashes should be considered.

- **Surface Conditions.** The high-rate group had a slightly higher percentage of crashes occurring on wet pavement than the low-rate group (14.3 versus 10.1 percent). The low-rate group had a higher percentage of crashes occurring in snowy conditions (3.4 percent) than the high-rate group (0.4 percent) or the mid-rate group (0.9 percent).

- **Month-of-Year.** More crashes occurred in May, July, and October for all groups, with the lowest percentage of crashes occurring in February.

- **Day-of-Week.** More crashes occurred on Friday, Saturday, and Sunday, with Saturday having the highest percentage (over 18 percent for each group).

- **Time-of-Day.** Similar observations can be made as in the Lighting Conditions.

- **Manner of Collision/Vehicle Movement.** All three rate groups have similar distributions.

- **First Harmful Event.** The high- and mid-rate groups had a higher percentage of fixed object crashes (35 and 33 percent) than the low-rate group (25 percent). The low-rate group had a higher percentage of overturned crashes (39 percent) than the other groups (26 percent for high-rate group and 27 percent for mid-rate group). With such a high percent of overturned/fixed object crashes (over 60 percent for each group), improvements to keep the vehicles on the road and maintain vehicle stability both on-road and off-road are critical. The data also show that approximately 4 to 6 percent of the crashes involved an animal as the first harmful event.

- **Object Struck.** The top three types of objects that vehicles struck were tree/shrub, fence, and culvert/headwall. For the high-rate group, the percentages were 13.3, 12.6, and 5.8 percent, respectively, while for the low-rate group, these percentages were 2.6, 13.7, and 4.0 percent, respectively. This finding demonstrates that trees/shrubs are important characteristics of the high-rate group.

- **Other Factors.** The three district groups had similar distributions for the Other Factors category. They reflect the low-volume nature of the roadways. Most of the crashes had no code applicable (70 to 72 percent). Codes that were selected included attention diverted (3.6 to 4.9 percent), swerving to miss an animal (4 percent), and moving vehicle entering driveway (2.1 to 3.5 percent).

Figure 3-2 shows the number of centerline miles by county (averaged over the seven-year period). Figure 3-3 presents KAB crash rates by county (in crashes per 100 MVMT). The darker the shading in Figure 3-3, the higher the crash rate.

The figure illustrates that higher KAB crash rates are present in the eastern portion of the state.

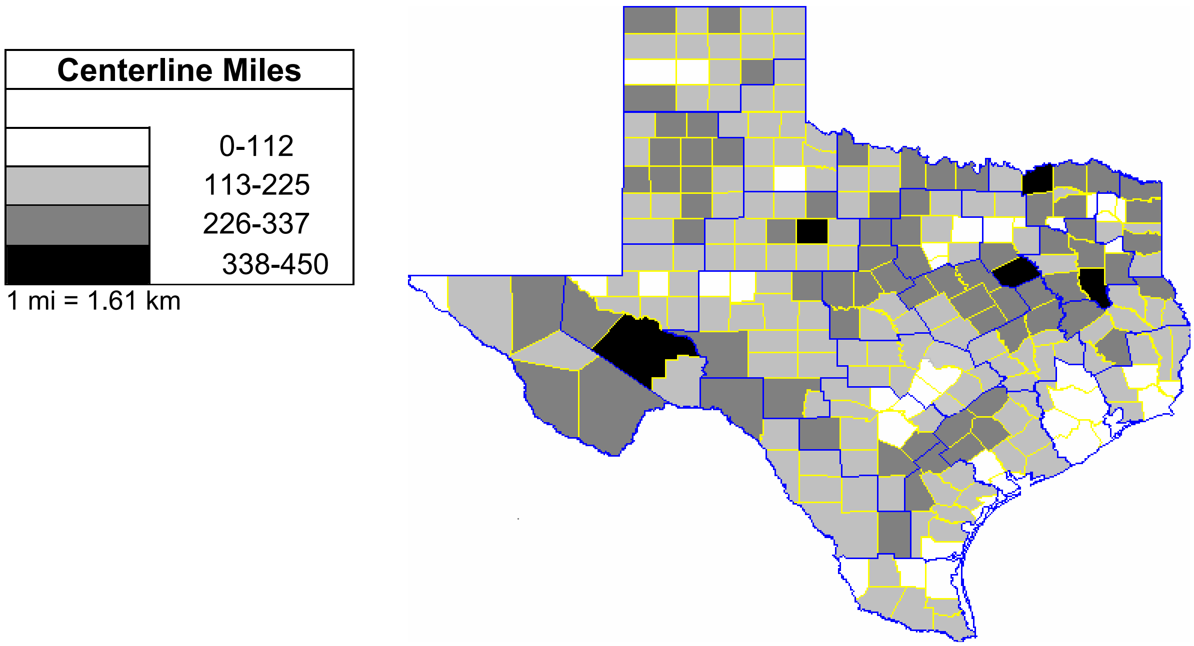


Figure 3-2. Centerline Miles by TxDOT County for On-System, Low-Volume, Rural Two-Lane Highways (average for 1992 to 1999).

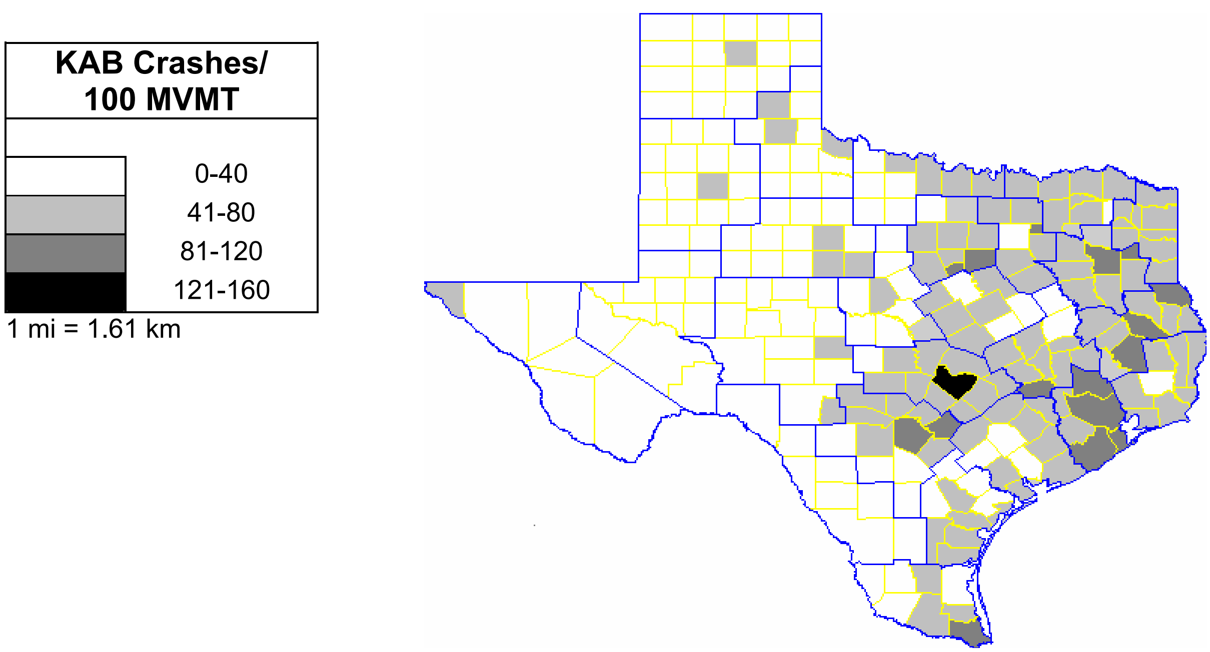


Figure 3-3. KAB Crashes/100 MVMT by TxDOT County for On-System, Low-Volume, Rural Two-Lane Highways (average for 1992 to 1999).

⇒Site-Level Analysis

When the crash rates by county were plotted, a definite pattern of areas with high rates versus areas with lower rates emerged (see Figure 3-3). The counties with the higher crash rates are located in the eastern portion of Texas. With only a few exceptions, most of the lower crash rates were found in west Texas. Known characteristics between east and west Texas that would contribute to this pattern include the pine forests of east Texas versus the deserts of west Texas and the typical cross section and alignment associated with the age of the roads in the areas. Older, rural roads in east Texas are assumed to be narrower and more curvilinear as compared to the rural roads in west Texas. To identify whether these assumptions are valid and to identify if other roadway characteristics are associated with the different regions, a sample of counties was selected to investigate which regional characteristics are associated with high and low crash rates.

Site Identification

Analysis identified two counties with the highest average KAB rates on low-volume, rural two-lane highways for 1992 to 1998: Angelina and Travis. Selecting two western counties with low KAB rates for comparison could result in a county that has a low KAB rate because it only had a few miles that met the less than 2000 ADT criteria. If so, then the difference in KAB rate could be because of the lack of opportunity for a crash (because of the low number of miles) rather than a true difference between the east and west regions. To control for that issue, counties that had a similar number of miles of low-volume, rural two-lane roads to Angelina and Travis Counties were identified. Martin County with 185 miles (297.9 km) of low-volume, rural two-lane roads was matched to Angelina County (189 miles [304.3 km]). Travis County with 22 miles (35.4 km) was matched to El Paso County (35 miles [32.2 to 48.3 km]). Figure 3-4 includes pictures of one of the study sites within each county.

Approximately 20 to 30 miles of roads within each county with the highest number of crashes were identified. The sites were initially identified by highway number and control section. As part of the data collection effort, the research team gathered roadway characteristics for each control section. During the trips to El Paso and Travis Counties, it was determined that significant portions of two of the sites had been expanded to four lanes and/or had ADTs much higher than 2000. Locations with four lanes were removed from the study. Most of the locations with ADTs over 2000 were also removed; although one section in El Paso with an ADT of 4188 vehicles per day was retained so that a similar number of miles would be available between El Paso and Travis Counties.

Martin County

Angelina County

El Paso County

Travis County

Figure 3-4. Samples of Study Sites in Four Texas Counties.

Data Collection

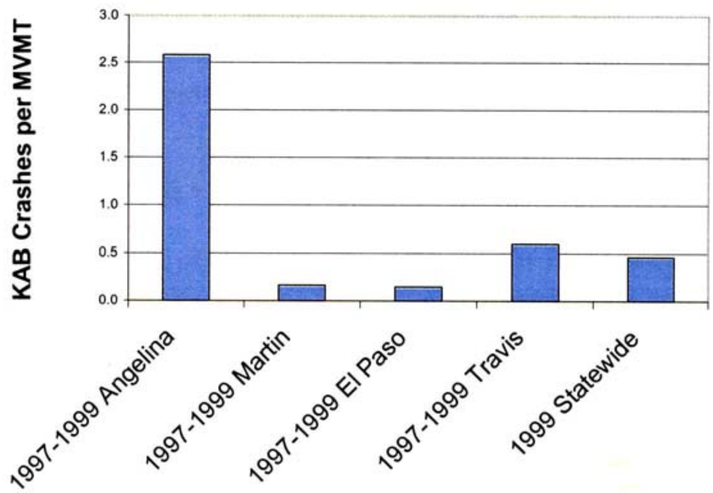
Two primary types of data were collected for this evaluation: site characteristics data and crash record data. TxDOT maintains the crash records for the state using information provided by the Department of Public Safety. These files identify the characteristics of the crashes on the sections identified within the four counties for the three-year period of 1997 to 1999. In order to fully appreciate the characteristics of the sections chosen for evaluation, it was necessary to visit the sections in person and record information about basic features. Data collected included roadside environment, roadside development, number of access points, lane and shoulder width, and other features.

Data Analysis

The crash rates for the control sections driven in the four counties varied from 0.15 in El Paso County to 2.58 KAB crashes per MVMT (0.09 to 1.6 KAB crashes per million vehicle kilometers traveled [MVKMT]) in Angelina County (see Figure 3-5). The selected roads in Angelina County had the most crashes of any of the counties included in the study, with 53 crashes. Travis County had 23 crashes, El Paso

County 8, and Martin County 4. Within the state, 14,742 KAB crashes occurred on rural two-lane highways with less than 2000 ADT from 1997 to 1999 for a crash rate of 0.46 crashes/MVMT (0.29 crashes/MVKMT traveled).

Most of the crashes on low-volume, rural two-lane highways in Texas occur away from intersections. Over 73 percent are coded as being non-intersection crashes. While the sections selected for this study also had most of the crashes coded as non-intersection (between 49 and 65 percent, excluding Martin County), they did have a greater portion coded as being at an intersection (between 25 and 100 percent) when compared to all low-volume, rural two-lane highways in Texas (10 percent).



(1 mi = 1.61 km)

Figure 3-5. KAB Rates for Selected Roadways.

Figure 3-6 shows the distribution of crashes on the roadways within each county. Along with having the majority of the crashes associated with intersections, the selected roadways had more of their crashes involving more than one vehicle and the first harmful event was, in most cases, striking another vehicle. As a group, the sites selected for this study have more intersection- or driveway-related crashes than most low-volume, rural two-lane highways in Texas.

The primary crash type in Angelina County was recorded as colliding with another vehicle; more than half the crashes were of this type. A third of the crashes were fixed-object crashes, and 11 percent involved overturned vehicles. Travis County crashes were divided into the same three primary categories seen for Angelina County, with fixed-object crashes accounting for almost half of the total. All of the crashes in Martin County were collisions between two vehicles. Almost half of the crashes in El Paso County involved fixed objects, with another 38 percent involving collisions between two vehicles. The vast majority (96 percent) of crashes on the selected control sections are in three categories: another vehicle in transport, fixed object, or overturned. Half of the crashes are collisions with another vehicle. The crashes for all Texas low-volume, rural two-lane roads are much more evenly distributed, although 93 percent of them are still in the same three categories as the study sections. Based on those observations it appears that western counties need to emphasize intersection treatments at a similar level as roadway segment treatments, while eastern counties emphasize segment treatments over intersection treatments.

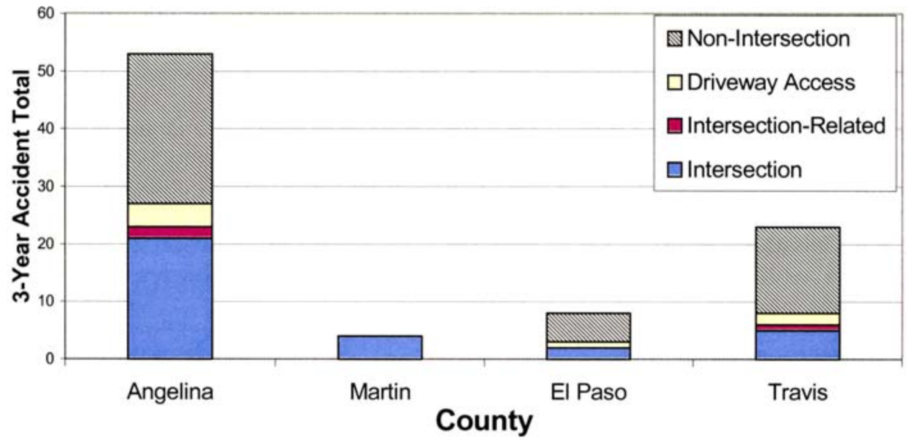


Figure 3-6. Crashes for Roadways by Intersection Influence.

Crashes in the eastern counties occurred on a variety of curves; however, well over half (65 percent) were on sections of roadway with no curve. Western county crashes were predominantly on straight sections of roadway; one crash was on a severe curve, and one was on a section of unknown curvature. The distribution of crashes statewide is similar to that of the eastern counties, with slightly more than half occurring at locations with no curve. This observation indicates that eastern counties should continue their emphasis on addressing safety needs on horizontal curves.

Over half of all control section crashes occurred in daylight hours, reflecting the trend in each individual county except for Martin County which had all four of the crashes occurring during the day. All Texas crashes exhibit a trend similar to that of the control sections, with a little more than half occurring during the day.

Site Characteristics Data

The site characteristics data collected from field visits were entered into a spreadsheet for further examination. The average roadside environment score is based on a five-point scale, used for the area within 2 ft (0.6 m) and within 10 ft (3.0 m) of the paved surface. The scores were assigned based on the most severe obstacle in the area, with values as follows:

1 = No fixed objects within 2 (or 10) ft (0.6 or 3.0 m) of the edge of the paved surface

2 = Yielding objects only (i.e., mailboxes, fence posts, delineators, etc.)

3 = Combination of yielding and isolated rigid objects

4 = Isolated rigid objects only (i.e., utility poles or trees more than 6 inches in diameter)

5 = Many or continuous rigid objects (i.e., tree line, guardrail, stone fence, etc.)

Predominant roadside development was determined by the technicians during data collection; categories included residential, commercial, farmland, trees, and park/school/campus. Lane and shoulder widths were measured in the field, from line to line for each lane and from edge line to edge of paved surface for each shoulder. The number of posted advisory speeds was used as a surrogate for counting horizontal curves; the more advisory speeds and the lower their values, the more winding the road was.

The findings show the following patterns between the eastern counties and the western counties:

A The number of vertical curves per mile are much higher in the eastern counties (1.2 to 2.7 vertical curves/mi [0.75 to 1.68 vertical curves/km]) than the western counties (0.1 to 0.4 vertical curves/mi [0.06 to 0.25 vertical curves/km]).

A The average roadside environment score, particularly within 2 ft (0.6 m) of the roadway has a similar trend—the eastern counties have a higher roadside environment score (1.4 to 5.0) than the western counties (1.0 to 3.0). A roadside environment score of 1 is associated with no fixed objects and a 5 represents many or continuous rigid objects.

A The observed roadside development is quite different between east and west, with farmland being predominant in the west and trees in the east (see Figure 3-4).

A Access density is also very different between east (14.2 to 21.6 access points/mi [8.8 to 13.4 access points/km]) and west (6.9 to 10.2 access points/mi [4.3 to 6.3 access points per/km]), especially when considering only driveway density (12.9 to 18.5 driveways/mi in the east versus 5.1 to 8.2 driveways/mi in the west [8.0 to 11.5 driveways/km in east versus 3.2 to 5.1 driveways/km in the west]).

A Shoulders were much wider, on average, in western counties (4.5 to 5.7 ft [1.4 to 1.7 m]) than eastern counties (0.0 to 1.2 ft [0 to 0.4 m]) as were total pavement widths (26.6 to 41.1 ft [8.1 to 12.5 m] in the west versus 18.0 to 30.5 ft [5.5 to 9.3 m] in the east).

A The number of advisory speeds posted on the study sites were much higher in the east (44 posted) than in the west (7 posted).

Relation of Crashes to Characteristics

Using the observed trends in the crash data and the characteristics data, in general, sites with a higher crash rate have more vertical curves, more horizontal curves, more narrow lanes and/or shoulders, higher access density, a higher average roadside environment score, and a roadside development that can more easily restrict sight distance and that may be more difficult to clear from the roadside.

As an example, Angelina County had the highest crash rate and the highest number of intersection crashes of the four counties studied. Sections in Angelina County had the most narrow lane widths, no shoulders, and the highest access densities (driveway, roadway, and combined). Conversely, Martin County had the lowest crash rate of the four counties; Martin County sections had the widest lanes and shoulders, the lowest access densities, the lowest number of vertical curves per mile, and no advisory speeds for horizontal curves.

Emphasis areas for the different regions of Texas include the following:

A Western counties need to emphasize intersection treatments at a similar level as roadway segment treatments, while eastern counties need to emphasize segment treatments over intersection treatments.

A Eastern counties should continue their emphasis on addressing safety needs on horizontal curves.

A Eastern counties should also continue their efforts on widening their roadways (lane and shoulders).

A Summary and Findings

This study found the following answers to questions asked regarding crashes on low-volume rural highways:

A How often do crashes occur?
In 1999, there were 45.7 KAB crashes/100 MVMT (28.4 KAB crashes/100 MVKMT) on low-volume, rural two-lane highways. For all on-system roads, the rate was 31.5 KAB/100 MVMT (19.6 KAB/100 MVKMT). For 1999, of the 44,606 KAB crashes in Texas, 31 percent occurred on two-lane highways with approximately 75 percent of those crashes occurring in rural areas. Approximately 11 percent of all KAB crashes in Texas in 1999 occurred on low-volume (# 2000 ADT), rural two-lane highways.

A Where do crashes occur?
More KAB crashes occurred in eastern counties (see Figure 3-3) than western counties. In general, sites with higher crash rates have more vertical curves, more horizontal curves, more narrow lanes and/or shoulders, higher access density, a higher average roadside environment score, and a roadside development that can more easily restrict sight distance and that may be more difficult to clear from the roadside.

A What types of crashes occur more often?
In general, crashes on low-volume, rural two-lane highways occur between intersections, by a single vehicle running off the road and then overturning, or striking a fixed object (fence, tree/shrub, culvert). Crashes on curves (level) and in dark, no-light conditions are more common on low-volume, rural two-lane highways than on urban roads.

Based upon the findings from the comparison of the crashes at the state and district levels, the following are key directions a district may want to pursue when considering various types of low-cost improvements:

A Treatments that either decrease the number of vehicles leaving the roadway, especially on tight horizontal curves, or that better communicate the nature of the curve;

A Improvements to reduce the number of nighttime crashes;

A Treatments that reduce crashes at driveways; and

A Improvements to minimize severity of crashes if a vehicle leaves the road.

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CHAPTER 4
TREATMENTS USED ON RURAL ROADS

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A Mailout Survey

A mailout survey was conducted to gather information on relatively low-cost safety improvements on low-volume roads within TxDOT Project 0-4048 (*1*). For purposes of this project, low-volume roadways were defined as two-lane roads with an ADT # 2000.

A total of 98 surveys were mailed to: all 25 district engineers in the state of Texas (with copies to forward to the area engineers in each district); district engineers (or the equivalent) in the states of California, Florida, and Washington; and one design engineer in each of the remaining states. Respondents were asked several questions including to check those safety improvements they have installed to address safety concerns on low-volume two-lane roads (by checking the items on the list provided). Texas produced 75 responses while other states offered 49 responses. One of the questions asked the respondents to identify safety treatments that have been installed. The following pages summarize the 124 survey responses received for the question.

Clear Zone Improvements

Upgrading safety appurtenances, removing trees, mowing, flattening side slopes, removing or adding fill around headwalls, and increasing clear zone had high responses from Texas and from other states (see Figure 4-1). One difference between the two groups was that 79 percent of Texas respondents have implemented culvert treatments, while only 30 percent of other state respondents checked this item.

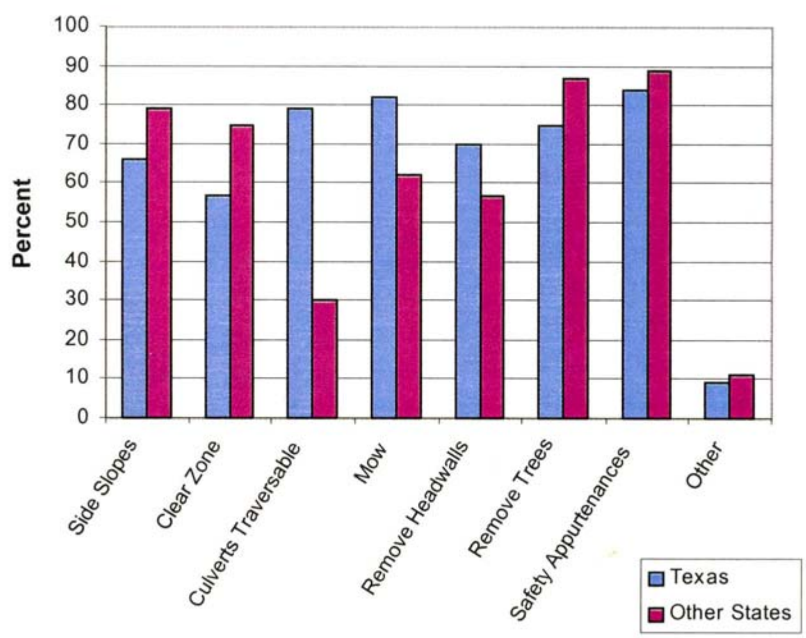

Figure 4-1. Clear Zone Improvements.

The "Other" responses to this category included adding shoulders, moving metal beam guard fence further from the edge line, providing safety lighting at intersections, trimming trees and brush, closing drainage to eliminate ditch lines, relocating utility poles, delineation of trees and utility poles, removing fixed objects, improving access location and sight distance, and adding guardrail.

Wildlife Control

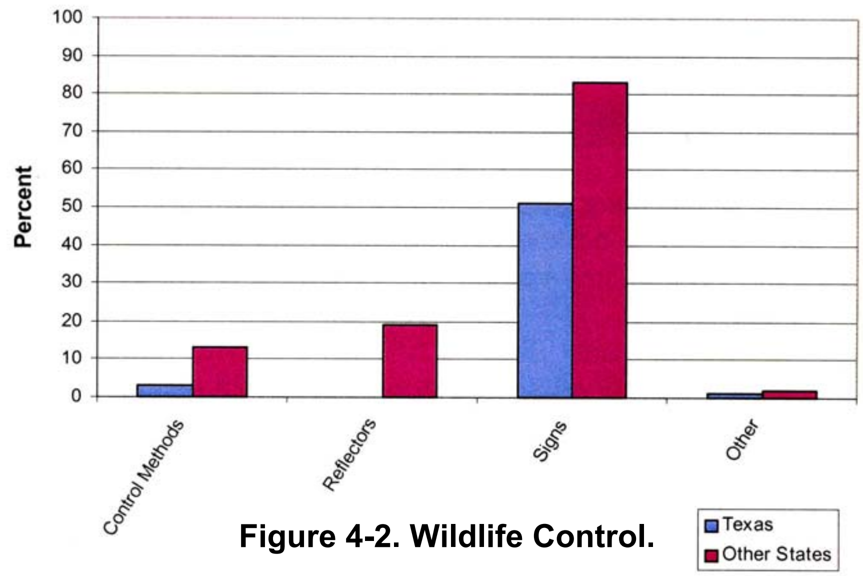

Figure 4-2. Wildlife Control.

Signs to alert drivers of wildlife are more widely used in other states (83 percent); only 51 percent of the Texas responses indicated that signs are used (see Figure 4-2). Also, 19 percent of other states use reflectors to alert wildlife of approaching vehicles, and none of the Texas respondents reported using this measure.

The "Other" responses to this category included adding culvert crossings as well as providing horse and duck crossings.

Additional Lane Improvements

Texas and other states' responses for the use of left-turn lanes, right-turn lanes, and two-way left-turn lanes were very similar (see Figure 4-3). However, other states use climbing lanes (47 percent versus 17 percent) and passing lanes (34 percent versus 18 percent) more frequently than Texas respondents.

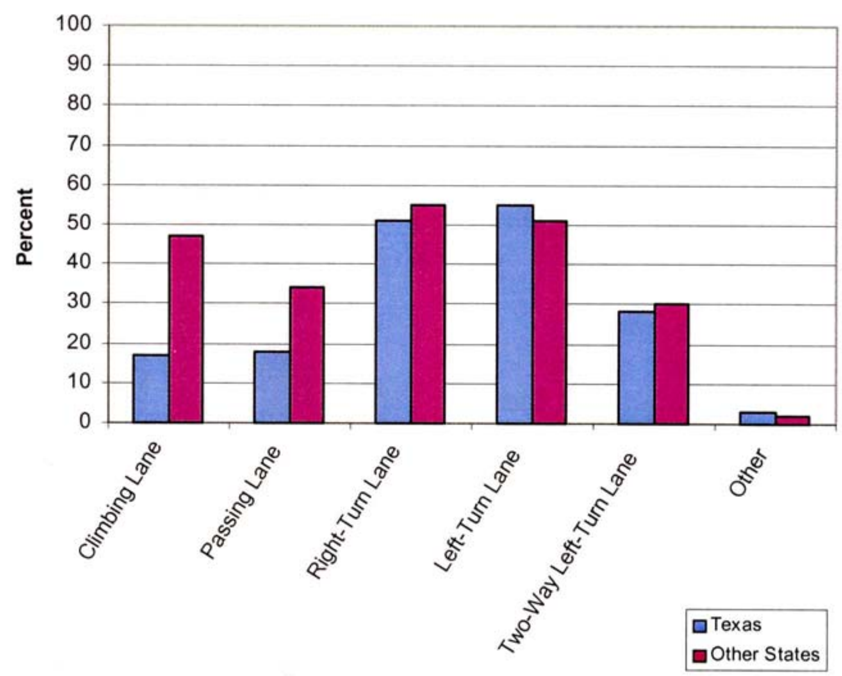

Figure 4-3. Additional Lane Improvements.

The “Other” responses to this category included: providing deceleration lanes at private drives with high ADTs (i.e., plants and stockyards); adding wider shoulders where driveways, mailboxes, or intersections are frequent enough that a large number of vehicles are entering or exiting the travel way; and using slow-moving vehicle turnouts in areas with poor passing opportunities and high recreational vehicle (RV) use.

Pavement Surface Treatments

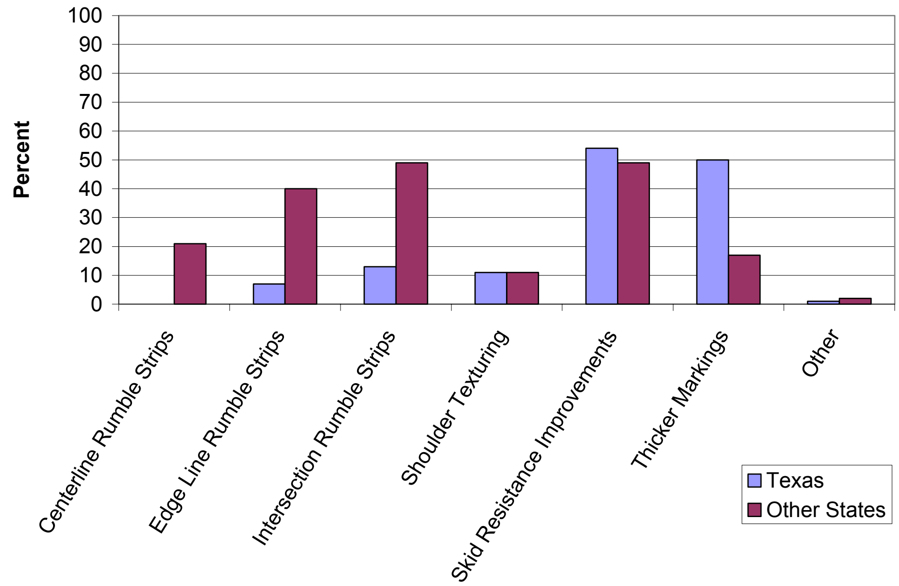

Figure 4-4. Pavement Surface Treatments.

Texas and other state respondents indicated similar uses of skid resistance improvements and shoulder texturing (see Figure 4-4). However, Texas has a much higher usage of thicker thermoplastic pavement markings than other states (50 percent versus 17 percent). Other states had a much higher usage of centerline rumble strips (21 percent versus 0 percent), edge line rumble strips (40 percent versus 7 percent), and rumble strips on approaches to intersections or horizontal curves (49 percent versus 13 percent).

The “Other” responses to this category included using larger glass beads and paved shoulders.

Pavement Markings

Texas and other states listed similar usage for adding on-lane pavement markings (PM), adding edge lines, adding retroreflective pavement markings (RPM), and reapplying existing pavement markings because they have faded (see Figure 4-5). Other states’ respondents use wider edge line markings more frequently than Texas respondents (19 percent versus 5 percent). Texas respondents use three treatments more frequently than other state respondents: oversized glass beads (29 percent versus 17 percent), raised pavement markers on centerlines or edge lines (75 percent versus 51 percent), and removing existing buttons to convert to guidance markings (37 percent versus 11 percent).

The "Other" responses to this category included using pavement marking rumble strips and using edge line striping regardless of the roadway width.

Sign Improvements

Texas and other state respondents listed similar use of advance signing for horizontal curves, advance signing for Stop signs, delineators, diamond grade sheeting at restricted width bridges, flashing beacons on stop signs, flashing beacons on warning signs, high-intensity strobes in advance of curves, and in-rail reflectors for guardrail and bridge rail (see Figure 4-6). Texas respondents indicated more use of flags on Stop signs than other state respondents (22 percent versus 13 percent) and of reflective corner caps of contrasting color on signs (12 percent versus 2 percent). Other state respondents indicated more use of diamond grade chevron signs at curves than Texas respondents (53 percent versus 36 percent).

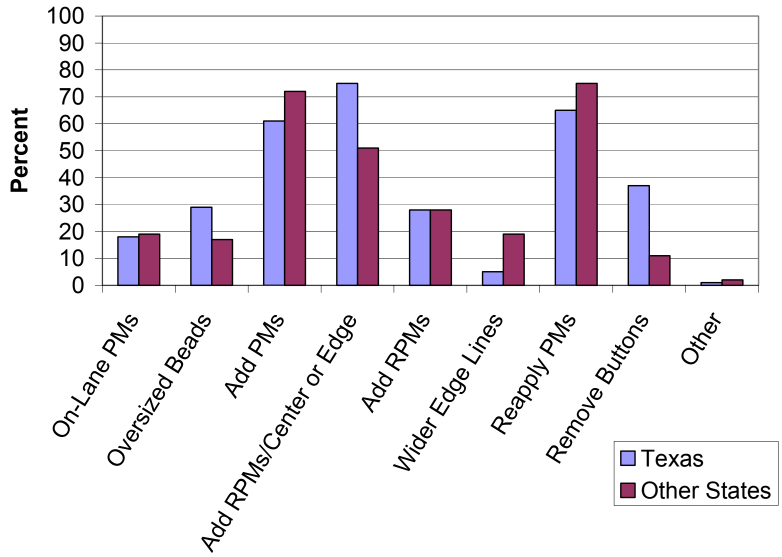

Figure 4-5. Pavement Markings.

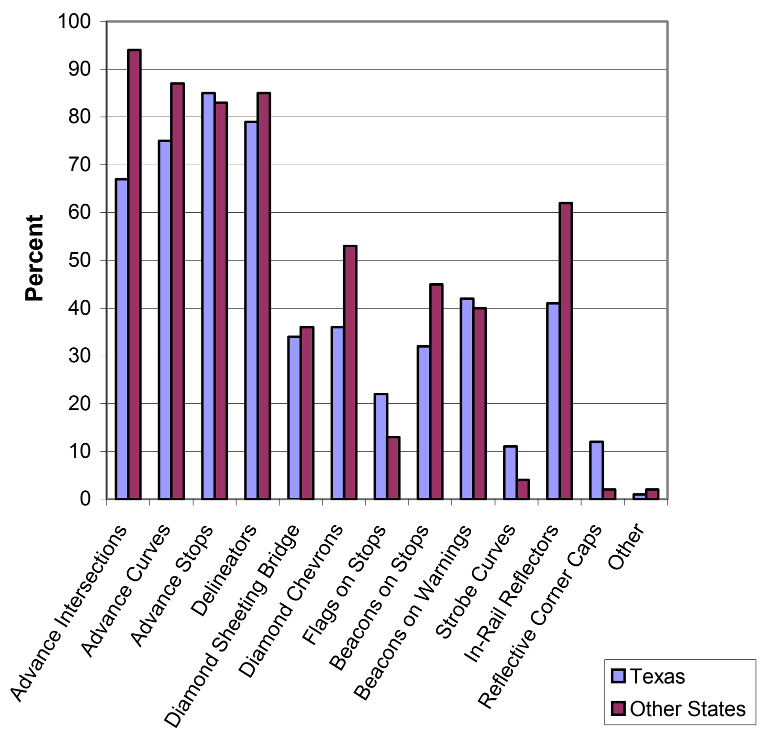

Figure 4-6. Sign Improvements.

The "Other" responses to this category included installing signs at intersections (W-10) and adding "orange mouse ears" on signs.

Signal Improvements

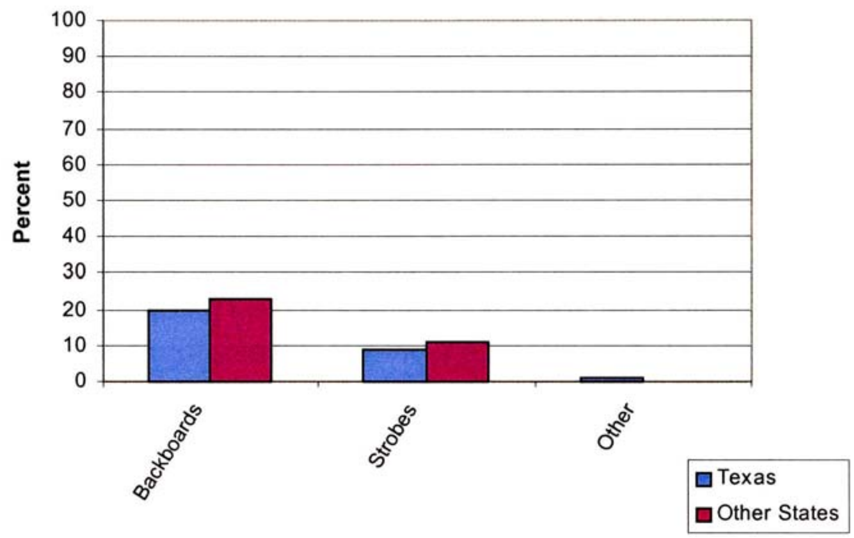

Figure 4-7. Signal Improvements.

Texas and other state respondents indicated similar uses of backboard for traffic signals and for high-intensity strobes in traffic signals (see Figure 4-7).

The "Other" response to this category included replacing loops in the pavement with video detectors.

Other Improvements

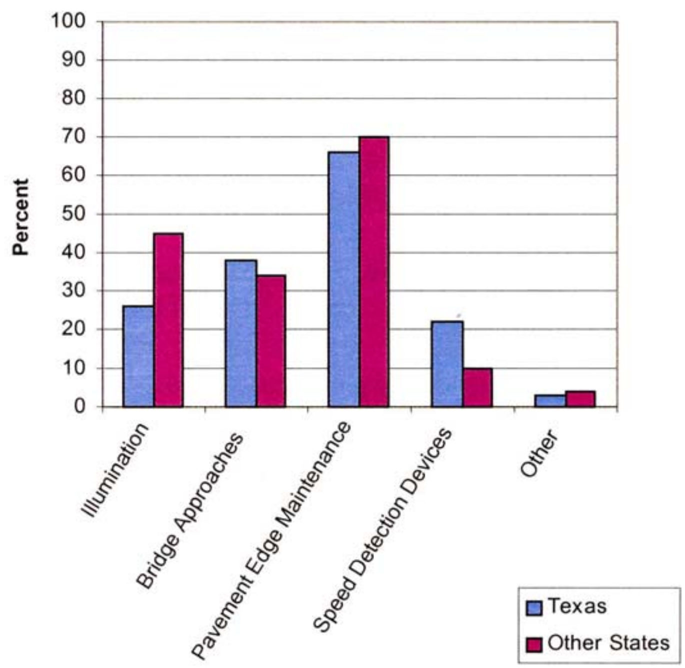

Figure 4-8. Other Improvements.

Texas and other states indicated similar uses of improving or standardizing approaches to narrow bridges and increasing pavement edge maintenance (see Figure 4-8). However, Texas respondents indicated more use of speed detection and notification devices (22 percent versus 11 percent), and other states indicated more use of illumination (45 percent versus 26 percent).

The "Other" response to this category included rumble strips, lane widening, guardrails, roadway geometry, and providing a 2-ft paved shoulder.

A Interviews

Meetings were held with representatives from several districts. Key items discussed include the following:

- **Hazard Elimination for Safety.** Each district participates in the HES program. The basic objective of the HES program is to reduce the number and severity of crashes. The districts prepare a Safety Evaluation Report form for each proposed highway safety project. These forms are submitted to the Traffic Operations Division who ranks the projects using the Safety Improvement Index and selects those approved for funding. In the FY 2005 HES Program the funding level was approximately $36 million. The funds available within the HES program provide for the majority of the safety treatments implemented within a district. Both rural and urban locations are considered within the HES program. One representative noted that rural two-lane low-volume roads may be at a disadvantage in funding competitions because the formula has ADT as a variable.

- **Safety Review Committee.** The Odessa District has a formal review committee that reviews every fatal crash. As part of the review, it obtains information on other crashes at the site and visits the site. The committee includes representatives of other public agencies such as the Metropolitan Planning Organization. They are encouraged to "think outside of the box" when identifying treatments. El Paso also mentioned its Safety Review Committee as a mechanism for improving safety within the district. The committee reviews plans for safety concerns at 30, 60, and 90 percent completion on large projects and once on smaller projects.

- **Identify Locations.** Potential locations are generally identified from either a district employee's knowledge of the roadway system or from complaints made to an area office or the district. Locations are rarely identified by using the crash database to identify intersections or roadways with high crash numbers or high crash rates. An exception to this is the annual wet weather review that is performed to identify locations with a high number of wet weather-related crashes.

- **Identify Treatments.** Treatments for a site are determined either based upon an engineer's judgment after reviewing the crash pattern or within a brainstorming session of a safety review committee. The recommendations are reviewed by others within the department as plans are being developed or as the SERs are being completed. Sources for ideas on treatments include: previous experience within the district, treatments being used in other districts (either from driving in other districts or conversations at meetings like the Transportation Short Course), findings from research studies, and suggestions from vendors.

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CHAPTER 5

TREATMENTS FOR RURAL HIGHWAYS

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A Treatments

This chapter discusses the following treatments:

A Rumble Strips,
A Passing Improvements,
A Two-Way Left-Turn Lanes,
A Lane or Shoulder Widening,
A Pavement Edge Drop-Off Improvements,
A Pavement Markings,
A Mowing,
A Skid Resistance Improvements,
A Side Slope Flattening,
A Recovery Distance Improvements,
A Tree Mitigation,
A Culvert Modifications,
A Advance Warning for Horizontal Curves,
A Delineation,
A Barrier Reflectors, and
A Animal Countermeasures.

A Rumble Strips

Overview	A rumble strip is a longitudinal design feature installed on a paved roadway shoulder near the travel lane. It is made of a series of indented or raised elements intended to alert drowsy or inattentive drivers through vibration and sound that their vehicles have left the travel lane.
Effectiveness	Research has found that **shoulder rumble strips** are an effective countermeasure to reduce run-off-road crashes. There are reports of between 15 to 70 percent reductions. Evaluation of **centerline rumble strips** has also found reductions in crashes.
Relative Cost	Low

Overview

Rumble strips warn motorists that they are leaving or about to leave the lane (see Figure 5-1). Specific concerns that affect the design of rumble strips and the locations where rumble strip installation is appropriate include: placement, weather, degradation of the pavement, type of pavement, pavement thickness, pavement overlay, noise, maintenance, motorist concerns, bicyclist concerns, motorcyclist concerns, and potential for increase in head-on crashes caused by drivers overreacting to the edge line rumble strip on a two-lane highway. Figure 5-2 contains examples of thermoplastic profile markings.

Effectiveness

Shoulder rumble strips (SRS) have proven to be an effective method for warning drivers that they are leaving, or about to leave, the roadway. Studies show that shoulder rumble strips are effective against run-off-road (ROR), fixed object, and rollover type crashes (*17*). Nationwide, ROR crashes account for approximately one-third of all traffic fatalities, with about two-thirds of these ROR fatalities occurring in rural areas.

Figure 5-1. Example of Edge Line Rumble Strips (*2*).

It has been estimated that 40 to 60 percent of these crashes are due to driver fatigue, drowsiness, or inattention (*18*).

Research shows that shoulder rumble strips are an effective countermeasure to reduce ROR crashes. Following is a summary of some of the findings:

A A 1985 FHWA study (*18*) included a detailed analysis of 10 sites. ROR crashes decreased by 20 percent while rates on comparable control sites increased by 9 percent.

Figure 5-2. Examples of Thermoplastic Profile Markings.

A Rumble strips are estimated to reduce the rate of ROR crashes between 15 and 70 percent on the FHWA website *Rumble Strips* (*19*).

A Data from the New Jersey Turnpike show a 34 percent drop in ROR-type crashes after installing shoulder rumble strips—at a time when overall crash rates increased by more than 11 percent (*20*).

A The Pennsylvania Turnpike also saw a decrease in ROR crashes on its multilane facilities as reported in a 1997 publication. Reductions of about 100 crashes per year are attributed to the rumble strips (*21*).

A Caltrans conducted an evaluation of the safety effects of continuous shoulder rumble strips (CSRS) on asphalt shoulders (*22*) for seven projects representing approximately 135 mi (217.4 km) of rural freeway in desert regions. The locations were described as having extremely monotonous driving conditions. The ROR crash rate was reduced by 49 percent in the year following installation.

A A 1998 study (*23*) compared total run-off-road crashes before and after the installation of CSRS and produced substantial results. ROR crashes went from approximately 570 per year to 120 per year.

A A 1999 study by Griffith (*24*) extracted data from California and Illinois and estimated the safety effects of continuous rolled SRS on freeways. The results from the analysis estimated that CSRS reduced single-vehicle ROR crashes on average by 18.3 percent on all freeways (with no regard to urban/rural classification) and 21.1 percent on rural freeways.

FHWA provided the data in Table 5-1 as a summary of the associated crash reductions for shoulder rumble strips.

Table 5-1. Shoulder Rumble Strips Studies and Associated Crash Reductions (*18*).

State (date)	Roadway Type	Percent Crash Reduction
Massachusetts (1997)	Turnpike, Rural	42
New Jersey (1995)	Turnpike, Rural	34
Washington (1991)	Six Locations	18
Kansas (1991)	Turnpike, Rural	34
FHWA (1985) – includes Arizona, California, Mississippi, Nevada, and North Carolina	Five States, Rural	20

The benefit-cost ratio for rumble strips has been estimated in two recent studies. A 1999 report (*24*) offers benefit-cost assumptions based on the reduction of crashes and the total cost of a single run-off-road crash. In this comparison, it is estimated that an average cost of $62,200 is prevented every three years based on an investment of $217. A 1998 analysis (*23*) compared the estimated cost of rumble strips including installation, maintenance, and protection of traffic and the cost of fatal, non-incapacitating, and property damage crashes on 486 mi (783 km) of New York Thruway. The results, based on reduction of crashes and a six-year estimated maintenance-free life, showed a benefit-cost ratio of 182 and a yearly savings of $58,893,500.

In addition to using edge line rumble strips on two-lane rural highways, some states are also installing centerline rumble strips as a treatment to reduce the number of head-on collisions. A FHWA Technical Advisory (*17*) stated that "some states have installed milled centerline rumble strips on two-lane roads having a history of head-on and opposite-direction sideswipe crashes. Most of these installations have consisted of transverse grooves extending across the double yellow centerline and the space between them. Initial evaluation efforts have shown reductions in the types of crashes that centerline rumble strips address." NCHRP 440 (*2*) reported on three sites where both edge line and centerline rumble strips are being used. A summary of those three sites follows:

A An increase in the number of fatal crashes on a state route in California in 1995 generated concerns from the local community and elected officials. Both centerline and edge line rumble strips were installed as part of the project. A feature of the treatment included markers in the center of the roadway in passing sections to provide audible warning to motorists crossing the center of the road. The installation of the pavement treatments was completed in November 1996. The estimated cost of the work in January 1996 was $789,000. Fewer crashes per month occurred on the 23.5 mi (37.8 km) segment in the 25 months after installation as compared to the 34 months in the before period. An average of 4.5 crashes occurred per month in the before period and 1.9 crashes per month occurred in the after period. In the before period, 10 crashes resulted in fatalities while the after period included only one fatal crash.

A The rumble strip work on a principal highway was completed in the fall of 1995 at a cost of $54,000. Approximately 15 mi (24.2 km) were treated. The department of transportation (DOT) completed a two-year before and two-year after study of the crashes within the rumble strip areas. Crashes were reduced between 40 and 50 percent; however, there does not appear to be a significant crash reduction attributed to the installation of the rumble strips (e.g., most of the reduction in crashes occurred in the "other" category rather than in the "off road - right" category).

A Previous investigation into the crash characteristics of a high-volume commuter route showed that several of the crashes were opposite-direction crashes, which suggests that they occurred because of passing maneuvers. The roadway generally has 12-ft (3.7 m) lanes and 8-ft (2.4 m) (or greater) shoulders with signals and left-turn bays at selected intersections. The DOT selected centerline rumble strips along with lane striping and guardrail installation as the countermeasures due to the high number of opposite direction crashes. These treatments were viewed as an interim measure until sufficient funding was available for widening the highway. The work was performed by the maintenance personnel for an approximate 10-mi (16.1 km) section and was completed in September 1995 (see Figure 5-3). A crash reduction of 23 percent was experienced in the year following the treatment installation with most of the reduction occurring because of a decrease in rear-end crashes.

Figure 5-3. Examples of Centerline Rumble Strips.

A Passing Improvements

Overview	Strategies used to provide for passing opportunities include passing lanes, climbing lanes, short four-lane sections, turnouts, and shoulder use.
Effectiveness	Passing improvements have been found to reduce total crashes between 25 and 40 percent.
Relative Cost	Moderate

Overview

The following are strategies for adding passing opportunities to a basic two-lane highway to improve operations and safety:

A Passing lanes (see Figure 5-4),

A Climbing lanes,

A Short four-lane sections,

A Turnouts, and

A Shoulder use sections (i.e., shoulders are used as driving lanes).

Figure 5-5 illustrates the above treatments.

Figure 5-4. Example of Passing Lane.

Effectiveness

Table 5-2 summarizes the results of a study that examined how sections of highways where the above mentioned countermeasures were implemented compared to adjacent "untreated" two-lane highway sections. Reductions in crash frequencies of 25 to 40 percent were reported for passing lanes, short four-lane sections, and turnout lanes (*25, 26*). Note that these reductions are based on sites that carried predominantly higher traffic volumes than average two-lane sections. Thus, the reductions shown in Table 5-2 may not apply to low-volume two-

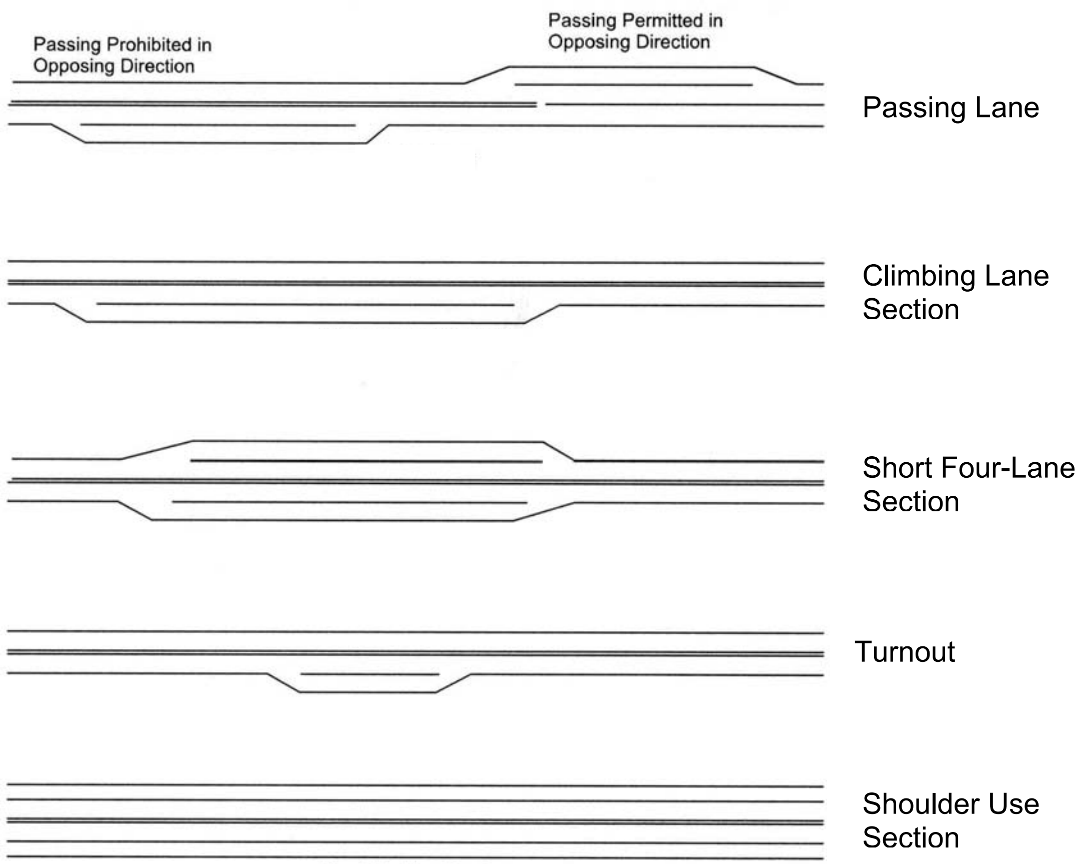


Figure 5-5. Typical Operational Treatments Used on Two-Lane Highways (*25*).

lane roads. The reader should use caution regarding the crash effects of these design alternatives because crash experience may vary widely depending on the specific traffic and site characteristics. In addition, not all of these alternatives are appropriate for all possible roadway sections. Also, while such alternatives may reduce some safety and operational problems, other problems may be created in some cases. More detailed guidelines for optimal use of these design alternatives are given in an *Information Guide* by Harwood and Hoban (*25*).

Table 5-2. Crash Reductions Related to Design Alternatives, as Compared to a Basic Two-Lane Road Design (*25, 26*).

Design Alternative	Type of Area	Percent Reduction in Crashes [a]	
		Total Crashes	F + I Crashes [b]
Passing lanes	Rural	25	30
Short four-lane section	Rural	35	40
Turnouts	Rural	30	40
Shoulder use section	Rural	(c)	(c)

Notes:
[a] These values are only for two-lane roads in rural or suburban areas.
[b] F + I = fatal plus injury crashes
[c] no known significant effect

A Two-Way Left-Turn Lanes

Overview	Two-way left-turn lanes (TWLTLs) are paved areas in the highway median marked to provide a deceleration and storage area for vehicles traveling in either direction to make left turns into intersections and driveways.
Effectiveness	A 1995 study found that the number of crashes at candidate rural TWLTL sites is small, but TWLTLs can reduce these crashes by up to 85 percent.
Relative Cost	Moderate

Overview

Urban and suburban arterial streets with commercial developments have used TWLTLs for many years to improve safety and to reduce delays to through vehicles caused by turning traffic. Highway agencies have recently begun to use TWLTLs in rural and urban fringe areas to obtain these same types of operational and safety benefits (see Figure 5-6).

TWLTLs are particularly appropriate at locations where high left-turn volumes are distributed across a range of driveways or intersections and at locations where there is a documented pattern of left-turn crashes spread over several intersections or driveways. Care should be taken not to overuse TWLTLs on two-lane highways because passing is prohibited in TWLTL sections. If used in areas with minimal development, TWLTLs can be operationally detrimental by denying drivers the opportunity to pass slow-moving vehicles, without any corresponding safety benefit. When evaluating whether to install a TWLTL, highway agencies should consider the availability of passing opportunities on the adjacent highway section. If the only good passing zone for miles in either direction is replaced by a TWLTL, illegal passing maneuvers are likely, and the potential for conflicts between passing and turning vehicles is increased.

Figure 5-6. Example of Two-Way Left-Turn Lane in Rural Area (*2*).

Effectiveness

TWLTLs are effective in reducing left-turn crash rates and rear-end crashes. TWLTLs have been found to reduce crash rates by approximately 35 percent when installed at urban and suburban sites, primarily on multilane highways (*27*). Comparable crash reduction effectiveness was found by Harwood and St. John *(26)* for installation of TWLTLs on two-lane highways in urban fringe areas. In rural areas, the number of crashes at candidate TWLTLs on two-lane highways is small, but TWLTLs can reduce these crashes by up to 85 percent.

A field study of traffic conflicts and erratic maneuvers at four rural TWLTL sites on two-lane highways found only one problem that was consistent: illegal passing in the TWLTL was observed by a relatively small fraction (0.4 percent) of vehicles *(26).* Since it is evident that some drivers will pass illegally in TWLTLs, a careful evaluation of any proposed TWLTL installation that would eliminate an existing passing zone is recommended.

A Lane or Shoulder Widening

Overview	Total roadway width is among the most important cross-section considerations in the safety performance of a two-lane highway. Generally, wider lanes and/or shoulders will result in fewer crashes.
Effectiveness	Widening a lane by as little as 1 ft (0.3 m) can reduce the frequency of related crashes by as much as 12 percent. Related crashes are estimated to be reduced between 16 and 49 percent when a shoulder is widened by 2 to 8 ft (0.6 to 2.4 m), respectively.
Relative Cost	High

Overview

Figures 5-7 and 5-8 illustrate an upstream cross section with narrow shoulders and one with a wide shoulder.

A 1987 Federal Highway Administration study quantified the effects of lane width, shoulder width, and shoulder type on highway crash experience based on an analysis of data for nearly 5000 mi (8050 km) of two-lane highway from seven states (*28*). The study controlled for many roadway and traffic features, including roadside hazard, terrain, and average daily traffic. Crash types found to be related to lane and shoulder width, shoulder type, and roadside condition include run-off-road (fixed object, rollover, and other run-off-road crashes), head-on, and opposite- and same-direction sideswipe crashes, which were termed as "related crashes."

Effectiveness

If a user knows only the number of total crashes on the section, Table 5-3 gives factors to convert between total and related types. Since ADT and terrain are factors which influence the proportion of various crash types on a section, the table provides adjustments for these factors. The expected effects of lane and shoulder widening improvements on related crashes follow.

Figure 5-7. Example of Previous Cross Section.

Figure 5-8. Example of Wider Shoulders.

Table 5-3. Factors to Convert Total Crashes to Related Crashes* on Two-Lane Rural Roads (28).

ADT (vpd)	Terrain Adjustment Factors		
	Flat	Rolling	Mountainous
500	0.58	0.66	0.77
1000	0.51	0.63	0.75
2000	0.45	0.57	0.72
4000	0.38	0.48	0.61
7000	0.33	0.40	0.50
10000	0.30	0.33	0.40

*Related crashes include run-off-road, head-on, opposite-direction, and same-direction sideswipe.

Table 5-4 summarizes the percent reduction in crash frequency as a result of increasing lane widths. Significant reduction in crash frequency can be achieved with only minor increases in lane widths. For example, widening a lane by as little as 1 ft (0.3 m) (e.g., from 10- to 11-ft [3.1 to 3.4 m] lanes) can reduce the frequency of related crashes by as much as 12 percent. Widening a lane by 4 ft (1.2 m) (e.g., from 8- to 12-ft [2.4 to 3.7 m] lanes) could result in a 40 percent reduction in related crash types.

Table 5-4. Percentage of Crash Reduction of Related Crash Types for Lane Widening Only (*28*).

Amount of Lane Widening, ft (m)	Reduction in Crash Types (%)
1 (0.3)	12
2 (0.6)	23
3 (0.9)	32
4 (1.2)	40
Note: These values are only for two-lane rural roads.	

It should be noted, however, that increasing lane widths above a total of 12 to 15 ft (3.7 to 4.6 m) has little benefit in reducing crash frequency. In fact, when lane widths become too wide, drivers can become confused as to the total number of lanes on a roadway. This can lead to an increase in some types of crashes, especially same-direction sideswipes.

Table 5-5 lists research results concerning reductions in related crashes due to widening paved or unpaved shoulders. For example, widening 2-ft (0.6 m) gravel shoulders to 8 ft (2.4 m) will reduce related crashes by 35 percent (i.e., for a 6-ft [1.8 m] increase in unpaved shoulders). Adding 8-ft (2.4 m) paved shoulders to a road with no shoulders will result in an approximately 49 percent reduction of the related crashes (*28*). It should be noted that the predicted crash reductions given in Table 5-5 are valid only when the roadside characteristics (side slope and clear zone) are reestablished as before the lane or shoulder widening.

Table 5-5. Percentage of Crash Reduction of Related Crash Types for Shoulder Widening Only (*28*).

Shoulder Widening per Side, ft (m)	Reduction in Related Crash Types* (%)	
	Paved	Unpaved
2 (0.6)	16	13
4 (1.2)	29	25
6 (1.8)	40	35
8 (2.4)	49	43
Note: These values are only for two-lane rural roads. *Related crash types = run-off-road (fixed object, rollover, and other run-off-road crashes), head-on, and opposite- and same-direction sideswipe crashes.		

An expert panel that recently convened as part of an FHWA study confirmed the Zegeer et al. study as the most reliable assessment of the effect of lane width and shoulder width on safety for two-lane highways with ADTs over 2000 vehicles per day (*28*, *29*).

A 1987 study for the Texas Department of Transportation investigated the relationship between crash rate and crown width (surface width) on rural, two-lane, farm-to-market roads (*30*). The percent reduction factors determined for single-vehicle crashes are listed in Table 5-6. The reduction factors were estimated based upon regression equations of approximately 1400 mi (2253 km) of roadways and 4000 crashes. The analysis indicated that widening existing rural, two-lane, farm-to-market roads carrying over 1000 vehicles per day to a minimum of 22, 24, or 26 ft (6.7, 7.3, or 7.9 m) would yield benefit-cost ratios of 1.07, 1.14, and 1.17, respectively. The major findings from the study were:

A Surface width has no demonstrable effect on multi-vehicle crash rate on rural, two-lane, farm-to-market roads with an average annual daily traffic (AADT) up to 1500.

A Surface widening can reduce single-vehicle crash rate on rural, two-lane, farm-to-market roads with AADTs up to 1500.

A While surface widening can reduce single-vehicle crash rates on rural, two-lane, farm-to-market roads with AADTs in excess of 400, such action is not cost beneficial at AADTs below 1000.

Table 5-6. Single-Vehicle Crash Reduction Factors (%) Associated with Surface Widening in Three ADT Categories *(30)*.

AADT	Existing Surface Width, ft (m)	Resurfaced Width, ft (m)			
		20 (6.1)	22 (6.7)	24 (7.3)	26 (7.9)
401 to 700	18 (5.5) 20 (6.1) 22 (6.7) 24 (7.3)	7	13 7	19 13 7	25 19 13 7
701 to 1000	18 (5.5) 20 (6.1) 22 (6.7) 24 (7.3)	12	23 12	32 23 13	41 33 24 13
1001 to 1500	18 (5.5) 20 (6.1) 22 (6.7) 24 (7.3)	14	27 15	38 28 16	49 40 30 17

A Pavement Edge Drop-Off Improvements

Overview	Drop-offs exist when there is a difference in height between the pavement and the roadside surface or between a lane and shoulder surface.
Effectiveness	Selected efforts to address drop-offs in various jurisdictions have had some success in reducing crashes.
Relative Cost	Low to Moderate Costs are minor for specific locations, but may be moderate for a significant length of roadway.

Overview

Drop-offs are caused when the edges of pavement are unstabilized and eroded, resulting in a difference in height between the pavement surface and the roadside surface (see Figure 5-9). This height difference could be anywhere from a fraction of an inch to several inches, depending on the level of erosion. The potential hazard of this drop-off is realized when one or more of a vehicle's tires leaves the pavement surface and drops onto the roadside. In attempting to return to the paved surface, the driver can over-correct to compensate for the change in surface height, as it becomes more difficult for the vehicle to return to the lane at a shallow angle. If the driver over-corrects, this could cause the vehicle to spin out in the lane or cross the centerline, increasing the potential for a crash. Shoulder drop-offs can also be a significant issue for liability, if it is determined that the responsible agency did not properly maintain the surface at the edge of the roadway.

Figure 5-9. Shoulder Drop-Off.

The *Roadside Design Guide* (*9*) states that loss of vehicle control can develop at speeds greater than 30 mph (48 km/h) under certain circumstances, where inattentive or inexperienced drivers return to the traffic lane by oversteering to overcome the resistance from a continuous pavement edge and tire-scrubbing condition. Height differences can be overcome with a 45-degree face or tapered at a rate of 6 inch horizontal per 1 inch of vertical (see Figure 5-10). Pavement edge drop-offs greater than 3 inches immediately adjacent to traffic are recommended to not be left overnight. If they are higher than 3 inches and cannot be corrected during that day, mitigating measures should be considered.

Effectiveness

Figure 5-10. Gradual Change in Height Between Shoulder and Roadside.

There was no recorded research prior to 1977, but since then there have been several efforts to investigate this situation. One study by Glennon suggests that at speeds of 60 mph (97 km/h) or greater, a tolerable vertical drop-off is 1 inch or less. The value for a tolerable drop-off could be increased if the edge is rounded or beveled (*31*). In order to detect these drop-offs before they become liability issues, one county agency decided to restructure their inspection and maintenance program, so that each section of paved highway was reviewed on a regular, and frequent, basis. Since the new program was instituted, the major claims against the county for crashes related to this type of maintenance were eliminated (*32*).

A Pavement Markings

Overview	Pavement markings are used to supplement traffic signs or signals and to communicate information that cannot be obtained with other types of traffic control devices.
Effectiveness	A Adding edge lines and centerlines to roadways where no delineation has been provided reduced crashes by 36 percent in a 1970s study. A Adding centerlines reduced crashes by 29 percent; adding edge lines to centerlines yielded an 8 percent reduction. A The effectiveness of 8-inch (20.3 cm) edge lines to reduce run-off-road crashes is questionable. They could be cost effective on rural roadways where the pavement width is at least 24 ft (7.3 m), the shoulders are unpaved, and the ADT is between 2000 and 5000 vehicles per day. A Eight-inch (20.3 cm) edge lines may be appropriate as a safety improvement when applied at spot locations such as isolated horizontal curves and approaches to narrow bridges.
Relative Cost	Low

Overview

Pavement markings are used to supplement the regulations or warnings of other devices such as traffic signs or signals. They are also used alone to produce results that cannot be obtained with other types of traffic control devices. In such cases, they serve as a very effective means of conveying certain regulations and warnings that could not otherwise be made clearly understandable. The *Texas MUTCD* (*5*) and the *MUTCD* (*6*) provide information on the use and installation of pavement markings along roadways and at intersections. Pavement markings studies have examined the effectiveness of edge line and centerline markings and whether there are benefits to using wider markings in certain areas.

Figures 5-11 and 5-12 show examples of centerline-only pavement markings and both centerline and edge line pavement markings.


Figure 5-11. Example of Centerline Only Pavement Markings.

Effectiveness

The use of 4-inch (10.2 cm) edge lines significantly reduced the number of crashes as compared with those sites with no edge lines (*33*). The use of 4-inch (10.2 cm) edge lines has also shown a significant reduction in the number of crashes at access points (i.e., driveways and intersections) (*34*). Adding edge lines and centerlines to roadways where no delineation had been provided reduced crashes by 36 percent in a 1970s study (*35*). Adding centerlines reduced crashes by 29 percent; adding edge lines to centerlines yielded an 8 percent reduction. A Kansas study involved control and treatment sites comprising 384 mi (618 km) of rural highway servicing between 550 and 3600 vehicles per day. Using these findings, it was determined that edge lines will yield benefits exceeding their costs if an average of one non-intersection crash occurs annually every 15.5 mi (25 km) of roadway (*36*).

Figure 5-12. Example of Centerline and Edge Line Pavement Markings.

Several states have experimented with using 8-inch (20.3 cm) edge lines to reduce run-off-road crashes (*37, 38, 39*). In general, the effectiveness of 8-inch (20.3 cm) edge lines to reduce crashes is questionable. Lum and Hughes made recommendations for their use in a *Public Roads* 1990 article (*39*). Wider (8 inch [20.3 cm]) edge lines could be potentially cost effective in reducing run-off-road crashes on two-lane rural roads where the pavement width is at least 24 ft (7.3 m), the shoulders are unpaved, and the average daily traffic is between 2000 and 5000 vehicles per day. Eight-inch (20.3 cm) edge lines are not cost effective on two-lane, rural roads with frequent heavy snowfall and use of deicing materials and abrasives that tend to deteriorate edge lines, pavement widths of less than or equal to 22 ft (6.7 m), and roads having paved shoulders over 6 ft (1.8 m) wide. Eight-inch edge lines may be appropriate as a safety improvement when applied at spot locations such as isolated horizontal curves and approaches to narrow bridges.

A 2002 study (*40*) identified the current use of wider markings among transportation agencies in the United States, Canada, and other countries. The total of 29 (of 50) state DOTs use wider markings to some degree for standard centerline, edge line, and/or lane line applications. The most widely cited reason for using wider markings is improved marking visibility (57 percent of respondents). Drawing on the findings from the literature and survey of agency practice, the researchers concluded that wider markings would likely have the greatest benefit when used in the following situations:

A Locations where a higher degree of lane or roadway definition is perceived as necessary to all drivers, including:

- Horizontal curves,
- Roadways with narrow shoulders or no shoulders, and
- Construction work zones;

A Locations where low luminance contrast of markings is common; and

A Locations where older drivers are prevalent and thus require added roadway visibility under all conditions.

A Mowing

Overview	Mowing in the right-of-way is intended to increase safety by improving the driver's ability to see and recognize the slope of the terrain and the location of roadside items.
Effectiveness	Little research has been done to determine the effects of mowing on safety; results are mixed.
Relative Cost	Low to Moderate Costs are minor for specific locations, but may be moderate for a significant length of roadway.

Overview

Mowing is a standard method for eliminating weeds and woody brush from highway roadsides (see Figure 5-13). Mowing programs are often designed to keep signs and other traffic control devices visible, and to help inform the driver of the characteristics of the roadside terrain (see Figure 5-14). Where the right-of-way is wide enough and has suitable terrain, the clear zone can assist the driver who loses control of a vehicle to recover control and possibly avoid a collision. Mowing is also important to the maintenance of roadside grass, which helps the soil be resistant to damage by storm runoff from the pavement (*41*).

Effectiveness

There has been only limited research conducted on the effects of mowing on sight distance, speeds, and crash reduction. The results of those research efforts provided little guidance or definitive conclusions as to how a mowing program should be carried out or improved.

Figure 5-13. Mowing Activity.

Various states have different standards for mowing height and frequency, and many states have some measure of “chemical mowing” as part of their overall program. Thus, the measurable benefits of mowing on highway roadsides have yet to be fully determined or quantified.

Figure 5-14. Mowed Area on an Inclined Shoulder.

A Skid Resistance Improvements

Overview	Skid resistance can be improved by using a larger maximum gradation so that more voids are present for better drainage.
Effectiveness	At a site in California where a 1-inch (2.54 cm) maximum open graded asphalt concrete mix was used, the average number of crashes went from 2.38 to 0.85 crashes per month while wet-pavement crashes dropped from 1.41 to only 0.22 per month.
Relative Cost	Moderate Estimated cost of 1996 California project was $200,000 for a 2-mi (3.2 km) segment.

Overview

Treatments for wet weather crashes include the Slippery When Wet sign and improving the skid resistance of a roadway surface. The Slippery When Wet sign is used to warn that a slippery condition may exist. When used, a Slippery When Wet sign should be placed in advance of the beginning of the affected section, and additional signs should be placed at appropriate intervals along the road where the condition exists.

Effectiveness

An example of a site where the skid resistance of a pavement was improved was presented in NCHRP 440 (2). A two-lane section of a rural highway located within a state park in northern California is a narrow windy road through an old growth redwood forest (see Figure 5-15). The redwoods form a canopy over the roadway which causes the roadway to stay wet and slippery for a while following rain or fog condensation. In addition, the needles dropping from the trees also contribute to the slipperiness of the roadway. The goal of the treatment was to reduce wet pavement crashes.

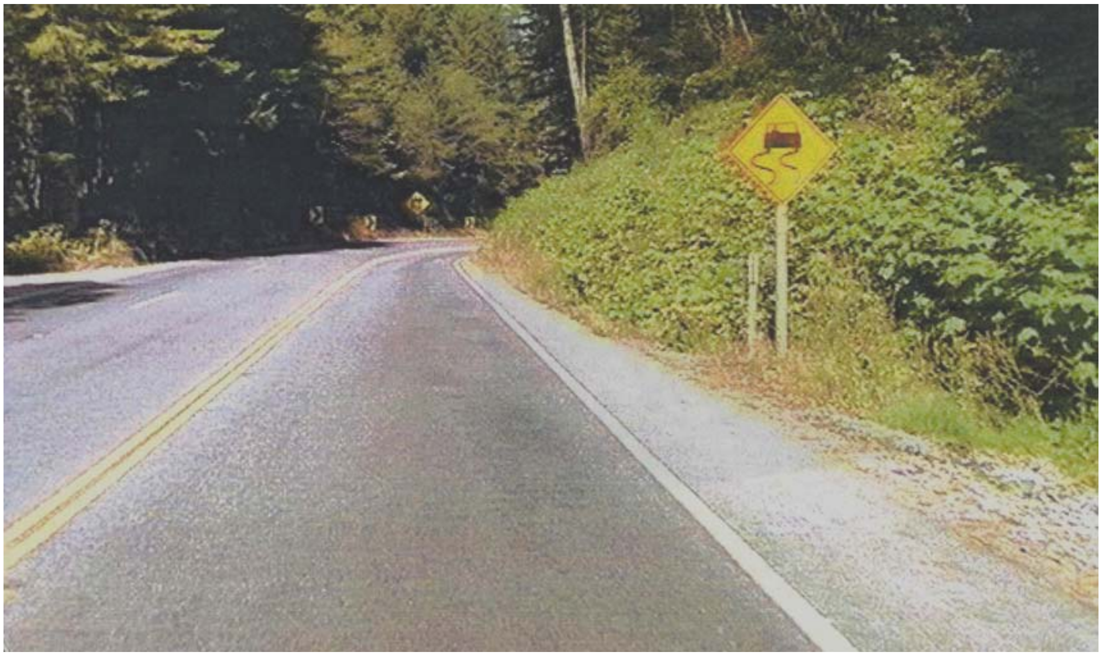


Figure 5-15. Two-Lane Rural Highway in an Old Growth Redwood Forest (2).

A 1-inch (2.54 cm) open graded asphalt concrete (OGAC) was used to reduce wet pavement crashes. A 1-inch (2.54 cm) maximum gradation provides more voids for better drainage and, thus, better skid resistance by having more voids than the 3/8-inch (0.95 cm) or 1/2-inch (1.27 cm) maximum OGAC standard mix. The existing surfacing was repaired, and dense graded asphalt concrete was placed to level the surface, especially in two existing pull-out areas. A tack coat was applied to the existing surface prior to the placement of the open graded material. The project proposed using a 0.15-ft (0.05 m) thick blanket of the 1-inch (2.54 cm) maximum OGAC on both lanes. The primary purpose of proposing this mix is that the larger amount of voids removes more water, increases traction, and thus reduces the number of crashes.

The estimated cost of the project was $200,000. The work was completed in September 1996. According to a Caltrans before-and-after study, in the 13 months prior to installation they had 16 wet-pavement-related crashes. Only two crashes have occurred in the six months after installation. Additional data were gathered as part of the NCHRP study. Crash data for 32 months prior to installation and 27 months following installation were obtained. The average number of crashes before installation was 2.38 crashes per month. Following installation, the number dropped to 0.85 crashes per month. Also noticeable was the decrease in the number of wet-pavement crashes. Before installation, an average of 1.41 wet-pavement crashes per month occurred; after installation, only 0.22 wet-pavement crashes per month occurred. Wet-pavement crashes represented almost 60 percent of all the crashes on the 2-mi (3.2 km) segment before treatment. After the treatment, they represented only about 26 percent of the crashes on the segment.

A Side Slope Flattening

Overview	The steepness of the roadside slopes affects the likelihood of an off-road vehicle rolling over or being able to recover back to the travel lane.
Effectiveness	Between 0 and 27 percent reductions in single-vehicle crashes have been estimated for side slope improvements.
Relative Cost	Moderate

Overview

The steepness of the roadside slopes, or side slopes, is a cross-sectional feature that affects the likelihood of an off-road vehicle rolling over or recovering back into the travel lane. In fill sections, side slopes that are 1:4 or flatter are generally desirable (see Figure 5-16). When a highway is in a cut section, the back slope may be traversable depending upon its relative smoothness and the presence of fixed obstacles. If the slope between the roadway and the base of the back slope is traversable (1:3 or flatter) and the back slope is obstacle-free, it may not be a significant hazard, regardless of its distance from the roadway. Ditches represent a unique roadside hazard in many areas. Designed primarily to collect and convey storm water runoff, their design should also consider what would happen if a vehicle were to leave the roadway. Warrants for the use of a roadside barrier and information on ditch design can be found in the *AASHTO Roadside Design Guide* (*9*).

Effectiveness

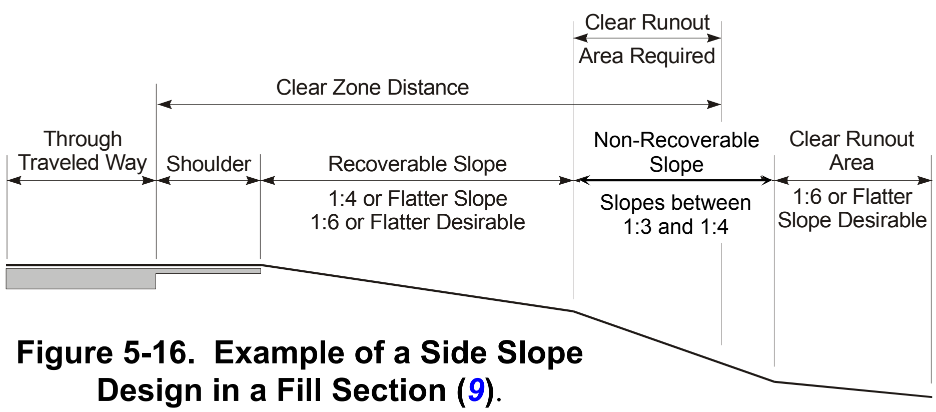


Figure 5-16. Example of a Side Slope Design in a Fill Section (*9*).

Figure 5-16 shows the relationship used to develop crash reductions matching various side slope flattening projects. As shown in Figure 5-17, single-vehicle crashes (as a ratio of crashes on a 1:7 slope) are highest for slopes of 1:2 or steeper and drop only slightly for 1:3 slopes. Single-vehicle crashes then drop linearly (and significantly) for flatter slopes. This plot represents the effect of side slope after controlling for ADT and roadway features (*28*).

The percent reductions are presented in Table 5-7 for single-vehicle and total crashes. For example, flattening an existing 1:2 side slope to 1:6 should result in a reduction of approximately 21 percent and 12 percent of single-vehicle and total crashes, respectively (*28*). These reductions assume that the roadside slope to be flattened is relatively clear of rigid obstacles.

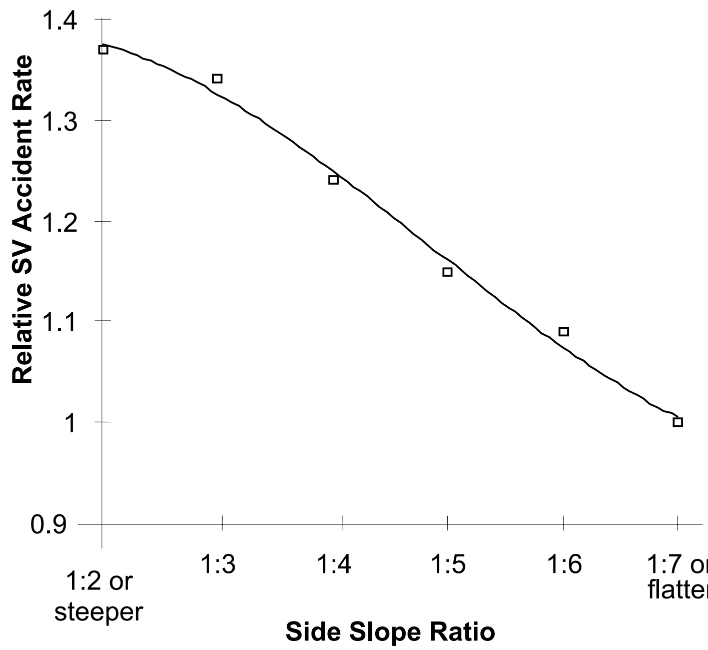


Figure 5-17. Plot of Single-Vehicle (SV) Crash Rate for a Given Side Slope to SV Crash Rate for a Side Slope of 1:7 or Flatter (*28*).

The use of flatter slopes not only reduces the crash rate, but it may also reduce rollover crashes, which are typically quite severe. In fact, injury data from three states reveal that 55 percent of run-off-road rollover crashes result in occupant injury, and 1 to 3 percent end in death. Of all other crash types, only pedestrian crashes and head-on crashes result in higher injury percentages. The FHWA study found that side slopes of 1:5 or flatter are needed to significantly reduce the incidence or rollover crashes (not 1:4, as is often assumed) (*28*).

Table 5-7. Effect (%) of Side Slope Flattening on Single-Vehicle and Total Crashes (*28*).

Side Slope Before Condition	Side Slope in After Condition							
	1:4		1:5		1:6		1:7 or Flatter	
	Single-Vehicle	Total	Single-Vehicle	Total	Single-Vehicle	Total	Single-Vehicle	Total
1:2	10%	6	15	9	21	12	27	15
1:3	8	5	14	8	19	11	26	15
1:4	0	-	6	3	12	7	19	11
1:5	-	-	0	-	6	3	14	8
1:6	-	-	-	-	0	-	8	5
Note: These values are only for two-lane rural roads.								

A Recovery Distance Improvements

Overview	The recovery area or "clear zone" should be traversable and free of obstacles.
Effectiveness	Reductions in run-off-road, head-on, and sideswipe crashes of between 13 and 44 percent are estimated when the roadside recovery distance is increased between 5 and 20 ft (1.5 and 6.2 m).
Relative Cost	Moderate

Overview

The concept of a forgiving roadside recognizes that motorists do run off the roadway and that a traversable recovery area could lessen serious crashes and injuries (see Figure 5-18). Ideally, this recovery area or "clear zone" should be free of obstacles such as unyielding sign and luminary supports, non-traversable drainage structures, utility poles, and steep slopes. Designers generally consider options for the treatment of these features in the following order:

Figure 5-18. Example of Traversable Culvert within the Recovery Distance.

- Remove the obstacle or redesign it so it can be traversed safely.
- Relocate the obstacle to a point where it is less likely to be struck.
- Reduce the impact severity by using an appropriate breakaway device.
- Redirect a vehicle by shielding the obstacle with a longitudinal traffic barrier and/or crash cushion if it cannot be eliminated, relocated, or redesigned.
- Delineate the obstacle if the above alternatives are not appropriate.

The roadside recovery distance is a relatively flat, unobstructed area adjacent to the travel lane (i.e., edge line) where there is a reasonable chance for an off-road vehicle to safely recover (*28*). Therefore, it is the distance from the outside edge of the travel lane to the nearest rigid obstacle (e.g., bridge rail, tree, culvert, utility pole), steep slope, non-traversable ditch, or other threat (e.g., cliff, lake) to errant motor vehicles.

Maintaining an adequate recovery area, free of obstacles and obstructions, is one way of reducing the crash exposure. Recommended roadside recovery distances (or clear zones) can be obtained from the *Roadside Design Guide* (*9*). The data were based on limited empirical data that were then extrapolated to provide data for a wide range of conditions; therefore, the numbers obtained represent a "reasonable measure" of the degree of safety suggested for a particular roadway.

Effectiveness

Examples of roadside improvements that can increase the recovery distance include cutting trees near the roadway, relocating utility poles further from the road, and use of side slopes of about 1:4 or flatter.

For roadways with limited recovery distances (particularly less than 10 or 15 ft [3.1 or 4.6 m] from the roadway edge line) where roadside improvements are proposed, crash reduction factors are in Table 5-8. For example, increasing the roadside recovery distance by 12 ft (3.7 m) (e.g., from 4 to 16 ft [1.2 to 4.9 m]) will reduce "related" crashes (defined as including run-off-road, head-on, and sideswipe crashes) by an estimated 29 percent.

Table 5-8. Crash Reduction Factors Due to Increasing Roadside Clear Recovery Distance (*28*).

Amount of Increased Roadside Recovery Distance, ft (m)	Reduction in Related Crash Types* (%)
5 (1.5)	13
8 (2.4)	21
10 (3.1)	25
12 (3.7)	29
15 (4.6)	35
20 (6.2)	44

*Related crash types = run-off-road, head-on, and sideswipe.

A Tree Mitigation

Overview	Trees become potential obstructions by virtue of their size and location in relation to vehicular traffic.
Effectiveness	Tree crashes can be reduced between 22 and 71 percent by removal of trees within 3 to 15 ft of the distance to roadway.
Relative Cost	Moderate

Overview

Any obstacle located on the roadside has the potential for being hazardous to an errant vehicle; therefore, efforts should be made to remove, protect, or make forgiving an obstacle or object that has to be located in the right-of-way.

Trees become potential obstructions by virtue of their size and location in relation to vehicular traffic (see Figure 5-19). Generally, a single tree with a trunk diameter greater than 4 inches (100 mm) is considered a fixed object. When trees or shrubs with multiple trunks or groups of small trees are together, they may be considered as having the effect of a single tree with their combined cross-sectional area. Tree removal should be considered when those trees are determined both to be obstructions and to be in a location where they are likely to be hit. If tree removal is impractical or infeasible, then shielding the trees with some type of roadside barrier may be justified. AASHTO's *Roadside Design Guide* (*9*) offers more information about the warranting and design of roadside barriers for protecting trees.

Effectiveness

Tree crashes can be reduced based on crash reductions shown in Table 5-9. Table 5-9 also includes the findings for guardrails and fences/gates. Clearing trees by 10 ft (3.1 m) (e.g., from 8 to 18 ft [2.4 to 5.5 m]) will reduce tree crashes by an expected 57 percent. These values assume that by clearing trees back from the roadway, run-off-road vehicles would have an additional roadside area to recover provided the trees were not on a steep side slope. Since trees are the fixed object most often struck on many rural roads, clearing trees back from the road (particularly on roads with severe alignment) can be an effective roadside safety treatment (*16*).

Figure 5-19. Example of Trees near Roadside.

Table 5-9. Percent Reductions in Tree, Guardrail, and Fence/Gate Crashes Due to Clearing to Greater Distance from the Roadway (*16*).

Increase in Obstacle Distance ft (m)	Trees (%)	Guardrails (%)	Fences/Gates (%)
3 (0.9)	22	36	20
5 (1.5)	34	53	30
8 (2.4)	49	70	44
10 (3.1)	57	78	52
13 (4.0)	66	N.F.	N.F.
15 (4.6)	71	N.F.	N.F.
N.F. = generally not feasible to relocate obstacles to specified distances. This table is appropriate only for obstacle distances of 30 ft (9.1 m) or less and only on two-lane rural roadways.			

A Culvert Modifications

Overview	Common drainage structures that might represent a hazard to motorists whose vehicles leave the roadway include the following: curbs, parallel and transverse pipes and culverts, and drop inlets.
Effectiveness	Culvert crashes can be reduced between 14 and 40 percent by moving the culvert an additional 3 to 15 ft (0.9 to 4.6 m) from the roadway.
Relative Cost	Moderate to High

Overview

Drainage features should be designed and built with both hydraulic efficiency and roadside safety in mind. Common drainage structures that might represent a hazard to motorists whose vehicles leave the roadway include the following: curbs, parallel and transverse pipes and culverts, and drop inlets.

The following list shows several options (in order of preference) to modifying drainage structures:

A Eliminate non-essential drainage structures.

A Design or modify drainage structures so they are traversable or present a minimal hazard to an errant vehicle (see example in Figure 5-20).

A If a major drainage feature cannot effectively be redesigned or relocated, it should be shielded by a suitable traffic barrier if it is in a vulnerable location. AASHTO's *Roadside Design Guide* (*9*) should be consulted for details on the design of these structures.

Figure 5-20. Example of a Culvert.

Effectiveness

Culvert headwalls can result in serious injury or death when struck at moderate or high speeds on rural roadways. While relocating such culverts further from the roadway may be feasible under certain conditions, the ideal solution would be to reconstruct the drainage facilities so that they are flush with the roadside terrain and present no obstacle to motor vehicles. Such designs would essentially eliminate culvert crashes, although run-off-road vehicles could still strike other obstacles (e.g., trees) beyond the culverts or roll over on a steep side slope. Crash reductions which correspond to placement of culvert headwalls further from the roadway are listed in Table 5-10. For example, a 40 percent reduction in culvert hits is expected for culverts located 15 ft (4.6 m) from the road as compared to 5 ft (1.5 m) (i.e., a 10-ft [3.1 m] difference in distance) (*16*).

Table 5-10. Percent Reductions in Specific Types of Obstacle Crashes Due to Clearing/Relocating Obstacles Further from the Roadway (*16*).

Increase in Obstacle Distance ft (m)	Mailboxes, Culverts, & Signs (%)
3 (0.9)	14
5 (1.5)	23
8 (2.4)	34
10 (3.1)	40
13 (4.0)	N.F.*
15 (4.6)	N.F.
*N.F. = generally not feasible to relocate obstacles to specified distances. This table is appropriate only for obstacle distances of 30 ft (9.1 m) or less and only on two-lane rural roadways.	

Ross et al. (*42*) developed preliminary guidelines for minimum spacing of driveways on high-speed roadways (see Table 5-11). The guidelines address safety concerns related to run-off-road crashes. The purpose of the guidelines is to minimize the risk to an errant motorist who leaves the road, crosses a driveway/sloped-end culvert, and then becomes airborne. It is desirable to have a safe recovery area downstream from the driveway — one that is free of hazardous features, including another driveway.

Table 5-11. Tentative Spacing Guidelines for Multiple Driveways (*42*).

Driveway Slope	Speed, mph (km/h)	Minimum Spacing Indicated ft (m)
1:6	45 (72.5)	50.2 (15.3)
	50 (80.5)	75.1 (22.9)
	55 (88.6)	100.0 (30.5)
	60 (96.6)	100.0 (30.5)
1:8	45 (72.5)	24.9 (7.6)
	50 (80.5)	24.9 (7.6)
	55 (88.6)	50.1 (15.3)
	60 (96.6)	75.1 (22.9)
1:10	45 (72.5)	0
	50 (80.5)	0
	55 (88.6)	24.9 (7.6)
	60 (96.6)	24.9 (7.6)

A Advance Warning for Horizontal Curves

Overview	Signs, pavement markings, and delineators in advance and at a horizontal curve can provide drivers with additional information concerning the upcoming roadway.
Effectiveness	Studies have also found that various **sign treatments** for reducing traffic speeds in the vicinity of horizontal curves have generally been ineffective. Reductions in traffic speeds have been observed from **pavement markings** designed to make the roadways appear narrower at the beginning of the curves or informing the driver of the appropriate speed for a horizontal curve.
Relative Cost	Low

Overview

Signs, pavement markings, and delineators in advance and at a horizontal curve can provide drivers with additional information concerning the upcoming roadway. Figures 5-21 and 5-22 are examples of advance pavement markings and signing, respectively, for a horizontal curve.

Figure 5-21. Example of Advance Pavement Markings for a Horizontal Curve.

A recent TxDOT study evaluated guide signing for rural highways with the final task of the study devoted to the development of a field book for guide signing on conventional highways (*43*). The *Sign Crew Field Book* is intended to provide field sign personnel with information beyond that contained in the *Texas MUTCD* or the TxDOT *Traffic Control Standard Sheets* so that guide signing can be applied in a more uniform manner.

Figure 5-22. Example of Advance Sign for a Horizontal Curve.

Effectiveness

A 1980s study in Ohio examined the effectiveness of advisory speed signs used in conjunction with curve warning signs (*44*). Based upon the findings from the 40 test drivers, the author concluded that advisory speed signs are not more effective in causing drivers to reduce their speeds through curves than curve and turn signs alone. Other studies have also found that various sign treatments for reducing traffic speeds in the vicinity of horizontal curve have generally been ineffective (*45, 46*).

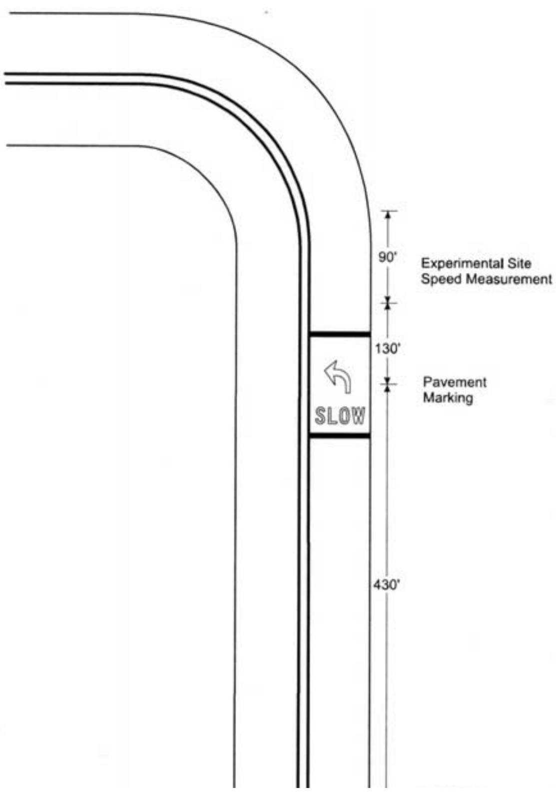


Figure 5-23. Pavement Marking and Speed Measurement Locations for Retting and Farmer's Study (*48*).

Transverse pavement markings have been tested to determine if drivers will slow down in advance of a curve. Average traffic speeds were reduced from 41.3 to 33.9 mph (66.5 to 54.6 km/h) one week after markings were installed at one site and, six months after treatment, the average speed was 34.8 mph (56.0 km/h) — 16 percent less than that observed during the baseline period (*46*). Another study (*47*) also reported reductions in traffic speeds, most notably high speeds, resulting from pavement markings designed to make the roadways appear narrower at the beginning of the curves. The pavement markings shown in Figure 5-23 were tested to determine whether excessive traffic speeds at rural and suburban two-lane roadway locations with sharp horizontal curves could be reduced. The pavement markings were associated with a decrease in vehicle speed of approximately 6 percent overall and 7 percent during daytime and late night periods (*48*).

A Delineation

Overview	Delineation has been defined as one or more devices that regulate, warn, or provide tracking information and guidance to the driver.
Effectiveness	The effectiveness of delineators on reducing crashes is mixed. Studies have found that delineation has been effective in some locations; however, others have reported that the delineation did not have any significant effect on the crash rate.
Relative Cost	Low

Overview

Delineation has been defined as one or more devices that regulate, warn, or provide tracking information and guidance to the driver. The *Roadway Delineation Practices Handbook* (*49*) was developed to assist in making decisions about roadway delineation systems. It covers current and newly developed devices, materials, and installation equipment, and presents each item's expected performance based on actual experience or field and laboratory tests.

Figure 5-24. Example of Post-Mounted Delineator.

Raised pavement markers can be used to show roadway alignment or to replace or supplement other pavement markings. Post-mounted delineators (PMDs) are light-reflecting devices mounted at the side of the roadway, in series, to show the roadway alignment (see examples in Figures 5-24 and 5-25). Their purpose is to outline the edges of the roadway and to accent critical locations.

Effectiveness

Several researchers (*50, 51, 52, 53*) have reported that post-mounted roadside delineation reduced the crash rate only on relatively sharp curves during periods of darkness. Studies by the Arizona Highway Department (*54*) suggest that neither edge lines nor post-mounted delineation have any significant effect on the crash rate on open tangent sections. Other studies indicate that post delineators do have an effect and that highways with post delineators (in the presence or absence of edge lines) do have lower crash rates than those without post delineators. Further, post delineators are cost justified for all values of cost and service life for highways with AADTs exceeding 1000 vehicles per day (*55*).

Figure 5-25. Post-Mounted Delineators with a Guard Rail.

Three post-mounted delineator systems used in Virginia were tested in the 1980s at five sites for their effectiveness in controlling run-off-road crashes (*56*). The changes in speed and lateral placement with the systems in place were taken as driver responses to the systems. The study indicated that drivers react most favorably to chevron signs on sharp curves greater than or equal to 7 degrees and to standard delineators on curves less than 7 degrees.

Bali et al. (*57*) in 1978 used crash data obtained from 500 plus sites in 10 states to predict crash rates. For tangent and winding alignments, they found that highways with centerlines had lower crash rates than highways without centerlines, that highways with RPM centerlines had lower crash rates than highways with painted centerlines, and that highways with PMDs had lower crash rates than highways without PMDs (both with and without edge lines). In the models for isolated horizontal curves, the type of delineation did not explain crash rate variance.

In the early 1980s, Niessner (*58, 59*) coordinated separate field evaluations of PMDs and RPMs. He concluded, based on field evaluations of PMDs in eight states, "It is not possible to state that the installation of post delineators under all conditions will result in a reduction in the number of run-off-the-road-type accidents. The data that was collected indicates a trend toward reducing the type of accident with the installation of post delineators" (*58*).

Other studies have also evaluated the operational effects of RPMs and PMDs at horizontal curves on two-lane highways. Zador et al. (*60*) evaluated chevrons, PMDs, and RPMs and found that vehicles moved toward the centerline when PMDs were added but moved away from the centerline when chevrons and RPMs were added. Krammes and Tyer (*61*) investigated the operational effectiveness of RPMs as an alternative to PMDs at horizontal curves using nighttime speed and lateral placement data using five curves. Operations with the RPMs compared favorably with the existing PMDs in both short-term and intermediate-term evaluations.

A Barrier Reflectors

Overview	Barrier reflectors are installed on the side of bridge rails and guardrails. They can be installed in the rail, on the rail, or on the post and are used to increase visibility.
Effectiveness	Lack of research has produced no clear conclusions as to the effectiveness of barrier reflectors.
Relative Cost	Low The cost of each reflector in 2002 was approximately $3.00. Installation costs for a single guardrail are low.

Overview

Barrier reflectors (also called in-rail reflectors) are intended to provide drivers with increased visibility of bridge rails, guardrails, and edge of pavement during nighttime and other low-visibility conditions. Specific applications of barrier reflectors could be focused on locations where the rates of guardrail hits are high, where there are unexpected curves, where there are significant changes in elevation beyond the edge of pavement, or where visibility could be improved.

Barrier reflectors primarily consist of the reflective surface and the mounting apparatus. The reflective surface may be trapezoidal or circular in shape, and may be white/crystal or yellow/amber in color (see Figures 5-26 and 5-27). Also, reflectors may be one-way or bi-directional, based on the needs of the site. Depending on reflective surface, color, and directionality, reflectors are sold for approximately $3.00 each, often purchased in quantities of 50 or 100 (*62*).

Figure 5-26. Reflector Installed in Guardrail.

Installation of barrier reflectors is fairly simple. Some reflectors come with a sticky base surface that is made to adhere to the surface of the guardrail, forming a seal bond. Others have a base that is bolted or screwed into the guardrail to permanently attach it.

Figure 5-27. Two-Lane Highway with Barrier Reflectors.

Effectiveness

Research to determine the effectiveness of barrier reflectors in reducing crashes or to quantify improvements in visibility is not available. However, their low cost and relative ease of installation are positive reasons for their use in locations where guardrails are struck often or where additional nighttime communicating of the roadway alignment is desired.

A Animal Countermeasures

Overview	A variety of treatments can be used to reduce the number and/or severity of animal-related crashes. Treatments include methods of discouraging or preventing animals from entering the roadway and signs to warn drivers.
Effectiveness	Several treatments have shown some effectiveness, but are generally costly, while others have had minimal effect, or the effect is reduced over time.
Relative Cost	Low for advance signs or moderate for fences and advance warning system.

Overview

Crashes between large animals, especially deer (see Figures 5-28 and 5-29), and vehicles are a significant safety problem for a number of rural two-lane highways. Deer are attracted to highways, partly because of salt leeching into the surrounding soil, and partly because of forage planted in the median and along the roadway. Additionally, deer cross roadways to move from open feeding areas to protected bedding areas in regular cycles, sometimes several times a day.

Figure 5-28. Pronghorn Antelope (*63*).

Nationally, it has been estimated that over 1.5 million deer-vehicle crashes (DVCs) occur annually (but that only about 50 percent of these are actually reported), and that the vehicle damage cost from those reported DVCs is over $1.1 billion (*64*). In Texas, about 3800 animal crashes occurred in 1999 on rural highways. The majority of animal crashes are non-injury or property damage only crashes. Over half were PDO crashes (56 percent) with 6 percent involving incapacitating injuries or fatalities. Vehicle-animal crashes occur more frequently at night. Of the reported animal crashes in the state, 73 percent occurred at night. Most of the animal crashes occurred in the fall months of October, November, and December. The deer mating season, associated with greater movement among deer, occurs during these months.

A selection of narratives for animal crashes occurring in a rural Texas district was obtained to identify the contributing factors to the animal crashes (*65*). The narratives showed that deer are the animal most frequently involved in crashes, although cows are still heavily represented. For the set of animal crashes, 62 percent of the animal crashes were with deer, and 25 percent of crashes were with cows. The narratives also provided the contributing factors identified by officers for the 279 crashes reviewed. In almost every crash, the contributing factor was an animal on the road, although several of the crashes were with domestic animals (28 percent) rather than wild animals (58 percent). Faulty evasive action was attributed to 7 percent of the animal crashes.

A review of five states' crash databases revealed that vehicle-animal crashes increased 69 percent between 1985 and 1991. In one state, vehicle-animal crashes composed more than one-third of all reported vehicle crashes on two-lane rural roads (*66*). Vehicle-animal crashes occurred more frequently at night. Of all reported animal crashes, 69 percent to 85 percent occurred at night. The greatest number of animal crashes occurred during the early morning hours (5 to 8 am) and the night hours (6 pm to midnight). The greatest number of reported vehicle-animal crashes occurred in November, with the second highest in October. These months represent mating season for the deer.

Effectiveness

Countermeasures used to decrease animal crashes have included signing, improvements to roadside vegetation, reflectors designed to redirect the light from vehicle headlights into the neighboring terrain, fences and underpasses, and a highway crosswalk system.

Figure 5-29. Mule Deer (*67*).

When an area is known to have significant deer activity or a deer-vehicle crash history, an advance deer crossing warning sign may be installed. The *Texas MUTCD* states that "Crossing signs may be used to alert road users to locations where unexpected entries into the roadway by pedestrians, bicyclists, animals, and other crossing activities might occur" *(5).* The effectiveness of advance warning signs is unknown. A concern with their use is that overuse of the deer crossing warning signs may result in a lack of attention to the message on the part of the motorists.

One method used to minimize or control the movement of deer onto the roadway is through improvements to roadside vegetation and landscape management. A 1980s study in Utah found that some deer collisions can be avoided by placing food at points away from the highways (*68*). These feeding areas intercepted foraging deer and kept them away from the highways, making the roads safer for passing motorists.

Reflective devices have been designed to redirect the light from vehicle headlights to create "optical fences" or create a red glow visible to the deer. Studies have attempted to determine whether the reflective devices are an effective treatment for reducing deer-vehicle crashes. Some studies have shown that fewer deer are hit when the reflectors are used; however, other studies have demonstrated that the deer are not reacting as anticipated *(69, 70, 71)*. A Minnesota study found that the reflector installations worked in rural Minnesota and failed in suburban areas. High traffic, increasing deer population, and the inability to effectively maintain the reflectors may have also been factors in the lack of success in the metropolitan area *(69).*

Use of fencing and underpasses has resulted in fewer deer crossing the roadways and fewer crashes *(72, 73, 74)*. A study of two segments of 8-ft (2.4 m) fences with one-way gates in Minnesota found that the reported number of deer hits was reduced by 60 and 93 percent *(73).* A high big-game fence was installed in Wyoming along an interstate to force deer to use specified locations for passing under the freeway. The passes were baited with alfalfa hay, fresh vegetable trimmings, and apple pulp to help lure the deer to the underpass. Difficulties associated with the fences included selection of the proper area for the fence, inadequacy of deer guards on ramps of an interchange, and the need for continuous monitoring for holes in the fence *(72)*. An 8-ft (2.4 m) high page wire fence in the Banff National Park with a system of 10 wildlife underpasses was highly effective in reducing wildlife collisions—over 94 percent for elk (*74*). However, problems have been identified and several unexpected wildlife impact occurrences were recorded.

A crosswalk system restricts deer crossings to specific, well-marked areas along the highways where motorists can anticipate them. Right-of-ways are fenced with deer-proof fencing to direct the animals to the designated crossing areas. A crosswalk system was installed in Utah as an initial implementation and testing of the crosswalk system. The authors concluded that the system warrants further testing due to observations of deer successfully crossing within crosswalk boundaries, the apparent maintenance of migratory behavior, and the reduced deer use of the highway right-of-way (*75*).

The increasing traffic mortality of the eastern brown pelican (see Figure 5-30) on the Queen Isabella Causeway prompted a 1988-1990 TxDOT study. The study concluded that the birds are not intentionally landing on the bridge deck. Rather, turbulence above the deck causes the birds to land if they attempt to fly over the bridge without sufficient initial altitude. The study determined that flashing lights, propane cannon, or other noise makers are not likely to discourage pelicans from intentionally landing. Alternate roosting structures and platforms or additional railing on the bridge were not effective. The study identified traffic control measures as the actions most likely to effectively reduce pelican mortalities *(76).*

As a result of meetings with many interested agencies and recommendations from the Texas Transportation Institute (TTI) report, TxDOT took the following actions:

- Flashing signs to reduce speed were installed at each end of the bridge and at the crest of the bridge. These signs were installed after it was determined that a silhouette sign previously installed was not effective.

- Lights on the causeway were adjusted to come on 30 minutes earlier in the evening.

Figure 5-30. Brown Pelican (*77*).

- Changeable messages were installed at each end of the bridge to warn motorists to slow down and drive cautiously for conditions that may exist on the bridge.

- Windsocks and banners to distract the pelicans were installed on light poles at the crest of the bridge.

- A “Pelican Patrol” consisting of TxDOT personnel was established to patrol the bridge during northers to pick up or assist downed pelicans and activate the warning signs.

- A plan was established to determine who would pick up the birds and where they would be taken. These measures are active during northers and inclement weather months, specifically from September through February.

- A public service announcement was produced by TxDOT and has been airing on local, national, and international television stations. The announcement was intended to make the public aware of the pelican population and its endangered status. The announcement encourages motorists to reduce speed on the causeway and provides information on how to assist downed or injured pelicans.

Four pelicans died during the winter following the use of these measures compared to eight during the previous winter. TxDOT is also considering other possible mitigation measures including adding more banners to the Causeway, a publicity campaign to include flyers and posters, adding call boxes at each end of the causeway, and installing weather monitoring devices to detect northers (*76*).

A A A

CHAPTER 6
TREATMENTS FOR RURAL INTERSECTIONS

A A A

A Treatments

The following treatments will be discussed in this chapter:

- A Advance Warning for Intersections,
- A Approach Rumble Strips,
- A Left-Turn Bays,
- A Shoulder Bypass Lanes,
- A Intersection Flashing Beacons,
- A Signalization,
- A High-Intensity Strobe Lights,
- A Backplates on Traffic Signals,
- A Illumination, and
- A Sight Obstruction Reduction.

A Advance Warning for Intersections

Overview	Signs and pavement markings have been used to warn a driver of a downstream intersection.
Effectiveness	Warning signs have been found to be effective in reducing crashes in two studies. Other studies have used driver behavior measures to evaluate effectiveness. Signs in certain situations are associated with reduced driver speeds while others are associated with increased speeds prior to a traffic signal.
Relative Cost	Low

Overview

The combination of infrequent intersections and high speeds along a rural two-lane highway creates a situation where conflicts are unexpected. Signs and pavement markings have been used to inform drivers of an intersection or a signal. Figures 6-1 to 6-4 are examples of advance signs and pavement markings used in Texas. Figure 6-5 is an example of using flashers on a Stop sign to increase the visibility of the sign.

Effectiveness

Figure 6-1. Example of Overhead Advance Signing.

Agent (*78*) noted that providing the driver adequate warning of the intersection is of primary importance. He recommends stop bars be placed on the stop approaches for the minor streets to encourage the drivers to stop at a location that would maximize their sight distance of vehicles on the through roadway. He noted that the number of side-street vehicles that do not stop at the Stop sign illustrates the need for adequate warning and Stop signs on the stop approach. He also suggested that the use of active advance warning signs should be considered at locations where a large number of avoidable crashes have occurred.

Figure 6-2. Example of Advance Warning Pavement Markings.

Lighted warning signs were found to be more effective than more traditional unlighted warning signs in reducing motorists' speeds in the vicinity of a rural intersection and increasing their awareness of both the signs and the conditions at the intersection (*79*). A FHWA study that used a driver simulator found that the Flashing Symbolic Signal Ahead (FSSA) sign was the most desirable sign. The Prepare to Stop When Flashing (PTSWF) sign was the most incorrectly identified sign (*80*).

Several studies have examined advance warning signs for high-speed signalized intersections (*81, 82, 83, 84*). A late 1990s study used 106 intersections to identify the effects of advance warning flashers (AWF) (*81*). The results from the study indicated that intersections equipped with AWFs have a lower frequency of crashes than similar locations without AWFs. However, the results were not statistically significant. A mid-1990s study (*82*) found that the impacts of the different signs vary among intersections with tangent and curved approaches. The study showed that the PTSWF and FSSA signs generally have similar effects on driver behavior. The authors recommend using the CFSSA (Continuously Flashing Symbolic Signal Ahead) sign before using the PTSWF sign because the PTSWF and FSSA signs had undesirable effects on vehicle speeds. When flashers are off and the signal indication was green or yellow, drivers on an approach with PTSWF or FSSA sign generally increase their speed in an apparent attempt "to beat the light." This behavior is particularly more evident on intersections with a tangent approach than on intersections with a curved approach because the roadway curvature provides restrictions to the drivers on the selection of their speed. The authors concluded the following:

- The PTSWF sign is preferable to the FSSA sign in Ohio. The FSSA sign should not be used as a replacement for the PTSWF sign.
- At any potential location for an advance warning sign with flashers, the CFSSA sign should be considered for selection prior to the PTSWF sign.
- The use of the PTSWF sign at a tangent approach to a high-speed signalized intersection is discouraged.

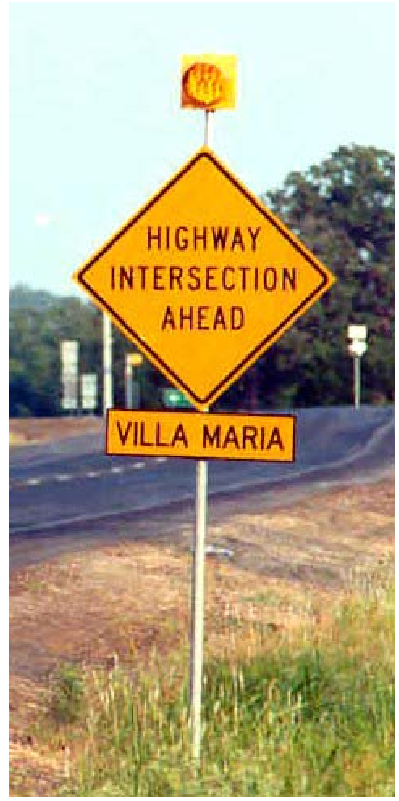


Figure 6-3. Example of Flasher on Advance Intersection Sign.

A survey of practices (*84*) revealed two state studies that examined the sign's effects on crashes. A 1980 Ohio Department of Transportation before-and-after study (*85*) evaluated the Prepare to Stop When Flashing sign at six locations. High-speed approaches revealed a statistically significant crash reduction for total, rear-end, property-damage-only, and truck-at-fault crashes. A 1982 Maryland study evaluated the flashing Red Signal Ahead sign through a before-and-after study that involved 22 intersection approaches (*86*). The Red Signal Ahead sign was determined to be successful in reducing right-angle crashes at sign-obstructed signalized intersections. The device appeared to be more effective in reducing rear-end and total crashes on horizontal curve approaches than on steep vertical approaches.

A two-year study (*87*) being conducted for TxDOT is testing the use of Be Prepared to Stop When Flashing signs. These signs are being implemented at two locations in Waco and Brenham. The study results and recommendations should be available in 2003.

Figure 6-4. Example of Flasher on a Stop Ahead Sign.

Figure 6-5. Example of Stop Sign with Flashers.

A Approach Rumble Strips

Overview	Approach rumble strips are raised or depressed areas of the roadway surface designed to alert the driver to unusual conditions.
Effectiveness	Research has indicated that approach rumble strips have been effective in reducing crashes.
Relative Cost	Low Approximate cost for a 2001 project was $500 per approach for materials plus installation costs.

Overview

Figures 6-6 and 6-7 show examples of rumble strips approaching intersections. While the *Texas MUTCD* (*5*) does not provide information on the use of rumble strips at an intersection, it does provide the following support for transverse rumble strips as temporary traffic control zone devices and as approach end treatments for curb islands.

A Rumble strips consist of intermittent narrow, transverse areas of rough-textured or slightly raised or depressed road surface that alert drivers to unusual motor vehicle traffic conditions. Through noise and vibration they attract the driver's attention to such features as unexpected changes in alignment and to conditions requiring a stop.

Figure 6-6. Example of Full-Width Approach Rumble Strips.

Figure 6-7. Application of Partial-Width Approach Rumble Strips.

The *MUTCD* (*6*) also provides the following options and guidance for rumble strips as temporary traffic control zone devices:

- Intervals between rumble strips may be reduced as the distance to the approached condition is diminished in order to convey an impression that a closure speed is too fast and/or that an action is imminent. A sign warning drivers of the onset of rumble strips may be placed in advance of any rumble strip installation.
- Rumble strips should be placed transverse to motor vehicle traffic movement. They should not adversely affect overall pavement skid resistance under wet or dry conditions.
- In urban areas, even though a closer spacing might be warranted, care should be taken not to promote panic braking or erratic steering maneuvers by drivers.
- Rumble strips should not be placed on sharp horizontal or vertical curves.

Effectiveness

Harwood (*88*) reported in 1993 that rumble strips placed on intersection approaches can provide a reduction of at least 50 percent in the types of accidents most susceptible to correction, including accidents involving running through a Stop sign. They can also be expected to reduce vehicle speed on intersection approaches and to increase driver compliance with Stop signs (*89*).

In an evaluation conducted in the early 1980s by the Virginia Department of Highways and Transportation (*90*) where rumble strips were installed at stop-controlled intersections, the total accident frequency was reduced by 37 percent, fatal accidents were reduced by 93 percent, injury accidents were reduced by 37 percent, and property-damage-only accidents were reduced by 25 percent. In this study, 39 of the 141 accidents in the before period were classified as being types susceptible to correction by rumble strip installation, particularly rear-end accidents and ran-Stop-sign accidents. The accident rate for these accident types was reduced by 89 percent (*89*).

Additionally, a study by Zaidel et al. indicated that transverse in-lane rumble strips maintained their speed-reducing effects when evaluated after one year (*91*).

A Left-Turn Bays

Overview	Left-turn bays separate slow-turning vehicles from through vehicles. It also provides a refuge space for turning vehicles that must wait for an adequate gap in on-coming traffic.
Effectiveness	A 2002 FHWA study found up to 48 percent reduction in crash rates after the installation of left-turn lanes.
Relative Cost	Moderate

Overview

The left-turn lane is generally the key auxiliary lane at an intersection (see Figure 6-8 for an example). It creates the opportunity to separate and avoid speed differences between the turning vehicle and the through vehicles. It also decreases the delay that can be experienced by through vehicles behind a turning vehicle. By increasing the operational efficiency of the intersection, the capacity and safety are also increased. In addition, left-turn lanes can provide increased visibility to the turning vehicle by the opposing traffic.

The AASHTO *Green Book* (*7*) indicates that left-turn lanes should be established on roadways where traffic volumes are high enough or safety considerations are sufficient to justify left-turn treatment (see *Green Book* Exhibit 9-75). Similar information is included in the TxDOT *Roadway Design Manual* (see chapter 3, section 4, “Left-Turn Lanes” of the TxDOT *Roadway Design Manual*). Additional information on left-turn treatments at intersections is included in NCHRP Synthesis 225 (*92*) and NCHRP Report 279 (*93*). Information on taper designs and deceleration and acceleration lengths for different grades or running speed assumptions is included in the *Green Book* (*7*).

Effectiveness

A 2002 FHWA study found that the addition of a left-turn lane can result in reductions of crashes from 7 to 48 percent (see Table 6-1) (*94*). Geometric design, traffic control, traffic volume, and traffic accident data were gathered for a total of 280 improved sites under the jurisdiction of the participating states, as well as 300 similar intersections that were not improved during the study period. The types of improvement projects evaluated included installation of added left-turn lanes, installation of added right-turn lanes, installation of added left- and right-turn lanes as part of the same project, and extension of the length of existing left- or right-turn lanes. An observational before-after evaluation of these projects was performed.

A 1967 California study examined the difference in the effectiveness of the raised barrier protected left turn versus the painted left turn in rural areas (*95*). Both treatments provided a significant reduction in crash rates with relatively little difference between the types of treatment for rural areas (see Table 6-2).

Table 6-1. Expected Percentage Reduction in Total Crashes from Installation of Left-Turn Lanes on Major Road Approaches. (*94*)

Intersection Type	Intersection Traffic Control	Number of Major-Road Approaches on Which Left-Turn Lanes are Installed	
		One Approach	Both Approaches
RURAL			
Three-leg intersection	Stop Sign Traffic Signal	44 15	
Four-leg intersection	Stop Sign Traffic Signal	28 18	48 33
URBAN			
Three-leg intersection	Stop Sign Traffic Signal	33 7	
Four-leg intersection	Stop Sign Traffic Signal	27 10	47 19

Table 6-2. Crash Rates Before and After Adding Left-Turn Channelization at Unsignalized Intersections in Rural Areas (*95*).

	Raised Barrier Protected			Painted		
	Rate Before	Rate After	Percent Change	Rate Before	Rate After	Percent Change
Crash Type						
Single Vehicle	0.10	0.07	-30	0.10	0.15	+50
Left-Turn	0.18	0.05	-72	0.28	0.15	-46
Rear-End	0.49	0.02	-96 S	0.51	0.09	-82 S
Crossing	0.28	0.27	-4	0.19	0.16	-16
Other	0.13	0.07	-46	0.07	0.03	-57
Severity						
Property Damage	0.72	0.34	-53 S	0.61	0.31	-49 S
Injury	0.39	0.15	-62 S	0.54	0.25	-54 S
Fatal	0.08	0.00	-100	0.01	0.01	0
Light Condition						
Day	0.67	0.25	-64 S	1.18	0.55	-53 S
Night	0.51	0.24	-53 S	1.13	0.63	-44
TOTAL	1.18	1.049	-58 S	1.16	0.58	-50 S

Changes indicated with "S" are significant at the 0.10 level using the Chi-Square test.
Crash rates are the number of crashes per million entering vehicles.

Figure 6-8. Examples of Left-Turn Lanes (*2*).

A Shoulder Bypass Lanes

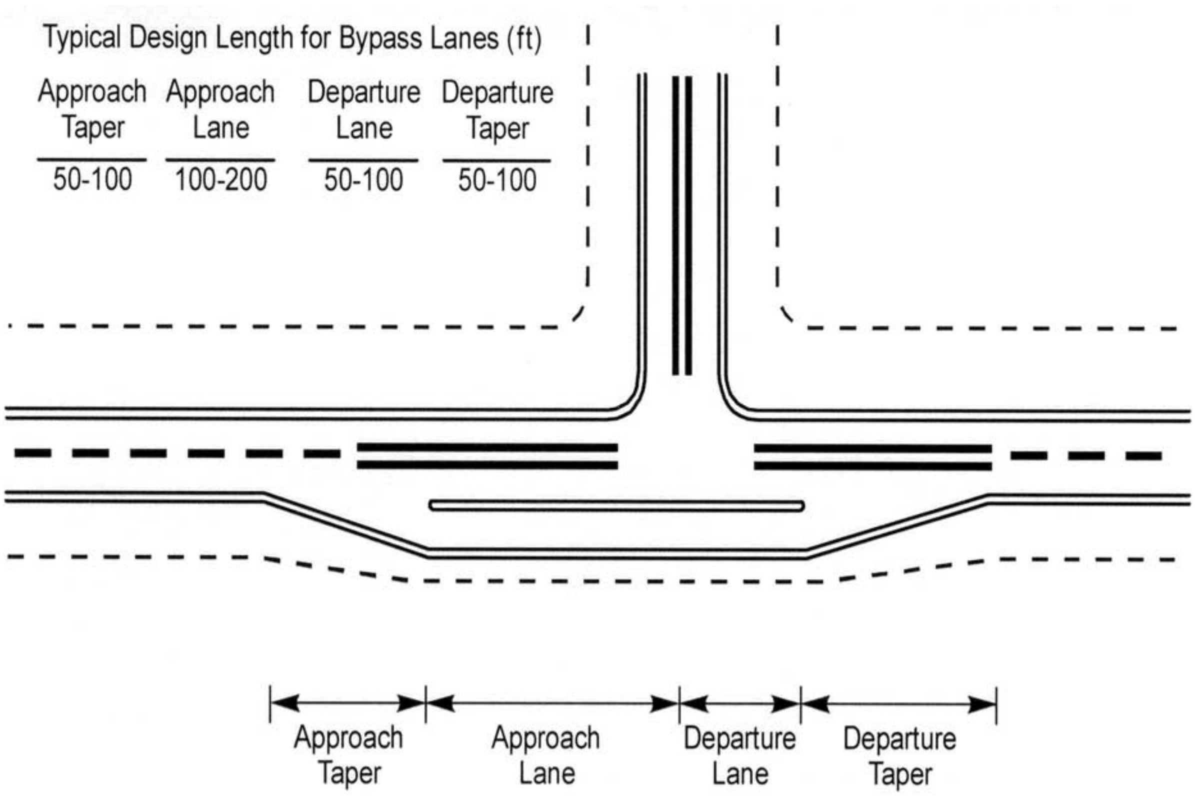
Overview	Shoulder bypass lanes are used at T-intersections when the paved shoulder is restriped to have the through traffic driving on the shoulder to bypass the slow or stopped left-turning vehicle.
Effectiveness	Crash experience of shoulder bypass lanes has not been formally evaluated; however, there are observations that the treatment is positive.
Relative Cost	Low

Overview

Shoulder bypass lanes are a low-cost alternative to intersection turn lanes for reducing delays to through vehicles caused by left-turning vehicles. Where a side road intersects a two-lane highway at a three-leg or T-intersection, a portion of the paved shoulder opposite the intersection may be marked as a lane for through traffic to bypass vehicles making a left turn. Where an adequate paved shoulder is already available, installation of a shoulder bypass lane may be as simple as remarking the highway edge line. Thus, provision of a shoulder bypass lane is often much less expensive than construction of a left-turn lane. Figure 6-9 illustrates a typical shoulder bypass lane at a T-intersection on a two-lane highway. If a vehicle is stopped in the through travel lane waiting to make a left turn, following vehicles can use the bypass lane to avoid having to stop themselves.

Effectiveness

Shoulder bypass lanes have been shown to be effective in reducing delay to through vehicles at T-intersections as well as reducing fuel consumption, vehicle operating costs, and pollutant emissions. No quantitative estimates are available for the delay reduction effectiveness of shoulder bypass lanes. However, a Delaware study found that, where shoulder bypass lanes are provided, 97 percent of the drivers who needed them to avoid delay did in fact use them (*96*). Similarly, an Illinois study observed over 90 percent usage of shoulder bypass lanes by drivers who needed them (*97*). Even bypass lanes as short as 150 ft (46 m) were used effectively by drivers.



1 ft = 0.305 m

Figure 6-9. Plan View of Typical Intersection with Shoulder Bypass Lane (*25*).

Shoulder bypass lanes were found to be more effective than paved shoulders alone in improving traffic operations. In Delaware, where use of both paved shoulders and shoulder bypass lanes to bypass left-turning vehicles is legal, only 81 percent of drivers used paved shoulders to bypass left-turning vehicles, whereas 97 percent of drivers used shoulder bypass lanes where necessary.

The crash experience of shoulder bypass lanes compared with that of separate left-turn lanes or compared with that of paved shoulders alone has not been formally evaluated. However, Nebraska has reported a marked decrease in rear-end crashes at shoulder bypass lanes, and other states have reported relatively few crashes occurring at shoulder bypass lane installations (*96*).

A Intersection Flashing Beacons

Overview	Flashing beacons are installed at intersections that do not justify conventional traffic signals but have special hazard conditions.
Effectiveness	Previous research studies have shown that intersection flashing beacons have a significant effect on reducing crashes of many types in both daytime and nighttime conditions; however, a recent study did find beacons to be not effective in reducing crashes.
Relative Cost	Moderate Approximately $3000 per approach in 2001, depending on number of signal heads and source of power.

Overview

Figure 6-10. Intersection Flashing Beacons.

Intersection control beacons have flashing yellow or red indications on each face (see Figure 6-10). They are intended for use at intersections where traffic or physical conditions do not justify conventional traffic signals but where high crash rates indicate a special hazard. Intersection control beacons are used in conjunction with Stop signs at isolated intersections or intersections having sight distance obstructions. Research findings recommend that they not be used at “Y,” offset, or intersections with more than four legs because the geometry of these intersections frequently does not provide an adequate line of sight from all intersection legs to a center-mounted beacon.

Effectiveness

A late 1990s study (*98*) used two to three years of crash data for seven beacon-controlled intersections. Right-angle crashes were used in the analysis. The data showed a decrease in fatal and serious injury crashes and an increase in minor visible injury and property-damage-only crashes. However, none of these results were statistically significant; therefore, the results were determined to be inconclusive. The authors did find that the use of intersection control beacons may result in lower vehicular speeds in the major directions, particularly at intersections with inadequate sight distance.

Another 1990s study (*99*) conducted an analysis using crash experience for three years before and three years after the installation of flashing beacons at eight intersections in Minnesota. Overall, there was a 39 percent reduction in crashes after the installation of overhead flashers, varying from a 4 percent increase to a 63 percent decrease in crashes.

Results of a 1970 study (*100*) of crashes before and after installation of flashers at Stop sign controlled rural intersections are shown in Table 6-3. The authors state that there was a statistically significant decrease in crash rates for the aggregate of the sites. Most noticeable was the decrease in single-vehicle crashes.

Table 6-3. Change in Crash Experience with Addition of Flashers at Stop Sign Controlled Rural Intersections (*100*).

Intersection Type	Percent Change					
	Total	Single Vehicle	Left-Turn	Rear-End	Angle	Other
4-Leg	- 18	- 62	- 24	- 5	- 18	- 4
3-Leg	- 65	- 62	--	- 100	- 100	- 50
Channelized	- 47	- 63	+ 70	- 63	- 50	- 33
Non-channelized	+ 24	- 50	+ 1	+ 3	+ 88	+ 32
TOTAL	**- 27**	**- 62**	**- 13**	**- 33**	**- 21**	**- 17**

-- = No crashes occurred in the before period.

Table 6-4 shows a comparison of safety impacts for different types of flasher control from a mid-1960s California study. It is interesting that the addition of four-way red flashers has an effect somewhat similar to that of traffic signal control: that angle collisions are reduced but rear-end crashes increase significantly. An overall decrease of 43 percent in total crashes and 80 percent decrease in fatal crashes was found in the study. An interesting facet of the California study was a comparison of the impact on crash rates produced when a four-way red flasher (i.e., four-way stop control) was installed at intersections with various previous forms of traffic control as shown in Table 6-5. The California study also analyzed the before-and-after severity of crashes, as a result of installing flashing yellow beacons at the approaches of intersections. While there was an increase in personal injury crashes, property damage crashes decreased 41 percent, and there was a 100 percent decrease in fatalities.

Table 6-4. Change in Crash Rates at Intersections with Addition of Flashing Beacons (*95*).

Crash Type	Percent Change		
	Red-Yellow Flashers		4-Way Red Flashers
	3-Leg	4-Leg	
Single Vehicle	- 29	- 82	- 52
Multiple Vehicle			
Left-Turn	- 7	- 44	- 82
Rear-End	- 46	--	100
Angle	- 33	- 14	- 82
Other	- 25	- 63	- 73
-- = No crashes occurred in the before period.			

Table 6-5. Change in Crash Rates When Four-Way Stop Control with Flashing Beacons Are Added to Intersections with Various Types of Traffic Control (*95*).

Previous Control	Percent Change				
	Crash Type		Severity		
	Single Vehicle	Multiple Vehicle	Property Damage	Injury	Fatal
2-Way Stop	- 30	- 71	- 57	- 71	- 100
4-Way Stop	- 100	- 7	+ 70	- 65	- 100
Red-Yellow Flashers	- 10	- 87	- 76	- 95	- 100

A study in Ohio examined 82 intersections, each of which was controlled by a flashing beacon (*101*). The results indicated that there is a reduction in crash rate with the installation of a flashing beacon. The evaluation of the different types of flashers revealed that intersections had a significant reduction in total crashes when equipped with the following types of flashers:

A Standard Stop sign on the side of the road with one or two flashing beacons attached to the support post;

A Single unit placed overhead in the center of the minor approach roadway and displaying two beacons flashing alternately; or

A Two units placed overhead, each centered over a lane on the minor road, each unit consisting of one beacon.

When intersection type was investigated, only one group had a significant reduction in crash rate—four-leg intersections with two-lane main and minor approaches.

The characteristics of traffic flow at rural, low-volume intersections controlled by Stop signs and by intersection control beacons in conjunction with Stop signs were examined in a 1990s study (*102*). The study found that intersection control beacons generally reduced vehicular speeds in the major directions, particularly at intersections with inadequate sight distance. The intersection control beacons had, in general, little or no impact on accepted or rejected gaps. A large proportion of drivers (40 to 90 percent) violated Stop sign laws by not completely stopping at the intersections. The intersection control beacons were not necessarily effective in reducing Stop sign violations or crashes (see examples in Figure 6-11).

Figure 6-11. Examples of Intersections with Flashing Beacons.

A Signalization

Overview	Traffic signals may be installed at intersections where volumes, turning movements, and/or crash rates are sufficiently high to warrant an increased level of traffic control.
Effectiveness	Previous studies have shown that traffic signals are effective in reducing the number of severe crashes at intersections. However, total crash rates may increase.
Relative Cost	High

Overview

Traffic control measures, such as signalization, are used at intersections where traffic volumes or conflicts are sufficiently large to require the management of the flows of individual movements and/or where crash rates are undesirably high (see Figure 6-12).

Figure 6-12. Example of Signalization.

Signals indicate the movements that are to use the intersection at a given time, which eliminates certain conflicts. Because signals can result in delay to vehicles on each approach, they should only be used when necessary. The key factor in the determination of when to use a signal is approach traffic volume; however, other factors such as pedestrian volume and crash experience can also influence the decision. Warrants on when to use signals are included in the *Texas MUTCD (5).*

Two recent studies examined rural signalized intersections (*103, 104*). One study developed a new intelligent detection-control system while the other developed guidelines for the use of video detection. The first study developed and tested a detection-control system that is capable of minimizing both delay and crash frequency at rural intersections (*103*). The second study gathered information about video imaging vehicle detection systems and developed guidelines that describe the "best" practices for Texas conditions (*104*).

Effectiveness

Properly located and operated signals typically reduce the frequency of certain types of crashes, especially the right-angle crashes. Some crashes (i.e., rear-end crashes), however, can increase. A comprehensive review of a large nationwide crash database led to the following conclusions (*105*):

- Signalization leads to a reduction in right-angle crashes and an increase in rear-end crashes.
- Signalized intersections have higher crash rates, but this is usually offset by less severity per crash, which leads to no significant change in total crash-related economic loss.
- There appears to be no clear-cut evidence that the installation of signals will reduce the adverse effects of crashes. This appears to hold especially for those cases where signals would not be warranted.
- As far as crash patterns are concerned, there is no clear-cut justification for lowering numerical warrant minimums for rural conditions. In fact, the effect of unwarranted signals is more adverse for rural conditions.

A study of 2301 intersection crashes in rural communities of Virginia confirmed previous findings on rear-end and right-angle relationships and total crashes (see Table 6-6). The findings in Table 6-6 are subdivided to show crash experience by type of intersection geometry in Table 6-7.

Table 6-6. Variation in Crash Type and Rate with Type of Control – Rural Municipalities (*106*).

Type of Control	Crash Type - Percent of Total				Crash Rate (crashes per million entering vehicles)
	Rear-End	Angle	Side-Swipe	Other	
Traffic Signal	43	37	12	8	1.26
Yield or Stop Sign	29	49	10	12	1.08

Table 6-7. Variation of Crash Type and Rate with Intersection Geometry and Traffic Control – Rural Municipalities (*106*).

Intersection Geometrics and Control		Crash Type - Percent of Total				Crash Rate (crashes per million entering vehicles)
		Rear-End	Angle	Side-Swipe	Other	
Cross	Signals	40	40	11	9	1.47
	Stop Sign	22	59	10	9	1.27
T	Signals	58	25	11	6	0.82
	Stop Sign	28	43	12	17	0.79
Y	Signals	42	29	25	4	1.40
	Stop Sign	66	23	4	7	1.04
Offset	Stop Sign	34	30	13	23	0.76

The general findings were similar to those from other studies of the same nature – that installation of traffic signal controls could result in slight increases in crash rates, significant increases in rear-end crashes, and comparable decreases in angle collisions. Table 6-7 adds further confirmation of previous studies showing that crash rates at T-intersections are markedly less than those at other types of crossings.

A sample of rural high-speed at-grade intersections was studied by Agent (*78*) to determine the type of traffic control measures used, to establish the types of crashes that occur, and to discover the factors that contribute to these crashes. Table 6-8 is a crash summary for the study sites. Crash rates were similar for the different types of traffic control. During the study period, 47 sites had a change in traffic control. Table 6-9 lists the change in crashes. Data showed that a slight benefit occurred with the installation of an intersection beacon. An overall benefit was observed when a traffic signal was installed, although results were not consistent.

The characteristics of crashes at rural intersections were compared with crashes occurring at all intersections in the state. The largest difference in type of crash was the much higher percentage of opposing left-turn crashes that occurred at the study locations. The comparison indicated that crashes at the study locations were:

- More severe,
- More likely to occur during darkness at an unlighted location,
- Less likely to occur during snow or ice conditions, and
- More likely to involve failure to yield right-of-way, disregard of a traffic control device, or defective brakes as a contributing factor.

Table 6-8. Crash Summary by Type of Right-of-Way Control (*105*).

Right-of-Way Control	Number of Locations	Crashes	Number of Vehicles (MV)	Crash per MV	MV per year
Stop Sign	27	338	309	1.1	5.6
Stop Sign with Beacon	37	541	448	1.2	4.8
Traffic Signal	46	1290	1058	1.2	6.1

Table 6-9. Change in Crashes When Right-of-Way Control Changed (*105*).

Change in Right-of-Way Control		Number of Locations	Change in Crashes/Year			Statistically Significant Change	
Original Control	New Control		Increase	Decrease	No Change	Increase	Decrease
Stop Sign	Stop Sign w/ Beacon	11	4	7	0	2	2
Stop Sign	Traffic Signal	16	7	7	2	4	3
Stop Sign w/ Beacon	Traffic Signal	20	7	12	1	3	6

A High-Intensity Strobe Lights

Overview	High-intensity strobe lights are installed inside the lens of a traffic signal head. They are used to increase the visibility of the signal.
Effectiveness	Research finds that high-intensity strobe lights have minimal to no effect on reducing crashes.
Relative Cost	Low Full installation of a new strobe-imbedded signal head in 2001 was approximately $800. Retrofit installation of a strobe light in an existing signal head in 2001 was approximately $600.

Overview

High-intensity strobe lights are intended to provide the approaching driver with improved visibility of signal heads. Note that the high-intensity strobe device is experimental. When considering new technologies not included in the *Texas MUTCD*, a request for experimentation is to be submitted and approved before installation of the device. Specific concerns that affect the locations where strobe light installation is appropriate include: approach speed, horizontal and vertical curvature, truck volumes, existing illumination, and isolation of the intersection (*107*).

Strobe-enhanced signals primarily consist of a standard signal head, with a custom visor and the strobe light components (see Figures 6-13 and 6-14). The strobe system provides a pulsating white strobe with the solid red indication. It is set to flash at a predetermined rate and duration whenever the red signal head is activated. A common flash rate is once per second for the entire duration of a red signal's interval (*108*). The idea is that the added visual stimulus of the flashing strobe will draw the driver's attention to the signal, thus improving visibility and available time to respond.

Strobe lights are used by the Virginia Department of Transportation primarily for the following:

A Areas with a high truck volume and high speed;

A Areas with a high crash rate;

A Areas with road geometries, especially grades (downgrades), horizontal curves, and other features, that result in limited sight distance; and

A Isolated intersections where a signal is unexpected (*109*).

They have also been suggested for use at the following locations:

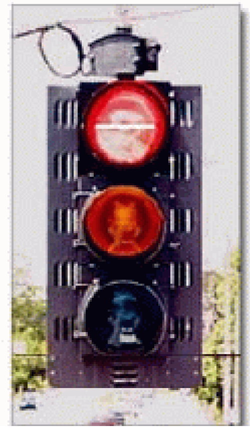


Figure 6-13. Example of a High-Intensity Strobe (*73*).

A Isolated, high-speed, rural intersections;

A First signalized intersection into an urbanized area after an extended road section without a signal;

A First signalized intersection after a transition from a grade-separated or limited access highway to an at-grade highway with intersections; and

A Locations where background lighting and signs (visual noise) are a problem.

Effectiveness

Virginia sponsored a study to evaluate the effectiveness of using strobe lights in the red lens of traffic signals (*109*). Its before-and-after analyses of six intersections found no statistical evidence indicating that strobe lights are effective in reducing crashes. Findings showed marginal improvements at some locations and no effect or negative effects at other locations. Changes in number of crashes varied from a 75 percent decrease (from four before to one after angle crash) to a 400 percent increase (from one to five angle crashes). The results from this study led the researchers to conclude that they had no basis to recommend the use of strobe lights. They did note that although the sample size was too small to allow definitive conclusions, the use of two strobe lights per approach appeared to be more effective than the use of one per approach.

Figure 6-14. Strobe-Enhanced Signal Heads.

Another study undertaken by Ryan (*110*) determined the change in crashes at intersections with strobe-enhanced signals. In a before-and-after study of 10 intersections, it was found that the number of crashes and crash rates decreased following installation of strobes; however, the number of observations or the change in crashes or crash rates was not statistically significant.

A Backplates on Traffic Signals

Overview	Backplates enhance the contrast between traffic signals and their surroundings.
Effectiveness	Backplates are especially effective at east-west approaches that experience sun glare and on high-speed approaches.
Relative Cost	Low

Overview

A signal backplate enhances the target value of signal faces when viewed against a bright sky or confusing backgrounds. The use of backplates enhances the contrast between the traffic signals and their surroundings for both day and night conditions, which is also helpful to older drivers (*5*).

Effectiveness

Backplates make it easier for the motorist to distinguish traffic signal displays from tree or sky background (see Figure 6-15). While a backplate would be helpful at any signal, areas of greatest need include:

A East-west approaches that experience sun glare, and

A High-speed approaches.

Figure 6-15. Heads with and without Backplates (*111*).

Backplates can attach easily to signals on mast arm poles. If a backplate is installed on a signal head that is suspended by a single span wire, it is recommended that a second span wire is attached to the bottom of the signal head.

The front surfaces of backplates are to have a dull black finish to minimize light reflection and to increase contrast between the signal indication and its background (see Figure 6-16) (*5*).

Figure 6-16. Backplates at Local Intersection.

AIllumination

Overview	The objective of a fixed lighting system is to supplement the headlights of automobiles and to render objects that are distant, complex, or that have low contrast more visible to motorists and pedestrians.
Effectiveness	Estimates of the safety effects of public lighting are, in rounded values, a 65 percent reduction in nighttime fatal crashes, a 30 percent reduction in nighttime injury crashes, and a 15 percent reduction in nighttime property-damage-only crashes.
Relative Cost	Low ($400-1500 installation and $50-500/yr/light maintenance and operations)

Overview

The objective of a fixed lighting system is to supplement the headlights of automobiles and to render objects that are distant, complex, or that have low contrast more visible to motorists and pedestrians. Figures 6-17 and 6-18 are examples of lighting used at a complex intersection. Because of costs, continuous lighting systems are not generally employed in rural areas; however, lighting systems can improve safety at isolated, rural at-grade intersections. The reader can consult the following for more information on the design of a lighting system:

Figure 6-17. Example of Lighting at Complex Intersection.

A AASHTO *Informational Guide for Roadway Lighting* (*112*),
A AASHTO *Roadside Design Guide* (*9*),
A FHWA *Roadway Lighting Handbook* (*113*), and
A FHWA *Addendum to Chapter Six of the Roadway Lighting Handbook — Designing the Lighting System Using Pavement Luminance* (*114*).

Wortman et al. (*115*) recommended that lighting should be considered at a rural intersection if the average number of nighttime crashes (N) per year exceeds the average number of day crashes (D) per year divided by 3. A benefit-cost analysis should then be performed to determine if the benefits of lighting the intersection exceed the cost of providing the lighting system (*115*). There are other sources that have warrants for roadway lighting including AASHTO's *An Informational Guide for Roadway Lighting* and NCHRP Report 152 (*116*).

Figure 6-18. Example of Lighting at Complex Intersection.

Effectiveness

Public lighting of roads is widely accepted as an effective road crash countermeasure. Numerous studies determined the effects of public lighting on the number of crashes. A synthesis of safety research related to traffic control and roadway elements summarized the results of research and found that "night crashes can be substantially reduced in number and severity by the use of good road lighting" (*117*). A quantitative meta-analysis of 37 evaluation studies was conducted to determine the safety effects of public lighting and to examine the validity of the combined results (*118*). The results of the evaluation studies were the same for all three environments: urban, rural, and freeway. In addition, roadway lighting appears to have a greater effect on pedestrian crashes than on other types of crashes and a greater effect at junctions than at other locations. It was concluded that the best estimates of the safety effects of public lighting are, in rounded values, a 65 percent reduction in nighttime fatal crashes, a 30 percent reduction in nighttime injury crashes, and a 15 percent reduction in nighttime property-damage-only crashes.

A report by the Federal Highway Administration documenting the effectiveness of various types of intersection and traffic control improvements found that intersection lighting had the highest benefit-cost ratio (21:1) of the treatments studied (*119*). A 1999 Minnesota report found that street lighting had a benefit-cost ratio of 15:1 and concluded that its use in reducing nighttime crashes at rural intersections would likely be far more effective than either rumble strips or overhead flashing beacons (*120*).

A Sight Obstruction Reduction

Overview	The sight distance at an intersection can be affected by obstructing foliage, buildings too close to the intersection, changes in vertical and horizontal alignment, parked vehicles, and signs on public or private properties.
Effectiveness	Whether urban or rural, studies show that the crash rate at most intersections will generally decrease when sight obstructions are removed.
Relative Cost	Low

Overview

A Federal Highway Safety Program indicated that out of a total of 34 different improvement types, the improvement of sight distances at intersections was the most cost effective. Improvement benefits exceeded costs by a factor of five (*121*).

Effectiveness

Hanna et al. (*122*) studied several intersections located in rural municipalities for a two-year period. They found that the intersections with poor sight distance on one or more traffic approaches tend to have a higher than normal crash rate, particularly with regard to angle collisions. In the study, the average crash rate was 1.13, while the average crash rate for intersections with poor sight distance is 1.33. This finding supports the statement that "intersections with poor sight distance experience a higher than normal" crash rate, however, "poor" sight distance was not quantified.

Sight distances at five intersections were improved in a before-and-after study in Concord, California. Total crashes at these intersections dropped from 39 in the year before to 13 in the year after obstruction removal (67 percent reduction). In the same study, many other intersections at other locations in Concord were improved by use of signal installation or modification, delineation striping, improved pavement markings, and increased police enforcement. Although all improvements resulted in a reduction in crashes, the greatest percentage of reduction was experienced at the intersections where the sight distances were improved (*123*).

A study using urban settings found that foliage and buildings obstructed the view at the majority of intersections, whereas linear obstacles (walls and fences) obstructed less often (*124*). The authors calculated expected reduction in crash rate for increased sight distance by ADT (see Table 6-10). For this calculation, they began with an intersection having an obstruction which allows drivers approaching the intersection to see only 20 ft (6.1 m) of side approach. The authors then derived the predicted reduction in crashes based on increasing the sight distance along the side approach to a given range.

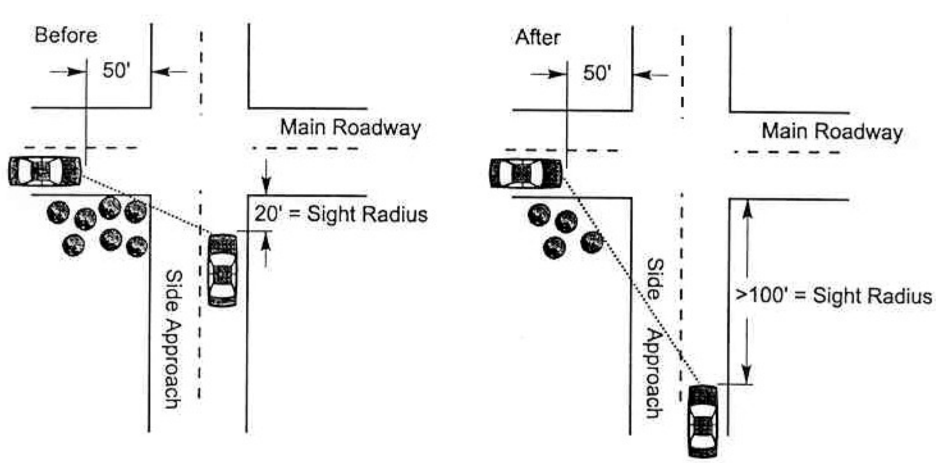
Table 6-10. Expected Effect of Increased Sight Distance on Side Approach on Crash Reduction by ADT (*124*).

Average Daily Traffic	Increased Sight Distance on Side Approach, ft (m) [a]		
	20-49 ft (6.1-14.9 m)	50-99 ft (15.2-30.2 m)	> 100 ft (> 30.2 m)
< 5000	0.18[b]	0.20	0.30
5000-10,000	1.00	1.30	1.40
10,000- 15,000	0.87	2.26	3.46
> 15,000	5.25	7.41	11.26

[a] At 50 ft (15.2 m) from intersection increasing obstruction on approaching leg from initial < 20 ft (6.1 m) from intersection.
[b] Crash reduction = crashes/year/intersection.

To illustrate the use of this table, consider the intersection in Figure 6-19 where at 50 ft (15.2 m) from the intersection, an obstruction exists which allows drivers to see an approaching vehicle on a side approach only if it is within 20 ft (6.1 m) of the intersection. Assume an ADT of less than 5000 vehicles per day. Increasing the sight distance on the side approach to more than 100 ft (30.5 m) from that intersection should result in a crash reduction of 0.30 crashes per year per intersection.

The Interactive Highway Safety Design Model (IHSDM) crash prediction algorithm for rural two-lane highways incorporates the judgment by an expert panel regarding sight distance. The panel determined that if there is a sight distance obstruction in one quadrant of a stop-controlled intersection and if the equivalent speed for the sight distance is more than 12.4 mph (20 km/h) less than the design speed of the major road, then crash frequency would increase by approximately 5 percent (*28*).



1 ft = 0.305 m

Figure 6-19. Example of Increased Sight Radius on Crash Reduction (*124*).

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CHAPTER 7
EXPERIENCES WITH TREATMENTS

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A Overview

The following experiences by TxDOT districts are discussed in this chapter, and their approximate locations are shown in Figure 7-1:

- Barrier Reflectors
- Intersection Reconfiguration and New Safety End Treatments
- Rumble Strips and Advance Signing at Intersection
- Super 2 Roadway with Edge Line Rumble Strips
- Shoulder Treatment
- Rumble Strips Approaching T-Intersection
- Speed Detection and Notification Device
- All-Way Stop Control and Warning Signs
- Roadway Widening
- Pavement Edge Drop-Off Improvements
- Profile Markings and Other Treatments
- Traffic Signals on High Center
- Systematic Intersection Improvements

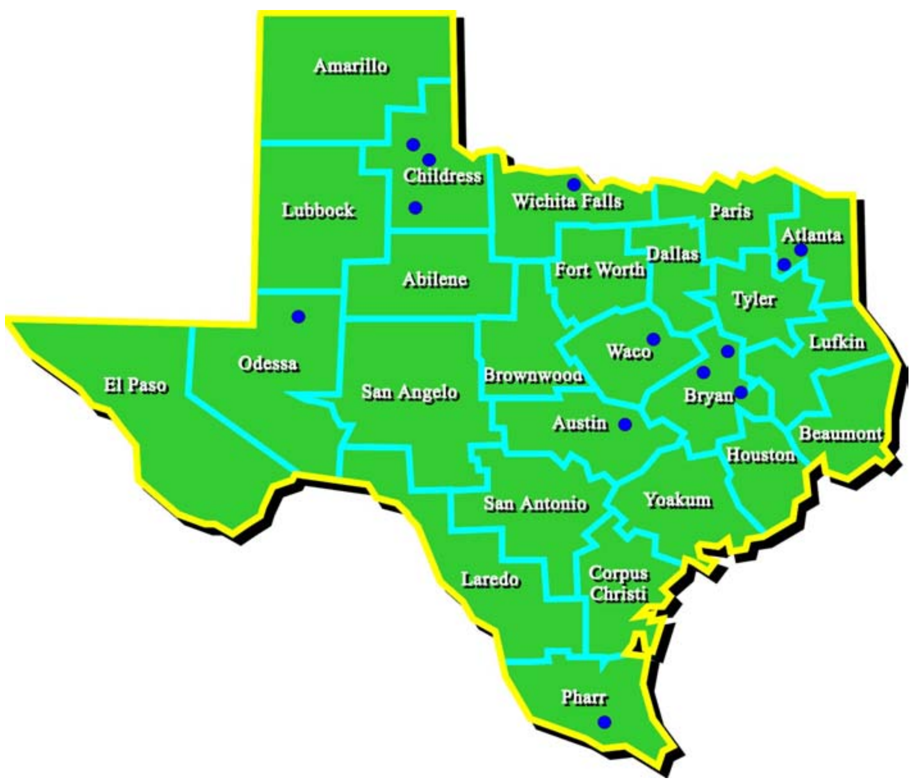


Figure 7-1. Location of Experiences in TxDOT Districts.

A Barrier Reflectors

In July 1998, TxDOT Pharr District personnel installed barrier reflectors (also known as in-line reflectors) on SH 16 north of Hebbronville (see Figures 7-2 to 7-4). The reflectors were installed because TxDOT personnel saw how they helped delineate guardrail locations in other parts of the state and wanted to try them in the Pharr District. The cost for the installation was minimal; TxDOT sign crews installed the reflectors while they were in the area for other activities. The material cost for the reflectors is $2.72 per reflector (TxDOT inventory stock number 153915), although another TxDOT district provided the materials for the installation at this site.

The ADT on SH 16 is 1600 vehicles per day, and there have not been any other significant changes or improvements on this roadway. Since the installation of the reflectors, maintenance crews report that they have had to repair more rails that did not have the reflectors than rails that did have the reflectors.

Figure 7-2. Guardrails on SH 16, North of Hebbronville.

TxDOT has received positive comments from the public, including comments that the bi-directional reflectors help guide drivers down the center of the road between the guardrails during fog or heavy rain. Additionally, long-haul truck drivers have stated that the reflectors help to delineate the guardrails from a much greater distance. Older drivers have noted that the rails are much more visible with the barrier reflectors.

Figure 7-3. Barrier Reflectors on SH 16 at Night.

Figure 7-4. Close-Up of Barrier Reflector.

A Intersection Reconfiguration and New Safety End Treatments

FM 1212 in Martin County is a rural roadway used by farmers, ranchers, and other local traffic in addition to oil-field traffic. The roadway has an ADT of 300 vehicles per day (1998). When it was time to repair FM 1212 in Martin County, TxDOT made the decision to improve the roadway by reconfiguring the intersection with FM 1208. Although the roadway did not have many crashes, TxDOT believed that this was a good opportunity to improve the safety of the site.

In 1999, TxDOT reconstructed the roadway using a new configuration that reduced the number of intersections from two to one. Figures 7-5 and 7-6 illustrate the roadway realignment plan, including the former roadway sections and intersections (which were obliterated) and the new intersection.

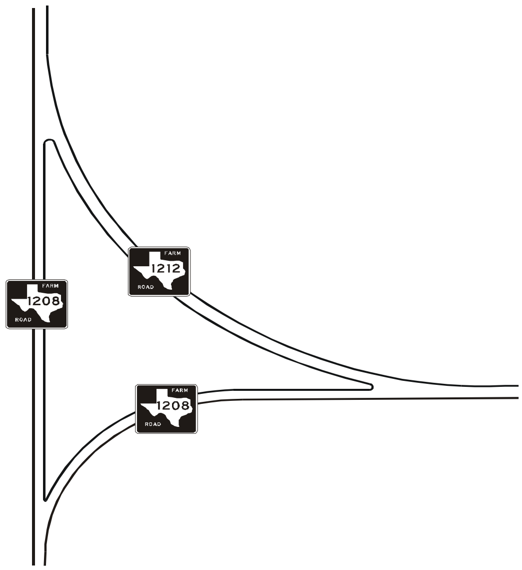


Figure 7-5. Previous Roadway Alignment.

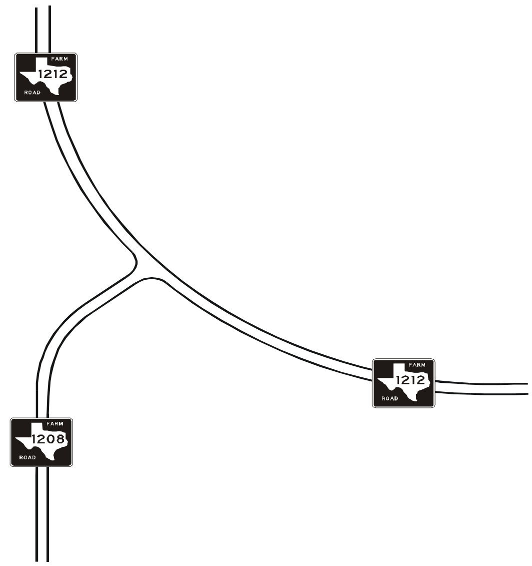


Figure 7-6. New Roadway Alignment.

Figures 7-7, 7-8, and 7-9 illustrate the realigned roadway and intersection. Older drainage structures were also replaced with safety end treatments (SETs) as part of this project (see Figure 7-10). The cost for the roadway realignment in 1999 was $52,751, and the cost for the SETs was $78,190.

The TxDOT district believes the treatment is effective because the number of intersections has been reduced from two to one, it has not received any complaints about the project, and the roadway is much easier to maintain. However, there are still a few drivers who bypass the intersection and drive on the abandoned roadway. TxDOT is planning two similar roadway realignments in northeast Midland County.

Figure 7-7. Obliterated Roadway Section.

Figure 7-8. New Roadway Section.

Figure 7-9. New Roadway Intersection.

Figure 7-10. New Safety End Treatment on FM 1212.

A Rumble Strips and Advance Signing at Intersection

FM 21 is a 60 mph (97 km/h) roadway with an ADT of 1650 vehicles per day located in Titus County. There is a severe sight distance restriction in one direction prior to the intersection with CR 2347 (see Figure 7-11). Although there was very little history of crashes at this intersection, there were several complaints about the intersection and the lack of sight distance. The district decided to warn drivers of the upcoming intersection.

Figure 7-11. Grade Change Sight Distance Restriction.

In October 2000, the Atlanta District installed rumble strips and "45 MPH" pavement markings on FM 21 on the approach with the sight distance restriction as shown in Figures 7-12 and 7-13. Although these measures were installed primarily in response to complaints, they may also be considered as preventative treatments for future traffic, as a subdivision is being developed on CR 2347. The cost for the rumble strips and pavement markings was approximately $2000.

Figure 7-12. Rumble Strips Warning of Approaching Intersection.

The TxDOT district considers the treatment to be effective because it has received many positive comments and fewer complaints from the public, indicating that drivers like this treatment.

Figure 7-13. Pavement Markings Supplementing Advisory Speed Sign.

A Super 2 Roadway with Edge Line Rumble Strips

TxDOT installed a Super 2 section on US 83 when upgrading the roadway section (see Figure 7-14). The Super 2 design provides alternating passing lane sections on a previous two-lane, two-way roadway (see Figure 7-15). The Childress District installed the Super 2 section because it believed the roadway would be an economically feasible solution to provide safe passing maneuvers on US 83. Figure 7-16 shows an example of a passing lane transition section.

Figure 7-14. Passing Lane Section on US 83.

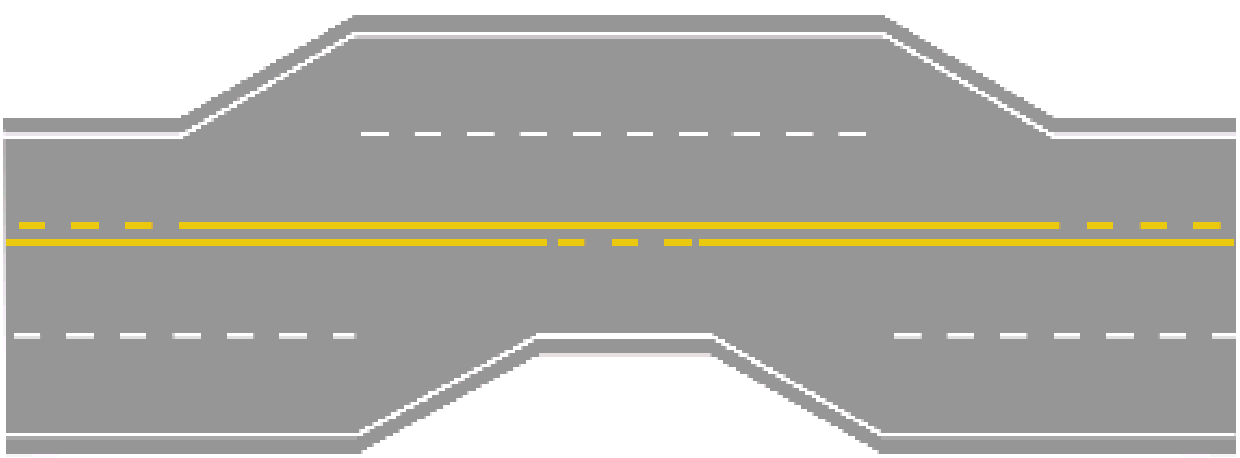


Figure 7-15. Passing Lane Configuration on US 83.

The project was completed in January 2000. The cost for the 6-mi (9.7 km) section was almost $5 million; however, 1.5 mi (2.4 km) of the project was a five-lane section leading into an urban area.

Figure 7-16. Passing Lane Transition.

Edge line rumble strips were also installed as a part of this project (see Figure 7-17). Based on positive feedback on the use of rumble strips on divided highways, TxDOT was willing to try the rumble strips on the Super 2 roadway to determine how the traveling public felt about their use on this type of roadway. TxDOT installed the rumble strips in accordance with TxDOT Standard ST (1)-96 for Depressed Shoulder Texturing, and the cost of installation was approximately $480 per mile (1.61 km) for both shoulders. TxDOT believes that the rumble strips have helped to prevent run-off-road crashes, keep vehicles in the driving lane, and help prevent driving on the shoulders. As an additional benefit, snow plow crews were able to feel the rumble strips during snow plowing operations and were warned that they were drifting onto the shoulder.

The Childress District has received positive comments from local farmers regarding the Super 2 treatment because they now have a lane in which to drive. It has also received positive feedback from the rest of the traveling public and believes that provision of designated passing lanes has increased safety during passing maneuvers.

Figure 7-17. Close-Up of Edge Line Rumble Strips.

A Shoulder Treatment

FM 3002 in Cooke County is located in the southeast corner of the county. It is a 40-ft (12 m) section, including two 12-ft (3.7 m) lanes and two 8-ft (2.4 m) shoulders. FM 3002 serves as a commuter route to Dallas-Ft. Worth, and it also carries tourist traffic to Ray Roberts State Park. The roadway was constructed in the mid-1980s with 8-inch (20.3 cm) base (but no surface) on the shoulders. Due to the increasing traffic, the need for paved shoulders, and some run-off-road crashes, TxDOT reconstructed the shoulders. It removed and recompacted 6 inches (15.2 cm) of the shoulders and surfaced the entire roadway width. As a part of this project, the shoulders were also texturized in order to provide visual, audible, and tactile clues when a vehicle was leaving the travel lane (see Figures 7-18 and 7-19). The texturing was accomplished by applying a larger, uncoated seal coat on the shoulder while using a smaller, coated aggregate seal coat on the driving lanes. (The entire roadway was surfaced with straight white aggregate, while an additional black surface was added to the driving lanes.) This work was completed in February 2001.

Figure 7-18. Shoulder Treatment on FM 3002.

There was no additional cost for installing this countermeasure versus not installing it because a surface was required on the shoulder. However, the approximate cost of just seal coating the shoulder is $1.00 per square yard (0.9 m) (if not resurfacing the roadway).

The TxDOT district believes this treatment has been effective operationally due to the visual, audible, and tactile cues when a vehicle strays onto the shoulder. It is also perceived to have reduced the number of single-vehicle run-off-road crashes. This treatment had also received positive public comments regarding the drastic visual effect it has for nighttime travel. TxDOT is now adding shoulders and using this treatment on two other roadways.

Figure 7-19. Another View of Shoulder Treatment.

A Rumble Strips Approaching T-Intersection

US 62/82 (SH 114) tees into US 83 in Guthrie, Texas in King County. Crashes were occurring where the drivers were not stopping at the intersection; instead, they drove through the intersection and into the property owner's fence. The Highway Intersection 1500 ft sign, Stop Ahead symbol sign with flashing beacons, and red flashing beacons on the mast arm post were installed in the summer of 1997 (see Figure 7-20).

Figure 7-20. Signs and Flashers at Intersection of US 62/82 with US 83.

In April 1998, TxDOT installed two sets of rumble strips on US 62/82 approaching the intersection in order to provide additional warning of the intersection (see Figure 7-21). The rumble strips consist of 10 strips that are 4.5-inches (11.4 cm) wide with a space of 9.5 inches (24.1 cm) between the rumble strips. The cost for materials and labor was $456. The sets of rumble strips were located at 480 ft (146 m) and 1236 ft (377 m) from the intersection. TxDOT also installed "Stop Ahead" pavement markings (see Figure 7-22) and a Rumble Strips Ahead sign during the summer of 1998.

The TxDOT district believes the treatment has been effective because there have been fewer crashes and fewer complaints from the property owner. A grade separation is being designed for this location and construction is planned for 2003, so this treatment is considered an interim measure.

Figure 7-21. Rumble Strips Preceding Flasher and Sign on US 62/82.

Figure 7-22. "Stop Ahead" Pavement Marking on US 62/82.

Speed Detection and Notification Device

FM 557 at Couch Mountain (Camp County) has a very tight 25 mph (40 km/h) curve that also includes a large change in elevation. The curve is located in a remote area between two towns. The ADT is 830, and the traffic is approximately 70 percent local with few trucks. Two fatalities occurred at this location when drivers missed the curve and went off the roadway.

When TxDOT responded to requests to improve the existing conditions, standard curve warning signs were in place. The W1-1 signs were located at 625 ft (191 m) prior to the curve on each approach. In September 1998, TxDOT added these measures in an effort to improve the safety on the curve (see Figures 7-23 and 7-24):

- Rumble strips, which were 4-inch (10 cm) lines of layers of hot tape. The original hot tape rumble strips have recently been replaced with preformed rumble strips, which are also 4 inches (10 cm) wide with 0.5-inch (1 cm) grooves (see Figure 7-25). These strips are installed with bituminous adhesive,
- "25 MPH" pavement markings approaching the curve,
- Flashing beacons on the warning signs, and
- A speed notification and detection device.

Figure 7-23. Various Warning Devices for Horizontal Curve.

TxDOT had looked for a dynamic solution that did not involve reconstruction. The solution was the addition of a speed notification and detection device—a flashing sign that advises drivers to reduce their speed when they are detected to be driving more than 5 mph (8 km/h) over the speed limit. A radar detector measures speeds and displays them using a speed display sign stating: "YOUR SPEED IS . . .". The setup was modified for this project so that when a speed is determined, a contact closure is opened or closed depending upon whether the beacons need to be activated.

Figure 7-24. Flashers Activated When Speeds Exceed 30 MPH.

When approaching the curve, drivers see the W1-1 warning sign at 625 ft (191 m) prior to the curve. Knowing that drivers don't normally slow to 25 mph (40 km/h) at this point, the overhead sign is located in the point of curvature for the curve to again warn drivers to slow. The radar is set to start processing the speed data about 300 ft (92 m) before reaching the overhead sign. The beacons will start flashing within 0.5 second if a vehicle is traveling at 30 mph (48 km/h) or over, will stop flashing if the vehicle slows to below 30 mph (48 km/h), and will be triggered again if the vehicle speeds up. The intent is that the beacons are flashing only for vehicles that are traveling at 30 mph (48 km/h) or greater rather than flashing continuously, making the system more dynamic and driver responsive. The cost for the sign system and installation was approximately $18,000.

The speed detection and notification device system was considered so successful that it has now been installed at additional curves in the district. Requests for additional installations have also been received.

Note that the speed detection and notification device system is experimental. When considering new technologies not included in the *Texas MUTCD,* a request for experimentation is to be submitted before installation of the device.

Figure 7-25. Recently Replaced Rumble Strips.

A All-Way Stop Control and Warning Signs

The intersection of State Highway 7 and State Highway 79 has experienced several severe right-angle and rear-end collisions over the past 25 years. Several approaches have been implemented at this location to improve safety with limited results. In November 1980, the TxDOT Bryan District installed overhead flashing signals at the intersection. A flashing red beacon was installed on the minor highway, and yellow flashing beacons were placed overhead for the major approach. Officials noticed improvement for the intersection, but as traffic volumes continued to increase, crashes directly associated with the intersection increased. One potential concern with the overhead beacons was that unfamiliar drivers did not receive adequate decision time because of the complex and unexpected intersection on a relatively straight rural roadway.

In September 1994, right-turn lanes were added to all four approaches with Cross Street Does Not Stop advance warning signs on the minor approach. Severe crashes in 1997 prompted a review of the location. In December 1997, a decision was made to remove the overhead flashers and to convert the intersection to all-way stop control. In addition to converting the control at the intersection to an all-way stop, additional signing and beacons were added. District personnel installed advance flashing beacons with Stop Ahead signs on all approaches (see Figure 7-26). At the intersection, flashers were added to the Stop signs (see Figure 7-27). The project was completed in March of 1998.

Figure 7-26. Beacons on Stop Ahead Sign.

Figure 7-27. Different Views of Beacons on Stop Sign.

Preliminary results in early 1999 suggested that the countermeasures were effective at reducing the number of crashes. Interviews conducted with state traffic operations officials and local store owners indicated that there have not been any crashes at that location since installation of the advance warning signs and the flashing beacons, and that the treatment is well received.

Additional data are now available, and a review of the crash data available reveals that only one crash occurred at the intersection in the 21 months following the completion of the project. The average number of crashes per month decreased from 0.76 crashes per month (before the all-way stop control and signs were installed) to 0.05 crashes per month (after the stop control and signs were installed).

A Roadway Widening

FM 183 in Coryell County has an ADT of 200 vehicles per day, consisting of primarily local traffic. The two-lane roadway was originally 18 ft (5.5 m) wide. Although the roadway did not have a history of crashes, it did have raveled edges, narrow lanes, no shoulders, and pavement edge drop-offs. Previous improvements to the roadway included pulling the edges, making minor edge repairs with pre-mix, and adding base to the edges with unacceptable drop-offs.

In April and May of 2001, the TxDOT Waco District widened 10 miles of the roadway by adding a total width of 4 ft (1.2 m) (2 ft [0.6 m] on each side). Figures 7-28 and 7-29 show views of the roadway. The additional roadway width was added in order to provide a more permanent roadway upgrade. The cost of the roadway widening was $199,000.

Figure 7-28. Widened Section of FM 183.

The TxDOT district notes that if using this technique again, it would use a Type B hot mix on the first course to give it more stability and then add type D hot mix on the second course for the finished surface.

The roadway widening provides better driving conditions, including lanes that are 11 ft (3.4 m) wide versus 8.5 to 9 ft (2.6 to 2.7 m) wide. The TxDOT district believes that this treatment would be beneficial for other narrow farm-to-market roads that do not require a lot of subgrade work.

Figure 7-29. Another View of FM 183.

A Pavement Edge Drop-Off Improvements

US 287 in Hall County near Memphis, Texas, was overlayed as part of a TxDOT construction project. Rains and wind gradually eroded the shoulder backfill in the one- to two-year period following the construction. A result of the resurfacing was pavement edge drop-offs, as shown in Figure 7-30.

In August 2002, TxDOT added fill material to eliminate the pavement edge drop-offs and to stabilize the eroded shoulder backfill (see Figure 7-31). Work crews rolled and seeded the fill material and placed a tackifier emulsion new fill material in an effort to prevent further erosion. The emulsion contains glue to help hold the seeding materials in place.

The TxDOT district believes the treatment is working well in the four months since the fill material has been installed.

Figure 7-30. Shoulder Drop-Off Examples.

Figure 7-31. Motor Grader Adding Fill Material to Shoulder.

A Profile Markings and Other Treatments

A section of SH 6 between College Station and Navasota has experienced ongoing safety challenges for the past several years. SH 6 is a divided four-lane highway just south of College Station which changes to a four-lane non-divided highway a few miles further south (see Figures 7-32 and 7-33).

Figure 7-32. State Highway 6 South of College Station.

TxDOT has taken many actions in an effort to improve safety and reduce crashes along this roadway section. The treatments installed to date are listed in chronological order.

A In October 1995, TxDOT provided for the addition of left-turn lanes at Paradise Way and Westward Ho (two county roads intersecting SH 6). Crash statistics had indicated problems with turning vehicles, rear-end, and right-angle collisions at these intersections. The protected turn lanes were added under the HES program.

A In December 1997, TxDOT conducted spot speed studies to determine if lowering the speed limit below the 70 mph (113 km/h) maximum was warranted. The studies revealed that the 85^{th} percentile speed was in excess of 70 mph (113 km/h), and there were individual speeds in excess of 90 mph (145 km/h) through the area.

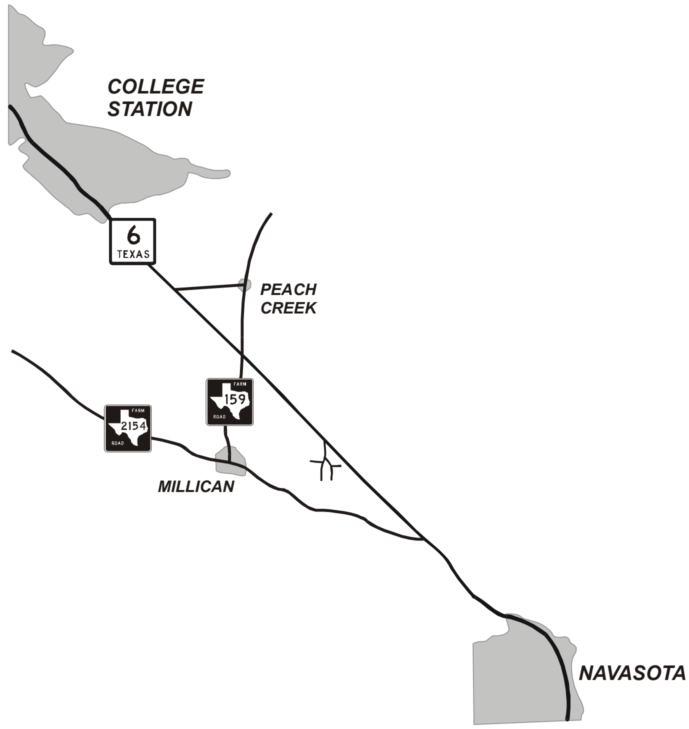


Figure 7-33. Map Illustrating State Highway 6 and Intersecting Roadways South of College Station.

A In January 1998, TxDOT stepped up the planning process for the development of a six-lane section with frontage roads to provide for the separation of traffic in opposing directions as well as addressing the increased traffic in the area.

A In the summer of 1998, TxDOT completed a hot mix asphaltic concrete overlay of the undivided roadway section in order to provide better ride quality and skid resistance. This project also allowed installation of a two-way left-turn section in the developed section south of FM 2154.

A In the summer of 1999, maintenance forces placed spot asphalt level-up to address several areas that showed the potential for vehicle hydroplaning during wet weather. An additional grate inlet was also added at the end of the concrete median barrier to catch the runoff water from the divided section. TxDOT also added Watch for Water on Road signs.

A In September and October 1999, TxDOT provided for shoulder texturing by placing traffic buttons (Figure 7-34) along the outside edge of the edge line to produce an audible warning and to alert errant vehicles before they run off the sides of the travel lanes. The traffic buttons were designed to address the significant number of single-vehicle run-off-road crashes in this roadway section.

Figure 7-34. Shoulder Texturing with Traffic Buttons.

A In April 2000, TxDOT installed profile markings on the edge lines and centerlines (see Figures 7-35 and 7-36).

A In July and August 2000, a Selective Traffic Enforcement Program was initiated in this area.

A In August 2000, TxDOT installed two portable message trailers (one northbound and one southbound) with varying messages such as "Speed Limits Strictly Enforced" and "Watch for Turning Vehicles."

A In November 2000, TxDOT closed the rest area south of FM 159.

A In August 2001, TxDOT constructed a center barrier south of FM 159 and removed the frontage road access points near Peach Creek.

Figure 7-35. Centerline Profile Markings.

A In April 2002, TxDOT constructed a two-way left-turn lane between Paradise Way and Westward Ho (two county roads south of FM 159).

TxDOT's long-term solution to reduce the number and severity of crashes in this area will be the construction of a six-lane freeway section with frontage roads. TxDOT has given this project a very high priority and is working toward its completion.

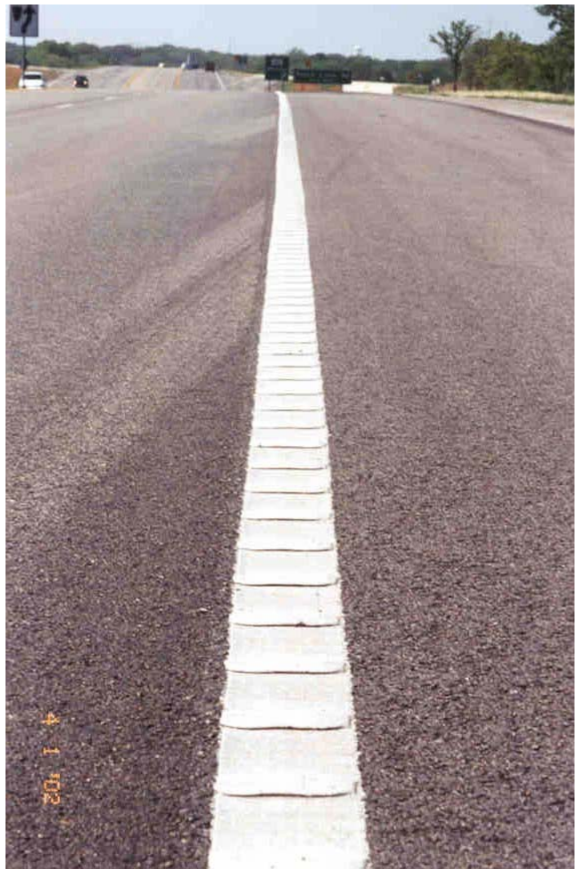


Figure 7-36. Edge Line Profile Markings.

A Traffic Signals on High Center

The intersection of US 290 at FM 3177 (just east of Austin) is located between two crest curves (see Figure 7-37). In early September 2000, the city of Austin installed traffic signals to replace flashing beacons at the intersection. Some drivers ignored the traffic signals and continued to treat the intersection as a four-way stop.

Figure 7-37. Rumble Strips and Warning Signs on an Approach to Signal Just Beyond Crest of Vertical Curve.

In mid-September 2000, TxDOT installed three, three-section, vertical signal heads for eastbound and westbound traffic to supplement the existing signals and to provide additional visibility to the signal indication. The two eastbound signal heads and one westbound signal head are mounted on high centers so that they can be seen earlier when approaching the intersection (see signal heads mounted high on posts in Figures 7-38 and 7-39 a and b).

Figure 7-38. Close-Up of Traffic Signal on High Center on US 290 at FM 3177.

In late September and early October, TxDOT also installed rumble strips on both eastbound and westbound lanes of US 290 approaching the intersection with FM 3177 (see Figure 7-37). The preformed white reflective strips have an alternating height of 0.15 inch (0.38 cm) to 0.25 inch (0.63 cm). The rumble strips are 6-inches (15.2 cm) wide and are spaced 5 ft apart (1.5 m). The first rumble strip is located 1700 ft (519 m) from the first signal head post. The rumble strips provide visual, audible, and tactile warnings and were applied using contact cement.

The TxDOT district believes that these treatments have been effective at this intersection, and the traffic signals on high centers have also been installed at several other intersections in this vicinity.

(a) Traffic Signal Just Visible Beyond Crest of Hill.

(b) Traffic Signal More Visible Beyond Crest.

Figure 7-39. Approach to Traffic Signal at Intersection of US 290 and FM 3177 (Decker Lane).

A Systematic Intersection Improvements

SH 47 in College Station is a four-lane divided highway that serves as a connector from College Station to SH 21. It was opened to traffic in August 1996. FM 1179 (Villa Maria) intersects and crosses northbound and southbound SH 47. The traffic on Villa Maria stops at the intersection with SH 47, while the SH 47 traffic does not stop (see Figures 7-40 and 7-41). Stop signs were installed on Villa Maria when the road was opened to the public. Various traffic control improvements have been installed at this intersection during the previous five years in response to safety concerns.

In August 1999, TxDOT improved or added these treatments on Villa Maria:

A 48-inch Stop signs on Villa Maria,

A Orange warning flags on the Stop signs and Stop Ahead signs (see Figure 7-42),

A Three sets of approach rumble strips (to alert drivers of approaching stop conditions on the westbound approach), and

A Relocated the Stop signs to address potential visibility issues.

Figure 7-40. Intersection of Villa Maria and SH 47.

Figure 7-41. Another View of the Intersection of Villa Maria and SH 47.

The first set of rumble strips begins at 1770 ft (540 m) from the Stop sign at the intersection (see Figure 7-43). Other signs and pavement marking locations are illustrated in Figure 7-44.

In December 1999, TxDOT improved or added these treatments on Villa Maria:

A Painted “Stop Ahead” symbols on the approach pavement, and

A Replaced the orange flags on the Stop signs with a temporary warning flasher.

They also added a treatment on SH 47:

A Solar-powered 24-hr flashers to the eastbound FM 1179 Stop Ahead sign and to the northbound and southbound intersection warning signs on SH 47 (see Figure 7-45).

Figure 7-42. Orange Warning Flags on Stop Ahead Sign.

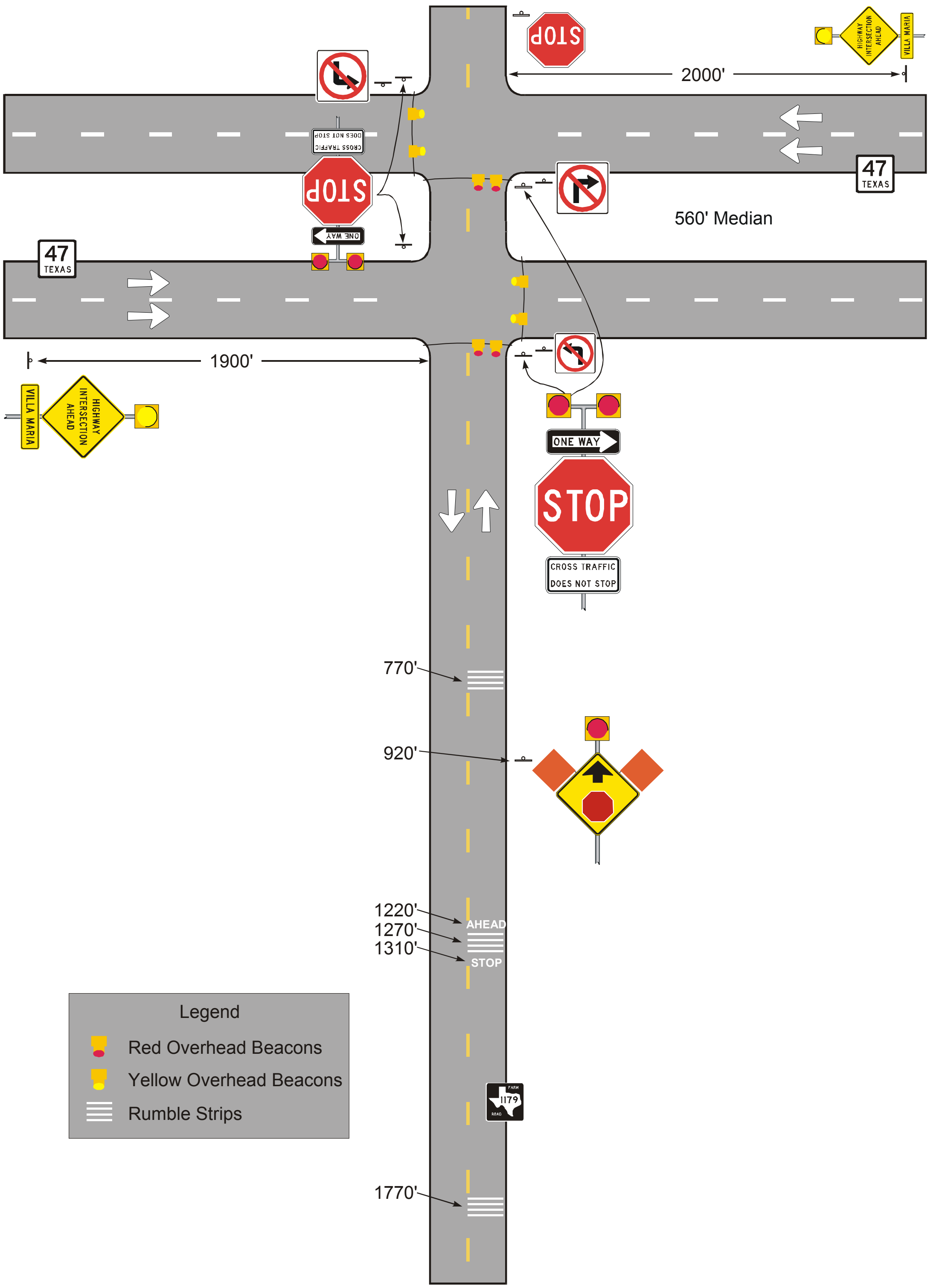
In May 2001, TxDOT installed:

A Overhead intersection flashing beacons for both intersections of SH 47 and FM 1179, and

A Illumination and dual flashing lights on each Stop sign.

TxDOT continues to evaluate and monitor the treatments at this intersection, as crashes still occur on a random basis.

Figure 7-43. Rumble Strips and Pavement Markings on FM 1179.



1 ft = 0.305 m

Figure 7-44. Schematic of Treatments at SH 47 and Villa Maria.

Figure 7-45. Solar-Powered Flashers on Intersection Warning Sign.

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