Technical Report Documentation Page

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

4. Title and Subtitle
CHARACTERISTICS OF AND POTENTIAL TREATMENTS FOR CRASHES ON LOW-VOLUME, RURAL TWO-LANE HIGHWAYS IN TEXAS

5. Report Date
October 2001

6. Performing Organization Code

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8. Performing Organization Report No.
Report 4048-1

9. Performing Organization Name and Address
Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843-3135

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
Project No. 0-4048

12. Sponsoring Agency Name and Address
Texas Department of Transportation
Research and Technology Implementation Office
P. O. Box 5080
Austin, Texas 78763-5080

13. Type of Report and Period Covered
Research:
September 2000-October 2001

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
Low-volume, rural two-lane highways carry less than 8 percent of the total vehicle miles on state-maintained (or on-system) highways and have approximately 11 percent of the total on-system vehicle crashes. These roadways also have relatively more severe injuries when vehicle crashes do occur. For example in 1999, about 26 percent of the Texas on-system crashes were KAB crashes (i.e., fatal, incapacitating injury, or non-incapacitating injury crashes), while over 40 percent of the crashes on low-volume on-system roads in 1999 were KAB crashes. In general, crashes on low-volume, rural two-lane highways occur between intersections by a single vehicle running off the road. Crashes on curves and in dark, non-lighted conditions are more common on low-volume, rural two-lane highways than on urban roads. The study in crash characteristics also demonstrated that more KAB crashes occurred in eastern counties than western counties in Texas. A sample of counties was selected to investigate which regional characteristics are associated with high and low crash rates. In general, sites in the eastern counties had less driver-friendly characteristics—more horizontal and vertical curves, narrower lanes and/or shoulders, less forgiving roadside development, higher access density, and higher roadside development scores. Eastern counties also had more crashes at intersections than western counties. To obtain information about the types of treatments being used on these types of facilities, a mailout survey was distributed to the TxDOT districts and to other states. A literature review was conducted to identify the known effectiveness of treatments used on rural two-lane highways.

17. Key Words
Low-Volume (<2000 ADT), Rural, Two-Lane Highways, Crashes, Treatments

18. Distribution Statement
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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	242	

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Sponsored by the
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TEXAS TRANSPORTATION INSTITUTE
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DISCLAIMER

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.

The research team would also like to recognize the more than 125 individuals who provided information on treatments by responding to our mailout survey. We also 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 team would also like to express appreciation to the following Texas Transportation Institute staff who assisted with data collection and with developing materials for this report: Maria Medrano, Stephanie Elmquist, Justin Burns, Jeremy Davis, Charles Stevens, Todd Hausman, and Dan Walker.

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" and was sponsored by the Texas Department of Transportation in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

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CHAPTER 1

INTRODUCTION

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 (average daily traffic). 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, about 26 percent of the Texas on-system crashes are KAB crashes (i.e., fatal, incapacitating injury, or non-incapacitating injury crashes), while over 40 percent of the crashes on low-volume on-system roads in 1999 were KAB crashes (See Table 1-1).

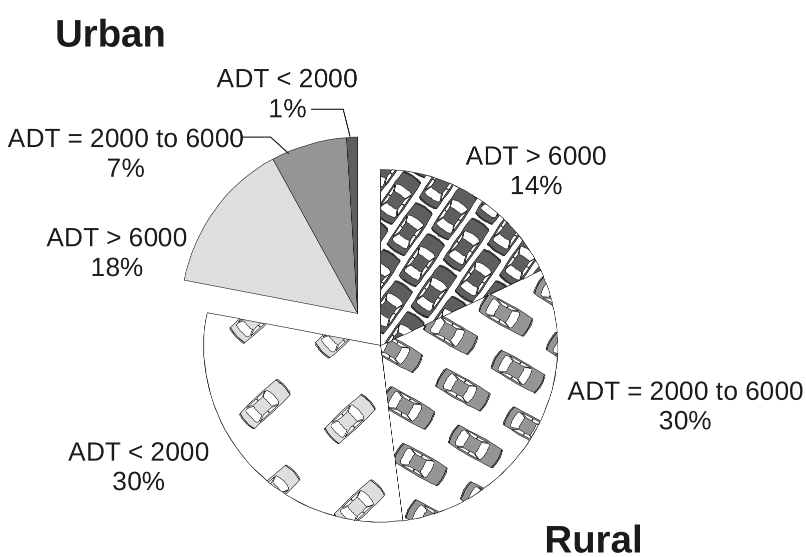


Figure 1-1. Distribution of Crashes by ADT on Two-Lane Highways in Texas.

Table 1-1. Low-Volume (≤ 2000 ADT), Rural Two-Lane Highway Crashes for 1999.

	On-System, Low-Volume, Rural Two-Lane Highway Crashes		All On-System Crashes	
	Frequency	**Percent**	**Frequency**	**Frequency**
PDO: Non-Injury	4407	36.2	58,288	33.8
C Crashes: Possible Injury	2959	24.3	69,836	40.4
B Crashes: Non-Incapacitating	2946	24.2	31,902	18.5
A Crashes: Incapacitating Injury	1418	11.6	10,331	6.0
K Crashes: Fatal	460	3.8	2373	1.4
TOTAL	**12,190**	**100.0**	**172,730**	**100.0**
KAB Crashes	4824	39.6	44,606	25.9
Intersection	1734	14.2	41,112	23.8
Intersection-Related	1331	10.9	32,798	19.0
Driveway Access Related	1092	9.0	16,296	9.4
Non-Intersection	8033	65.9	82,524	47.8
TOTAL	**12,190**	**100.0**	**172,730**	**100**

Little information exists to help transportation practitioners evaluate the effectiveness of low-cost measures, especially the effectiveness on low-volume roads. Therefore, there is a need to provide information that discusses the safety improvement options for low-volume roadways. Objectives for year one of a Texas Department of Transportation project included identifying common types of crashes on low-volume roadways; characteristics of low-volume, rural two-lane highway crashes; and potential safety improvements. This report summarizes the project's first-year activities.

This report is divided into the following chapters and appendices:

- Chapter 1 contains an introduction concerning crashes on low-volume, rural two-lane highways.
- Chapter 2 provides information gathered from a mailout survey and from interviews conducted at four TxDOT district offices.
- Chapter 3 introduces the methodology used to conduct the literature review for the project, the appendices that contain the details from the review, and summaries of other references that could be valuable when selecting treatments for a low-volume, rural two-lane highway.
- Chapter 4 presents information on 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.
- Chapter 5 discusses an evaluation of the differences in crashes between counties in the eastern and western portions of the state.

- Chapter 6 summarizes the findings from the year one efforts of the TxDOT project.
- Appendix A provides information on treatments for lane departure crashes.
- Appendix B discusses treatments for hazards located in the roadside.
- Appendix C presents suggestions on treatments that are within the roadway cross section.
- Appendix D reviews treatments used along an alignment.
- Appendix E discusses treatments used to decrease crashes associated with wet pavement.
- Appendix F provides information on treatments for narrow bridges.
- Appendix G presents treatments for crashes at intersections or driveways.
- Appendix H provides information on animal crashes and treatments that have been used.
- Appendix I provides an overview of sources of information on treatments for work zone crashes.
- Appendix J presents the details on the statistical characteristics of vehicle crashes for three ADT groups within rural and urban environments.
- Appendix K presents the statistical characteristics of vehicle crashes for three district groups.

CHAPTER 2

FINDINGS FROM SURVEYS AND INTERVIEWS

MAILOUT SURVEY

A mailout survey was conducted to gather information on relatively low-cost safety improvements on low-volume roads. (For purposes of this project, low-volume roadways are defined as two-lane roads with an ADT $\leq$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 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);
- list the three to five most recent safety improvements used on a low-volume two-lane road to address a safety concern;
- list candidate sites for the improvements listed in the first question (asked of Texas respondents only);
- provide additional comments or suggestions; and
- indicate if they would like to receive a copy of the survey results.

Texas produced 75 responses while other states offered 49 responses. The following pages summarize the 124 survey responses received. Eighty-nine respondents asked to receive a copy of the survey results, while 18 respondents did not want to receive a copy, and 23 respondents did not respond to this question. A one-page, front-and-back summary was prepared and distributed to those requesting a copy of the survey results.

QUESTION 1. Please check the safety improvements you have installed to address safety concerns on low-volume, two-lane roads (ADT $\leq$2000).

This question was divided into eight categories with several safety improvements listed in each category. The differences between the responses from Texas and other states are summarized in graphs with supporting text. For the graphs, the values on the vertical axis indicate the percentage of responses for that question. For example, in Clear Zone Improvements, 75 percent of the Texas respondents have removed trees to improve the clear zone, while 87 percent of respondents from other states have removed trees to improve the clear zone. Table 2-1 lists the number and percent of responses.

Table 2-1. Installed Safety Improvements.

Potential Safety Treatments	Texas Responses		Other State Responses	
	Number	Percent (%)	Number	Percent (%)
Clear Zone				
Flatten side slopes	50	66	37	79
Increase clear zone	43	57	35	75
Make culverts traversable by adding bars to prevent tires from entering culvert	60	79	14	30
Mow	62	82	29	62
Remove headwalls or adding fill to bring ground level with headwall	53	70	27	57
Remove trees	57	75	41	87
Upgrade safety appurtenances	64	84	42	89
Other	7	9	5	11
Wildlife Control				
Methods to control wildlife management	2	3	6	13
Reflectors to alert wildlife of approaching vehicles	0	0	9	19
Sign (with or without flashers) to alert drivers of wildlife	39	51	39	83
Other	1	1	1	2
Additional Lane				
Climbing lane	13	17	22	47
Passing lane	14	18	16	34
Right-turn lane	39	51	26	55
Left-turn lane	42	55	24	51
Two-way left-turn lane	21	28	14	30
Other	2	3	1	2

Table 2-1. Installed Safety Improvements (continued).

Potential Safety Treatments	Texas Responses		Other State Responses	
	Number	**Percent (%)**	**Number**	**Percent (%)**
Pavement Surface Treatments				
Centerline rumble strips	0	0	10	21
Edgeline rumble strips	5	7	19	40
Rumble strips on approaches to intersections or horizontal curves	10	13	23	49
Shoulder texturing	8	11	5	11
Skid resistance improvements	41	54	23	49
Thicker thermoplastic pavement markings	38	50	8	17
Other	1	1	1	2
Pavement Markings				
Add on-lane pavement markings (painted curve arrow, slow speeds, etc.)	14	18	9	19
Add oversized glass beads	22	29	8	17
Add pavement markings (e.g., edgelines)	46	61	34	72
Add raised pavement marker on centerline or edgeline	57	75	24	51
Add retroreflective pavement markers	21	28	13	28
Reapply existing pavement markings because they have faded	49	65	35	75
Remove existing buttons to convert to guidance markings	28	37	5	11
Other	1	1	1	2

Table 2-1. Installed Safety Improvements (continued).

Potential Safety Treatments	Texas Responses		Other State Responses	
	Number	Percent (%)	Number	Percent (%)
Sign Improvements				
Advance signing for intersections	51	67	44	94
Advance signing for horizontal curves	57	75	41	87
Advance signing for stop signs	64	84	39	83
Delineators	60	79	40	85
Diamond grade sheeting at restricted width bridge	26	34	17	36
Diamond grade chevron signs at curves	27	36	24	53
Flags on stop sign	17	22	6	13
Flashing beacon on stop sign	24	32	21	45
Flashing beacon on warning sign	32	42	19	40
High intensity strobe (HIS) in advance of curves	8	11	2	4
In-rail reflectors for guardrail and bridge rail	31	41	29	62
Reflective corner caps on signs (contrasting colors)	9	12	1	2
Other	1	1	1	2
Signal Improvements				
Backboards for traffic signals	15	20	11	23
High intensity strobe (HIS) in signal	7	9	5	11
Other (please list):	1	1	0	0
Other Improvements				
Illumination	20	26	21	45
Improve/standardize approaches to narrow bridges	29	38	16	34
Increase pavement edge maintenance	50	66	33	70
Speed detection/notification devices	17	22	5	10
Other (please list):	2	3	2	4

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 2-1). One difference between the two groups was that 79 percent of Texas respondents said they had made culverts traversable, while only 30 percent of other state respondents checked this item.

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

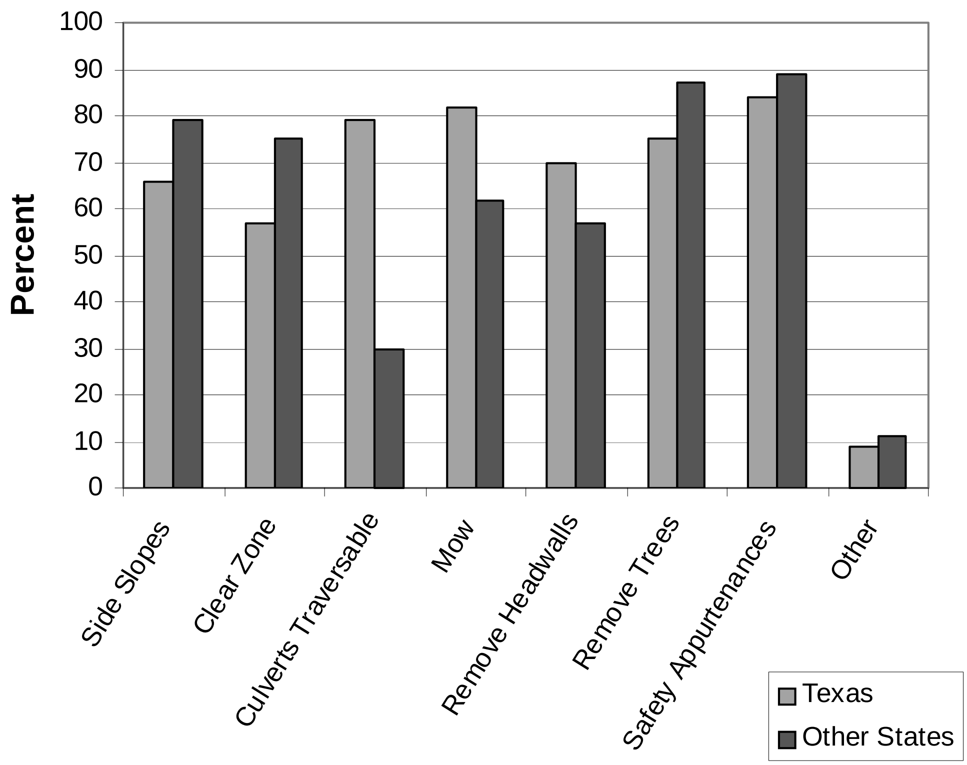


Figure 2-1. Clear Zone Improvements.

Wildlife Control

Signs to alert drivers of wildlife are used widely in other states (83 percent), while only 51 percent of the Texas responses indicated that signs are used (see Figure 2-2). 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.

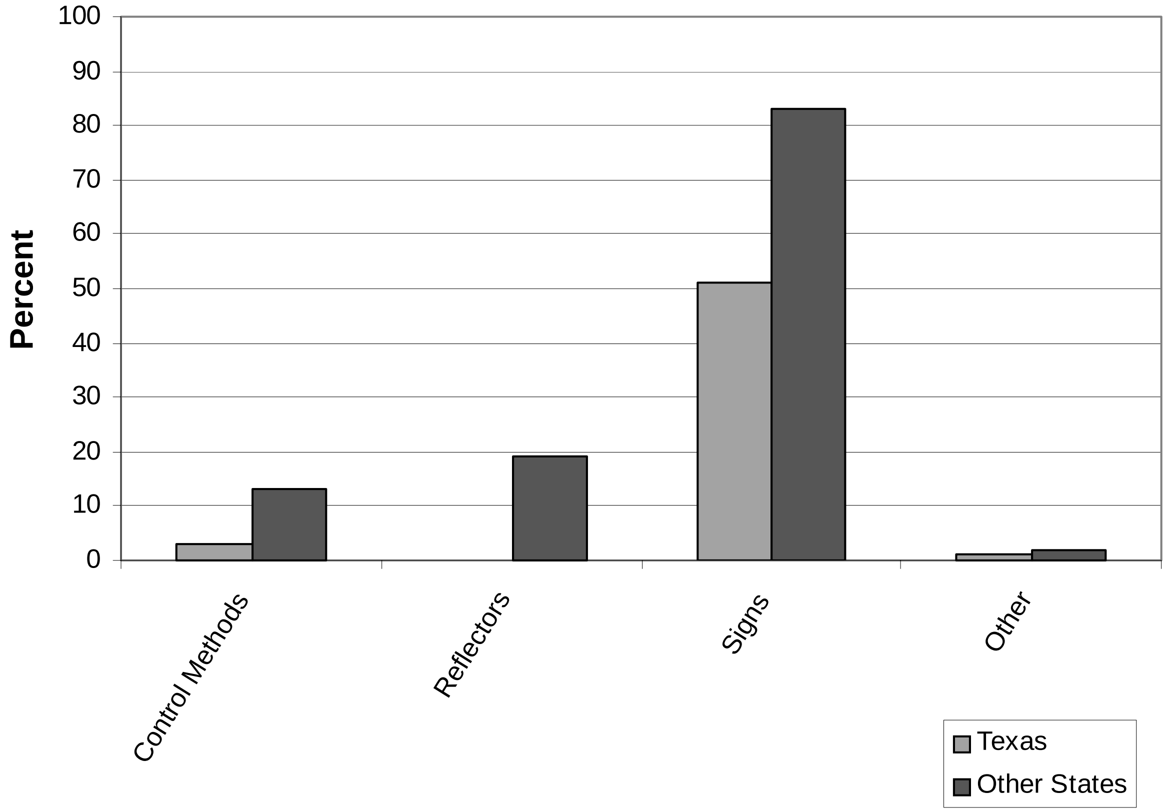


Figure 2-2. Wildlife Control.

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 2-3). However, other states use climbing lanes (47 percent versus 17 percent) and passing lanes (34 percent versus 18 percent) more frequently than Texas respondents.

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.

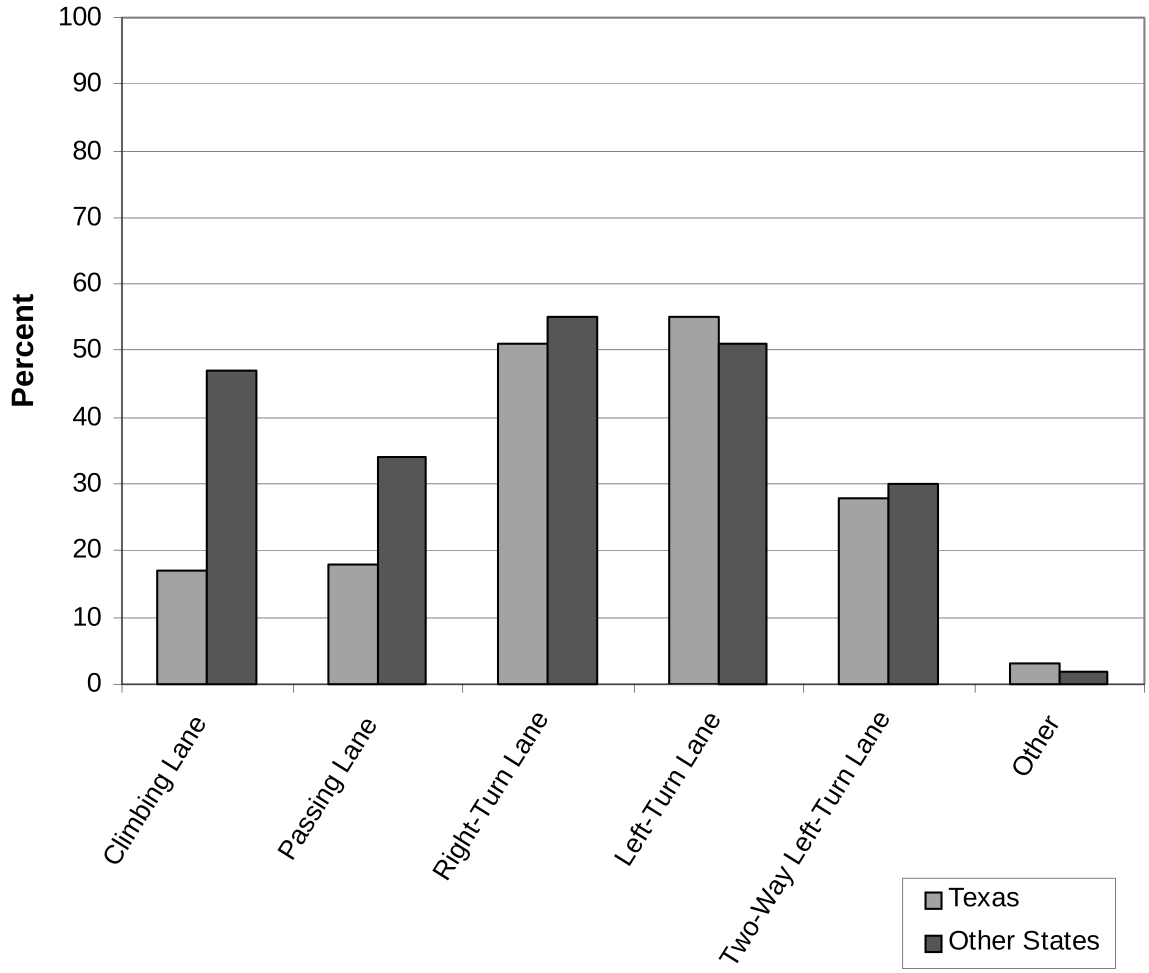


Figure 2-3. Additional Lane Improvements.

Pavement Surface Treatments

Texas and other state respondents indicated similar uses of skid resistance improvements and shoulder texturing (see Figure 2-4). 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), edgeline 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.

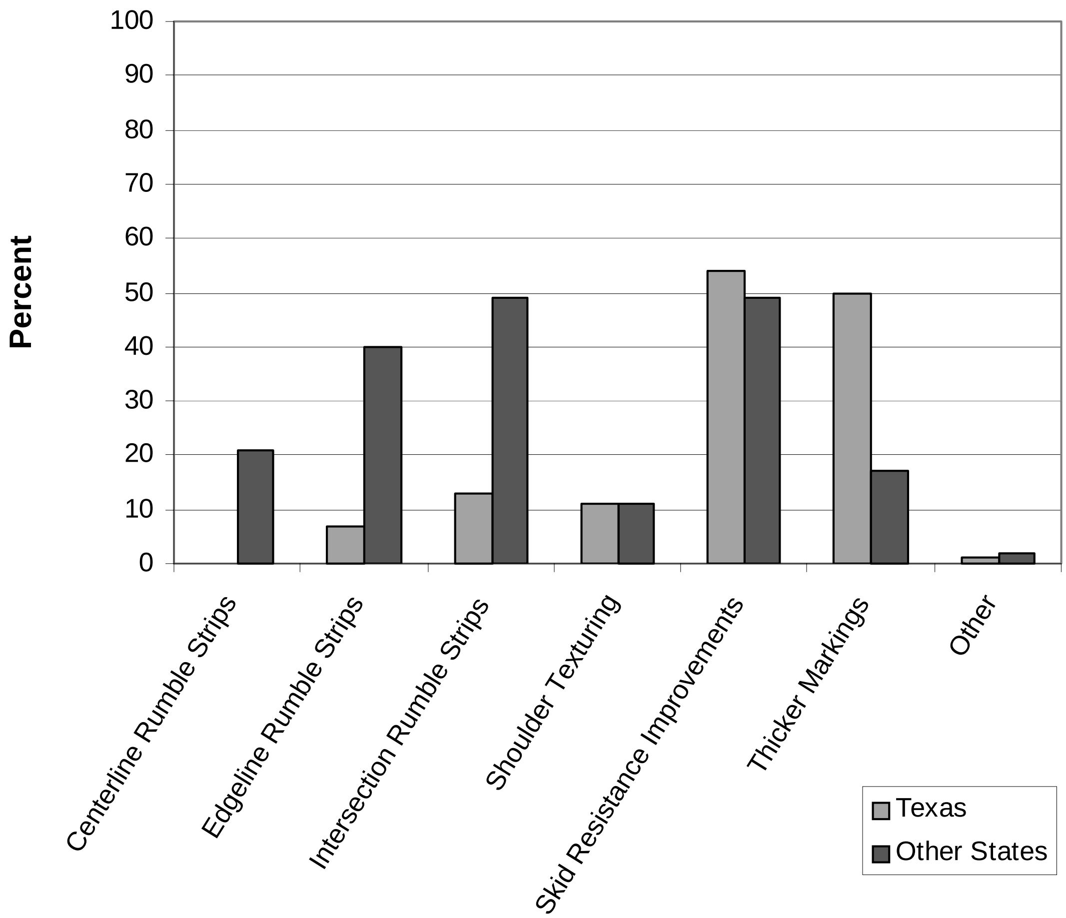


Figure 2-4. Pavement Surface Treatments.

Pavement Markings

Texas and other states listed similar uses for adding on-lane pavement markings (PM), adding edgelines, adding retroreflective pavement markings (RPM), and reapplying existing pavement markings because they have faded (see Figure 2-5). Other states' respondents use wider edgeline 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 edgelines (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 edgeline striping regardless of the roadway width.

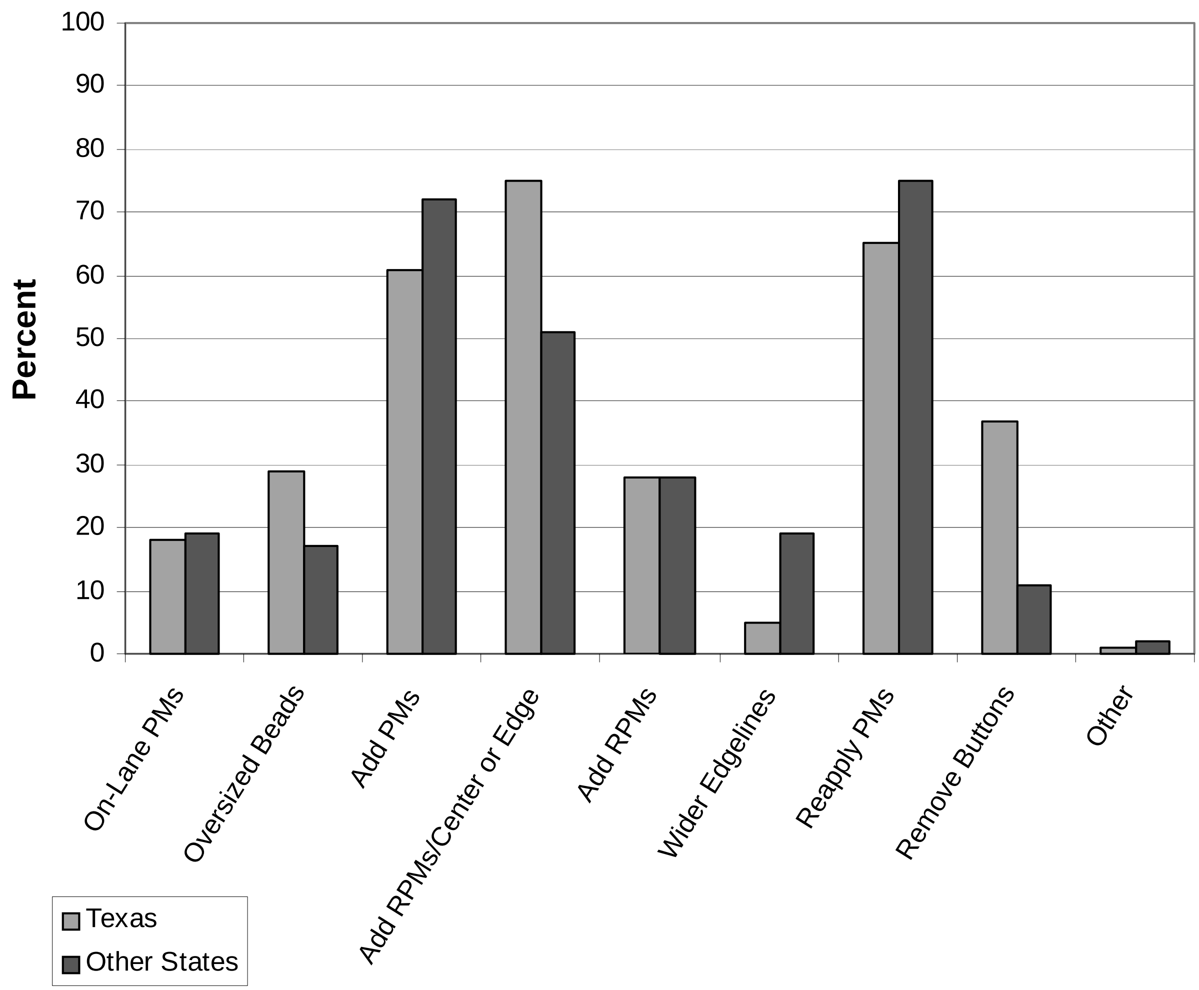


Figure 2-5. Pavement Markings.

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 2-6). 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).
The "Other" responses to this category included installing signs at intersections (W-10) and adding "orange mouse ears" on signs.

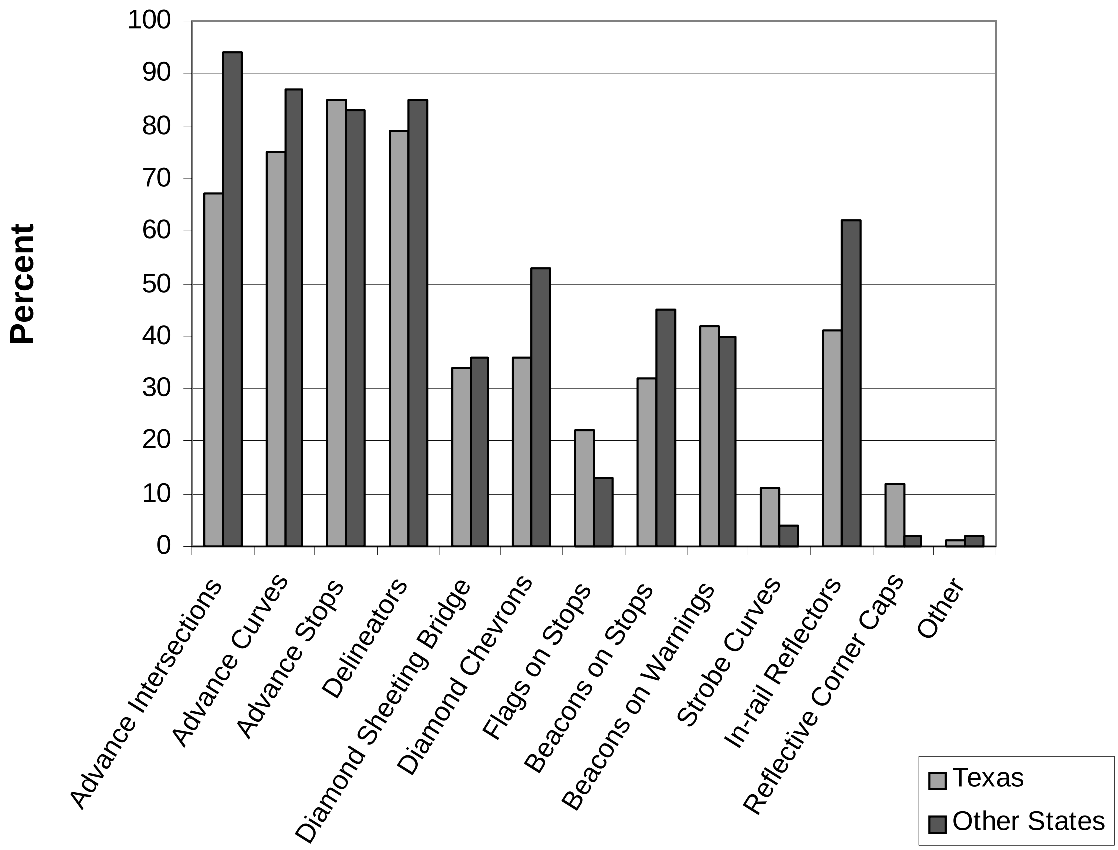


Figure 2-6. Sign Improvements.

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 2-7).

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

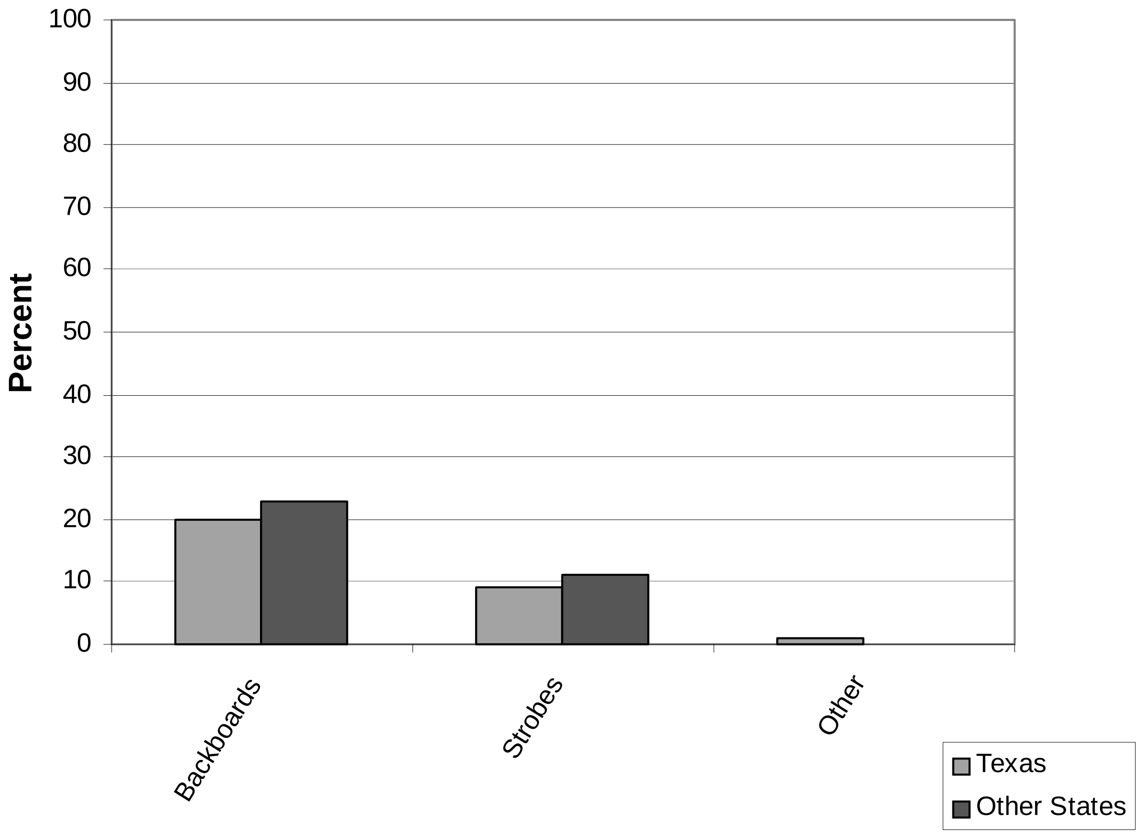


Figure 2-7. Signal Improvements.

Other Improvements

Texas and other states indicated similar uses of improving or standardizing approaches to narrow bridges and increasing pavement edge maintenance (see Figure 2-8). 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.

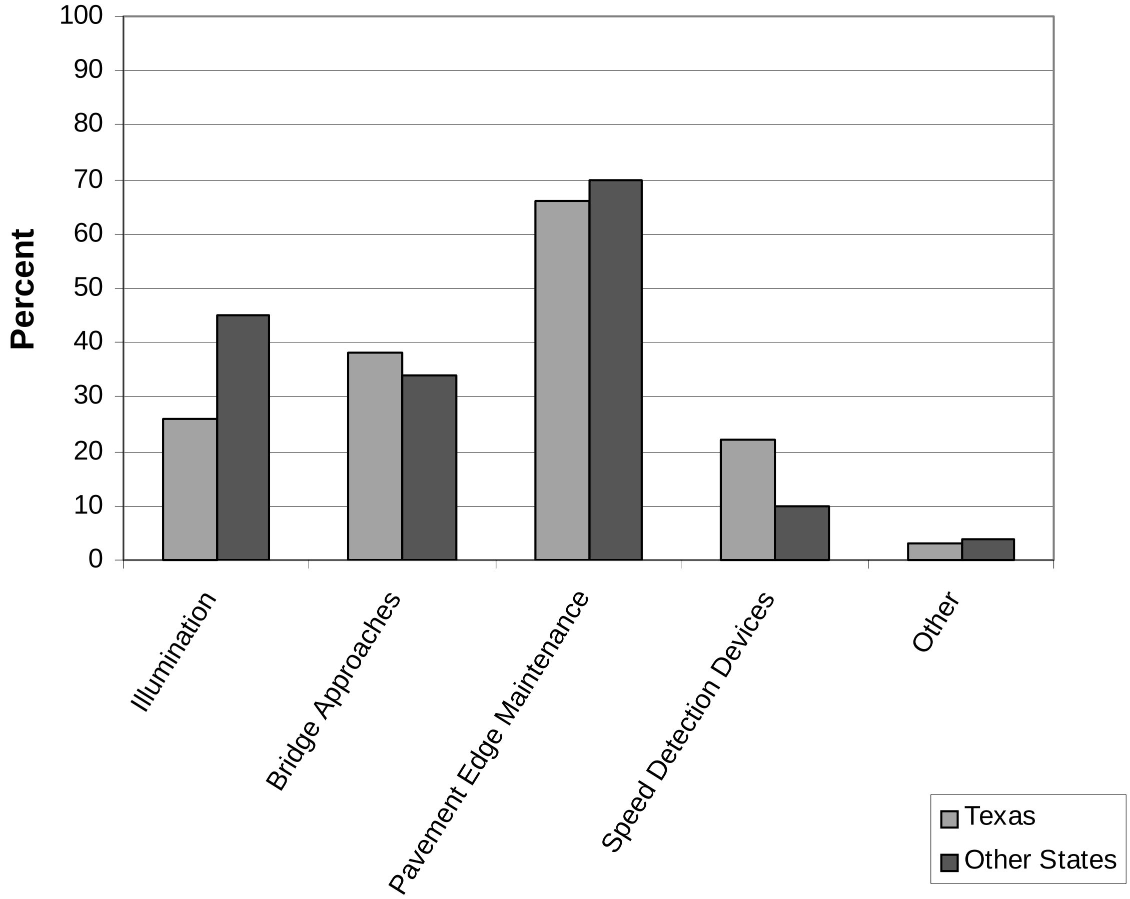


Figure 2-8. Other Improvements.

QUESTION 2. Please describe the 3 to 5 most recent safety improvements you have used (or plan to use) on a low-volume, two-lane road (ADT ≤2000) to address a safety concern.

The responses are summarized by the condition treated on the following pages. Because the number of responses for most items was low, the responses are presented in number of responses rather than in percentages (as reported in Question 1). **Respondents could check more than one condition treated for each safety improvement.**

A. Roadside Objects—The highest responses for Texas and other states for safety improvements associated with roadside objects were safety end treatments, sign improvements, increased clear zone, pavement resurfacing, removing or trimming trees, and adding shoulders (see Table 2-2).

Table 2-2. Number of Respondents Indicating Use of These Improvements Used as a Treatment for Roadside Objects.

Safety Improvement	T*	O*	Safety Improvement	T*	O*
Add or improve safety end treatments	39	11	Add raised median	1	0
Sign improvements including sheeting, upgrading, posts, and one strobe	13	4	Add / widen pavement markings	1	2
			Upgrade mailboxes	1	0
Increase clear zone	9	5	Reconfigure intersection	1	0
Pavement resurfacing or rehabilitation/ grading	9	3	Flatten slopes	0	3
Remove or trim trees / brush	7	4	Intersection sight improvement or sight distance improvement	0	3
Add shoulders	7	4	Illumination	0	1
Add reflectors or delineators for guard rail	5	0	Replace / Improve guardrail	0	1
			Consistent lane and shoulder width	0	1
Add guardrail or guard fence	4	2	Correct superelevation	0	1
Widen bridge or improve bridge approach	4	0	Right-turn taper	0	1
			Shoulder texturing	0	1
Pave or improve shoulders	4	0	Ledge removal to prevent rock from falling	0	1
Pavement edge maintenance or improvement	3	0	Eliminate ditch	0	1
Mow, clear brush, or clear right-of-way	3	1	Edgeline rumble strips	0	1
Alignment improvements	2	2	Truck escape ramp	0	1
Widen roadway	2	0	Utility pole initiative	0	1
Add raised pavement markers on edgelines	1	0	Flashing beacons on warning signs	0	1
Remove island and replace with striping	1	0	Improve intersection: remove island, reconfigure 4-way stop	0	1
Add climbing lanes	1	1			

*T - Number of Texas Responses
*O - Number of Other State Responses

B. Driver Inattention—Highest Texas responses for safety improvements to reduce driver inattention were: sign upgrades; safety end treatments; raised pavement markers; advance flashers; widening the road, shoulders, or lanes; and adding, improving, or reapplying pavement markings (see Table 2-3). The highest responses from other states included: chevrons or delineators in curves; edgeline rumble strips or shoulder texturing; roadway realignment; sign upgrades; widening the road, shoulders, or lanes; adding, improving, or reapplying pavement markings; and intersection rumble strips.

Table 2-3. Number of Respondents Indicating Use of These Improvements Used as a Treatment for Driver Inattention.

Safety Improvement	T*	O*
Sign upgrades and posts	12	4
Safety end treatments	8	3
Install advance flashers	6	0
Install raised pavement markers	8	2
Widen road, shoulders or lane, or add shoulders	6	4
Add, improve markings, or reapply pavement	6	4
Add delineators or reflectors on guardrail	5	1
Widen bridges	4	0
Pave shoulders or improve pavement edge maintenance	4	0
Add oversized stop, or advanced stop signs and/or bars	2	2
Edgeline rumble strips or shoulder texturing	2	5
Add turn lanes (left, right, or two-way left-turn)	2	2
Flatten side slopes	2	5
Install skid resistant surface	2	0
Upgrade 4-way flashers	2	0
Improve clear zone	2	3
Add bridge and guardrail	2	2
Add chevrons and delineators in curves	3	10
Install raised median or center island	1	1
Upgrade mailbox	1	0
Install warning sign at T-intersection	1	0
Intersection rumble strips	1	4

Safety Improvement	T*	O*
Strobes in signal head / black signal faces	1	2
Upgrade school flashers	1	0
Flashing signal	1	0
Roadway realignment	1	6
Remove / trim trees or brush	1	2
Thicker thermoplastic striping	1	0
Grade separation structure	1	0
Passing lane	1	0
Illumination	1	1
ISD improvement	0	3
Mow	0	1
Truck escape ramp	0	2
Rumble strips	0	4
Centerline rumble strips	0	1
Rumble strips on pedestrian path	0	1
Rumble strips on curves	0	1
Oversized speed limit signs	0	1
Advance signs	0	2
Intersection warning program	0	1
Curve warning program	0	1
Fluorescent yellow cross-road sign	0	1
Additional sidewalk, crosswalk, curb, cut ramps, and signs	0	1
Add centerline striping	0	1
Oversized and high-intensity truck warning signs	0	1
Warning signs for school bus stop	0	1
Traffic signal	0	1

*T - Number of Texas Responses
*O - Number of Other State Responses

C. Shadows and Blinding—The highest Texas responses to reduce shadows and blinding were removing or trimming trees and bushes, installing flashing beacons on warning signs, and adding or reapplying pavement markings (see Table 2-4). There was only one response from another state for shadows and blinding, and it included installing signs, advance road signs, oversized truck warning signs, safety end treatments, turn lanes, and through lanes.

Table 2-4. Number of Respondents Indicating Use of These Improvements as a Treatment for Shadows and Blinding.

Safety Improvement	T*	O*	Safety Improvement	T*	O*
Remove trees / trim brush	3	0	Improve signs	0	1
Install flashing beacons on warning signs	2	0	Advance road signs	0	1
			Oversized truck warning signs	0	1
Improve sight distance	1	0	Replace / upgrade guardrail	0	1
Add / reapply pavement markings	2	0	Safety end treatments	0	1
Illumination	1	0	Add turn lane	0	1
More delineation on guardrails	1	0	Add through lane	0	1
Add rumble strips	1	0			

*T - Number of Texas Responses
*O - Number of Other State Responses

D. Rural Intersections—The highest Texas responses for improving safety at rural intersections were upgrading and standardizing signs; installing left-turn lanes; advance warning flashers; rumble strips and advance signing; realign alignment; illumination; and adding pavement markings (see Table 2-5). The highest other state responses were chevrons and curve warning signs; wildlife reflectors; resurfacing or adding chip seal; upgrading or standardizing signs; shoulder texturing or rumble strips; and improving clear zones.

Table 2-5. Number of Respondents Indicating Use of These Improvements Used as a Treatment for Rural Intersections.

Safety Improvement	T*	O*	Safety Improvement	T*	O*
Upgrade / standardize signs	5	2	Advance stop signs with flags at T-intersection	1	0
Left-turn lane at intersection	4	0			
Install advance warning flashers	4	0	Advance stop signs with flashing lights	1	0
Add rumble strips and advance signing	3	0	4-way stop	1	0
Roadway realignment	3	1	Warning sign at T-intersection	1	0
Illumination	3	1	Strobe in signal head	1	0
Add pavement markings	3	0	Add two-way left-turn lane	1	1
Right-turn lane	2	0	Bouncing lights and buttons	1	0
Upgrade 4-way flashers	2	0	Painted warning on roadway	1	0
Add flashing beacons on stop signs or 4-way stop signs	2	0	Larger stop signs	1	0
			Curve warning signs / chevrons	0	3
Safety end treatments	2	0	Wildlife reflectors	0	3
Reflective strips on stop signs	1	0	Resurface / chip seal	0	2
Shoulder texturing or shoulder rumble strips	1	2	Advance road signs	0	1
			Install guardrail	0	1
Widen roadway	1	0	Flatten slopes	0	1
Improve clear zone	1	2	Intersection warning program	0	1
Grade separation structure	1	0	Replace guardrail	0	1
Add passing lane	1	0	Improve intersection sight distance	0	1
			Mow	0	1

*T - Number of Texas Responses
*O - Number of Other State Responses

E. Unexpected Alignment Changes—The highest Texas responses for improvements for unexpected alignment changes were raised pavement markers; chevrons, signs, and delineators on horizontal curves; improving and upgrading signs; and adding pavement markings (see Table 2-6). The highest responses from other states were chevrons, signs, and delineators on horizontal curves; and safety end treatments.

Table 2-6. Number of Respondents Indicating Use of These Improvements Used as a Treatment for Unexpected Alignment Changes.

Safety Improvement	T*	O*	Safety Improvement	T*	O*
Raised pavement markers	7	1	Delineation at bridge ends	1	0
Delineators / chevrons / warning signs on horizontal curves	4	8	Shoulder texturing / shoulder rumble strips	1	1
Improve / upgrade signs	3	0	Realignment to reduce curve severity	1	1
Add pavement markings	3	1	Advance warning flashers for intersections and stop signs	1	0
Safety end treatments	2	4			
In-rail reflectors on guardrails	2	0	Advance warning flashers on stop and stop ahead signs	1	0
Flashers on warning signs	2	0			
Add 10-foot shoulders	1	0	Replace bridge beam	1	0
Resurfaced roadway	1	1	Illumination	1	0
Speed detection and notification devices	1	0	Improve skid resistance	1	1
Climbing lanes	1	0	Wildlife reflectors	0	2
Raise headwalls to decrease slopes	1	1	Upgrade guardrail	0	1
Rumble strips (intersection and centerline)	1	2	Truck escape ramp	0	2
			Cut trees / brush	0	2
Reapply pavement markings	1	0	Improve clear zone	0	1
Increase thickness of thermoplastic pavement markings	1	0	OGAC	0	1
*T - Number of Texas Responses *O - Number of Other State Responses					

F. Unexpected Developments (small towns, factories, etc.)—Only two respondents provided safety improvements for unexpected developments—one from Texas and one from another state (see Table 2-7).

Table 2-7. Number of Respondents Indicating Use of These Improvements Used as a Treatment for Unexpected Developments.

Safety Improvement	T*	O*	Safety Improvement	T*	O*
Upgrade school flashers	1	0	Curve warning signs	0	1
Widen roadway	1	0	Mow	0	1
Improve clear zone	1	0	Extend culvert headwall	0	1
Sign standardization	1	0	Utility pole initiative	0	1
Signs (watch for slow moving vehicles)	1	0	Add raised pavement markings	0	1
*T - Number of Texas Responses *O - Number of Other State Responses					

G. Weather—The highest number of safety treatments from Texas respondents for weather conditions were safety end treatments, resurfacing or seal coating the roadway, raised pavement markers, shoulders, improving skid resistance, and removing trees or fixed objects from the clear zone (see Table 2-8). Other state respondents listed curve warning signs and/or chevrons and rumble strips most frequently, although the number of responses was low.

Table 2-8. Number of Respondents Indicating Use of These Improvements Used as a Treatment for Weather.

Safety Improvement	T*	O*	Safety Improvement	T*	O*
Safety end treatments	8	0	Signs at intersections	1	0
Resurface / seal coat roadway	8	1	Add edgelines	1	0
Raised pavement markers	7	0	Raise grades in low areas	1	0
Add shoulders	5	0	Pavement edge maintenance	1	0
Improve skid resistance	5	1	More delineation at guardrails	1	0
Remove trees or fixed objects / clear zone	4	2	Curve warning signs / chevrons	0	3
Add pavement markings	2	0	Rumble strips	0	2
Increase thickness of thermoplastic pavement markings	2	0	Edgeline rumble strips	0	1
Improve drainage (at intersection, at guardrail)	2	0	Intersection rumble strips	0	1
Climbing lanes	1	0	Flatten slopes	0	1
Reapply existing pavement markings	1	0	Improve guardrail	0	1
Upgrade signing	1	1	Flashing beacon on warning signs	0	1
			Fencing	0	2
			Minor sight benches	0	1

*T **-** Number of Texas Responses
*O **-** Number of Other State Responses

H. Wildlife Encroaching on Roadway—Only two survey respondents provided improvements for wildlife encroaching on the roadway, indicating no defined safety improvements for this condition (see Table 2-9).

Table 2-9. Number of Respondents Indicating Use of These Improvements Used as a Treatment for Wildlife Encroaching on a Roadway.

Safety Improvement	T*	O*	Safety Improvement	T*	O*
Widen roadway	1	0	Clear brush	1	1
Improve clear zone	1	0	Wildlife reflectors	0	0
Widen shoulders	1	0	Signs	0	0

*T **-** Number of Texas Responses
*O **-** Number of Other State Responses

I. Other Safety Concerns—Survey respondents were asked to list other safety concerns (not included in categories A through H) and to list the safety treatments installed in response to these concerns. The responses are summarized in Table 2-10.

Table 2-10. List of Other Safety Concerns and Safety Treatments Installed in Response.

Safety Concern	Safety Treatment	T*	O*
Increase skid resistance	• Surface friction improvement • Seal coat	2 2	0
Sight distance	• Tree trimming or removal • Intersection warning program	2	1
Narrow roadway	Widen road, resurface, safety end treatments, signs, minor alignment improvements	2	0
Narrow lanes	Lane widening with maintenance operations	1	0
Passing opportunities / truck passing	Added passing lanes (Super 2 roadway)	3	0
Low shoulder or drop-off	• 2-foot pavement widening on inside of curves • Closed drainage and eliminated ditch line • Add material to level surface • Widened edges on 2-lane highways to eliminate drop-off and narrow lanes	 1 1	1 1
Dead trees falling on road	Tree removal	2	0
Edges of roadway	Improved edges of roadway	1	0
Non-traversable ditches and structures	Changed geometry of large roadside ditch blocks so vehicles involved in off-roadway excursions may traverse the drainage structure	1	0
Clear zone	• Removed metal beam guard fence (MBGF) and extended box culverts • Safety end treatments	1 1	0
Durability	Thermoplastic striping and raised pavement markers	1	0
Improve stopping sight distance	Improve profile and skid resistance	1	0
No edgeline	Widen roadway by adding 2-foot shoulder	1	0
Rutting	Mill and inlay to remove rutting	1	0
Speed	Advance stop signs, T-intersection, flags	0	0
Unsafe maneuvers by drivers	No parking signs and channelizing devices	0	0
Errant traffic and safe recovery	Raise headwalls to decrease slopes	0	0
Grades	Rebuilding FM roadways	0	0

Table 2-10. List of Other Safety Concerns and Safety Treatments Installed in Response (continued).

Safety Concern	**Safety Treatment**	**T***	**O***
Passing	Directional arrow and sign for headlight use	0	1
Run-off-road	Shoulder rumble strips	0	1
Sub-standard superelevation	Correct superelevation	0	1
Drowsy drivers	Edgeline rumble strips	0	1
Right-of-way violation	Place stop signs on local street	0	1
Rocks falling onto road	Ledge removal to prevent rocks from falling	0	1
Upgrade to current standards	• Replace single-lane bridge with 2-lane structure • Replace or upgrade guardrail and end anchorages • Extend culvert headwall to proper clear zone requirement	0 0 0	1 1 1
Line of sight	Slope flattening	0	1
Pedestrian safety	Rumble strips along pedestrian path	0	1
High crash location	Flashing beacons on warning signs	0	1
Driving Under the Influence (DUI)	Corridor Review: Added ‘Buckle Up’ and ‘Alcohol .08 foot signs	0	1
Lighting	Illumination	0	1
Sight distance	Mow	0	1

*T - Number of Texas Responses
*O - Number of Other State Responses

QUESTION 3. Do you have sites that would be a good candidate for a treatment listed previously (Yes/No)?

This question was asked of Texas respondents in order to find candidate sites for this project. Of the 77 Texas responses, 38 respondents listed candidate sites, 19 did not have candidate sites, and 20 did not respond to this question.

QUESTION 4. Do you have any additional comments or suggestions?

Texas and other state respondent comments are listed and grouped by categories. The comments or suggestions are printed in italics.

Correlation with Crash Data

In depth study of crash data, before and after "improvements" are completed to see where the reduction is: crash frequency or crash severity.

On roadways of this traffic volume, we have used many of these improvements but they are not usually applied until a situation where several crashes happen at a given time.

Guardrail, Bridges, and Shoulders

Guardrail upgrades and safety end treatment grades are needed.

We continue to add safety end treatments to culverts, widen bridges, and pave shoulders on U.S. and state highways.

Issues Are Addressed by Other Departments

Most work on low volume FM roadways has been isolated to the problem areas handled with maintenance forces. Complete sections of roadways have been addressed in our hazard elimination program, but at this time, this work is concentrated to our higher volume roadways due to budget constraints.

The Alpine area office considers safety improvements on all proposed projects at the design concepts phase.

We do not do safety improvement projects as stand-alone projects in the Roadway Design Division. Traffic and Maintenance Divisions do more "safety improvements" projects; however, the Roadway Design Division includes the safety improvements marked on previous sheets in our reconstruction, widen/overlay projects.

Safety improvement projects in the Northern Virginia District of VDOT tend to be located on high-volume urban roads. The purpose of our low-volume rural projects is generally to pave poor quality gravel roads and bring them into overall compliance with state and AASHTO guidelines.

Improvements to less than 2000 ADT state roads are usually completed by force account and somewhat difficult to track; many counties do their own signing, vertical realignment and other improvements.

In answering this survey, we assumed that the questions applied to "stand-alone" projects. Other safety improvements have been used as part of other, larger parties.

Work has been done by maintenance via traffic operations' requests and help with funding.

Lighting

I have always thought it would be a good idea to illuminate rural "T" intersections. I believe this would help get the driver's attention.

Pavement Surface

Our district added rumble strips to pavement at all stop intersections in rural areas.

Texturing/rumble strips are limited to four-lane facilities. We need something for two-lane roads with comparable effects for errant/sleepy motorists–many fatalities.

Centerline rumble strips may be an effective, low-cost measure for improving the highway safety. VDOT has studied optimal shoulder rumble strips and implemented about 790 miles of it on Virginia Interstate system. We may study this later.

I have used centerline rumble strips on a two-lane pavement to reduce crashes. Three years prior, I had six fatal crashes with 12,000 ADT. Five years have passed and no fatal crashes. The strips covered about 2.5 miles of road at a cost of $13,000 and a 20,000 AADT today. I have more information if you are interested.

Widening the shoulder is another useful improvement.

Pavement Width and/or Shoulders

Our biggest problems on low-volume roads are narrow pavement and edge drop off. Just improving the roadway crown to 26 feet and using rip-rap to backfill along the edge of pavement is a big help.

Review advance signing for curves, intersections, etc., roadside delineation, minimum three-foot paved shoulder ribbons.

Policy / Procedure Issues

Concentrate on things that do not require ROW. May be more advantageous to widen base and surface, move ditches out, leave slopes steep outside clear zone. ROW purchase on low-volume roadway not high priority.

We are one of the smaller rural districts within Caftans, and although a majority of our roads are rural two-lane, historically the highways with < 2000 ADT have not been safety problems. Our district policy is to place open graded asphalt cement and rumble strips when practical.

DOT tailgating safety initiative is based on the two-second rule to address aggressive driving behavior.

In general, our roadways with volumes under 2000 ADT don't get a lot of attention unless they show up as a hazardous crash location or a risk location in our programming system. These roadways are typically bituminous surface treatments. When we apply a new chip seal, we upgrade guardrail ends and signing, and delineation. If there is a spot safety location with a benefit/cost ratio (b/c) over one we will fix it at the same time.

Signing, Reflectors, and Markers

I have several locations that have advance signing, but we still have problems with people running through the intersections.

Crash history is greater at horizontal and vertical curves. The addition of low-cost reflective devices helps guide traffic even when placed in locations not according to standards. Installation of chevrons on curves following standards forces large spacing between chevrons, and with the seven-foot height, the target value is not too great in dark, inclement weather.

We have one rural skewed intersection where we have utilized pavement markers to attempt to promote stopping traffic to stop perpendicular to the through traffic. According to local officials, we believe this has decreased the crashes at this intersection.

Flashing beacon on warning sign and stop sign.

Our pavement marker (raised reflective) seems to receive a lot of positive feedback from the public – more than anything.

Slopes

Distances have become a major factor for this kind of road with AADT < 2000 in Virginia. The standard/criteria may need to be studied and reviewed.

Wildlife

Prairie dogs are doing damage to foundation of roadway; and we need to provide a way to prevent this legally.

Other

We do not have specific hazard-cause crashes that I have attempted to rectify. Items marked in 1 are improvements added to roadways in construction/rehabilitation projects.

Add approach guardrail to bridge, safety dikes (escape ramps), and opposite "T" intersections; reduce horizontal degree of curvature; improve crest vertical; widen bridge; widen pavement; widen shoulders; relocate roadway to eliminate problems with horizontal/vertical curvature; eliminate bridge/culvert headwalls with new curvature meeting clear zone requirements; add chevrons; pave all part of shoulder; pave all or part of shoulder in curve and carry superelevation of curve into paved outside shoulder; and roll over into 6:1 forecloses.

This information relates to rural, non-state roads; and we are unable to provide specific location information at this time due to the overall number of agencies (e.g., cities, towns, counties) involved.

INTERVIEWS WITH DISTRICT REPRESENTATIVES

Members of the research team also met with representatives of four districts along with gathering information from the mailout survey. Meeting objectives included gathering information on how the district identifies locations for treatments and how the treatments are selected. Table 2-11 lists the questions used during the meetings. The four districts visited were Austin, El Paso, Lufkin, and Odessa. These are the districts responsible for the roads included in the evaluation of crashes on a selection of control-sections (see Chapter 5).

Table 2-11. Potential Questions for Meeting with District Representatives.

- Are low-volume rural roads treated differently than higher volume rural roads or urban facilities (e.g., identification of sites, funding, type of treatments, etc.)?
- Which positions within your district have responsibilities for identifying safety needs and developing safety treatments?
- Do you regularly conduct crash studies to identify high-crash locations? If so, how often?
- How do you decide which intersection to treat?
- How do you identify potential countermeasures?
- How often do you use a consultant to assist with this process?
- In what areas do the consultants assist?
    - Data collections
    - Identify high crash locations
    - Developing recommendations
    - Developing design plans
    - Constructing the improvements
- Do you have a hierarchy for safety improvements for an intersection? A roadway segment? What are the different levels of improvements?
- Do you have an example of a site that has undergone several improvements in response to a safety issue? If so, please describe experience.
- Did the media or community requests play a role in the timing or types of treatments?
- How do you fund safety improvements?
- Do you use reference manuals when conducting a safety study?
- What would you say is the most common improvement used within your district (e.g., signalization, pavement markings, etc.)? What are the most effective?
- Are there any potential countermeasures that you believe would be effective but haven't tried yet? If yes, what?
- Do you have potential sites for before-and-after studies for countermeasures in addition to those provided in the fall 2000 survey?

Key items from the meeting include the following:

- Each district participates in the Hazard Elimination (HES) program. The HES program is part of the Highway Safety Improvement Program. The basic objective of the HES program is to reduce the number and severity of crashes. The districts prepare a Safety Evaluation

Report (SER) form for each proposed highway safety project. These forms are submitted in mid-November to the Traffic Operations Division who ranks the projects using the Safety Index and selects those approved for funding. In 2000, 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. Some districts mentioned that, in a few cases, if a project was not funded through the HES program, they would use other funds to treat a location. 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 or axle as a variable.

- The Odessa District has a formal Safety Review Committee. This committee reviews every fatal crash. As part of the review, they obtain information on other crashes at the site and visit 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 their Safety Review Committee as a mechanism for improving safety within their district. Their committee reviews plans for safety concerns at 30, 60, and 90 percent completion on large projects and once on smaller projects. Their meetings are scheduled on a project-specific basis.

- 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.

- Consultants are used to perform traffic counts, delay studies, identify treatments for a specific location, and develop the plans for a location. They are not used to identify high-crash locations.

- 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. For most districts, there does not appear to be one key reference being used to generate ideas. One district suggested that having the information on a website would be more valuable than within a printed document.

- All districts mentioned the increased use of video detection at signalized intersections. The general consensus is that it is better than in-pavement loops and that its use will continue to increase.

- The most common types of improvements mentioned by the districts include:
  - signals,
  - safety end treatments,

  - updating pavement markings (especially left-turn bays),
  - signs,
  - left-turn lanes (with pavement markings and signs),
  - increased shoulder width,
  - illumination, and
  - buttons or rumble strips (buttons are being used in some locations due to the rumble strip depression being filled with sand or dirt that frequently blows in the area).

- Treatments being considered by districts include the following:
  - advanced rumble strips (also called audible strips),
  - shoulder texturing, and
  - rumble strips (edgeline).

- Treatments mentioned that had not been included on the mailout survey are:
  - butterfly reflectors within the W-beam rail of a guardrail (being used in Odessa and Corpus Christi),
  - signal on high center to improve visibility for vehicles on a crest vertical curve (Austin District), and
  - reflective red/white alternating material on stop sign post (Austin District).

CHAPTER 3

LITERATURE REVIEW

Just prior to the start of this Texas Department of Transportation project, the Texas Transportation Institute completed a project for the National Cooperative Highway Research Program (NCHRP) that developed an *Accident Mitigation Guide for Congested Rural Two-Lane Highways* (NCHRP Report 440) (*1*). A comprehensive literature search was conducted as part of the NCHRP project. Therefore, this project focused on research conducted during or after the NCHRP project was active and on literature that addressed **low-volume** (ADT $\leq$ 2000), rural two-lane highways. Appendices A to I contain information on treatments for crashes on rural two-lane highways from the NCHRP Report 440 report along with information identified since the national study.

OTHER VALUABLE REFERENCES

During the literature review process, several documents were identified that dealt with issues other than crash treatments that may be of value when evaluating the conditions at a location. Brief summaries of these documents follow with an overview of the NCHRP research findings and document. Also included is an overview of the Interactive Highway Safety Design Model (IHSDM) that the Federal Highway Administration (FHWA) is developing.

Interactive Highway Safety Design Model

The Federal Highway Administration has developed a software program called the Interactive Highway Safety Design Model (IHSDM) in cooperation with state departments of transportation and several vendors of computer-aided design and other software (*2*). It should enable highway designers to evaluate the safety of specific geometric designs for rural two-lane highways. The estimated date of completion for the model is 2002. The IHSDM will consist of the following seven evaluation modules:

- The policy review module allows designers to compare a proposed horizontal alignment with state and local design standards. If a curve's radius or superelevation deviates from recommended standards, relevant policy information is provided as well as a form that allows designers to explain why an exception may be merited.
- The crash data module provides users information on how proposed design features will increase or decrease the number and severity of crashes on a given stretch of road. By manipulating such factors as shoulder width, vehicle-per-day usage, and percentage of commercial vehicles on the road, designers can more accurately predict a road's safety record.
- The design consistency module will predict how a roadway alignment will affect operating speed.

- A driver/vehicle module will estimate vehicles' lateral acceleration, friction demand, and rolling potential.
- An intersection diagnostic review module will evaluate intersection design alternatives and identify possible countermeasures when geometric elements compromise driver safety.
- A roadside safety module will perform cost/benefit analyses of roadside design alternatives.
- A traffic analysis module will estimate how roads will perform under current and projected traffic flows using traffic simulation models.

The current software evaluates only two-lane highway designs. FHWA hopes to develop a second version of the program for multilane roads by 2006.

Causal Factors for Accidents on Southeastern Low-Volume Rural Roads (*3*)

Crashes from Kentucky and North Carolina from 1993 to 1995 were used to identify the relationship between driver, roadway, and environmental factors involved in crashes on low-volume roads. The analysis used the quasi-induced exposure technique, which identified driver and vehicle groups that are most at crash risk on rural, low-volume roads. Specific findings and conclusions include the following:

- In general, the crash trends observed for low-volume roads in Kentucky and North Carolina are similar to trends observed on other roads.
- Young drivers, under the age of 25, show higher crash ratios for single-vehicle crashes than any other group of drivers and are more likely to be involved in a single-vehicle crash on low-volume roads than any age group of drivers.
- The general trend of age differences was noted for two-vehicle crashes on low-volume roads. Therefore, middle-age drivers are safer than younger drivers, who in turn are safer than older drivers.
- For single-vehicle crashes, the differences among age groups are larger for crashes occurring at night and on roadways with higher speeds, narrowest lanes, both narrowest and widest shoulder widths, sharpest curves, and low-volume roads. In general, younger drivers were the least safe under all of these conditions.
- Shoulder width and roadway curvature showed that drivers have lower crash rates on roads with the worst conditions—no shoulder or sharpest curves—than on less dangerous segments. These data indicated that drivers increase their attention and lower their speeds—drive more safely—in adverse traffic environments, but they may drive less carefully in safer environments.
- Older drivers are less safe than younger and middle-aged drivers on roads with sharp curves, being involved in both single- and two-vehicle crashes.
- For two-vehicle crashes, the age differences are present and stronger than the roadway speed limit, lane and shoulder width, and curvature. The data analyzed show that these factors did not significantly affect the occurrence of two-vehicle crashes on low-volume roads.
- Female drivers are safer than male drivers. Moreover, younger female drivers are safer than younger male drivers, but older male drivers are safer than older female drivers. Female drivers from North Carolina have lower crash ratios than their Kentucky counterparts.
- Newer vehicles are more likely to be involved in single-vehicle crashes and are more likely to do so when driven by younger drivers.

- Older drivers are more likely to benefit from the increased safety levels of newer vehicles, a trend holding for both single- and two-vehicle crashes.
- Larger vehicles are more likely to hit other vehicles on the typically narrow low-volume roads, but smaller vehicles are more likely to be involved in single-vehicle crashes.

On the basis of these findings, a series of potential countermeasures is proposed that could improve the traffic safety of low-volume roads.

- Most of the findings indicate that younger drivers have higher crash ratios for single vehicles in all traditional geometric features of such roads: sharp curves, narrow lanes, no shoulders, and high speed limits. Driver education and graduated licensing appear to be the reasonable countermeasures for improving the safety of these drivers.

- Most of the countermeasures should focus on addressing the issue of single-vehicle crashes, because more than one-half of the crashes on low-volume roads are such crashes. Short-term solutions should focus on increased driver education as well as lowering the speed limit on certain roadway segments, because all age groups of drivers have their higher crash ratios on such roads. Long-term solutions include geometric improvements dealing with increasing lane and shoulder widths and eliminating sharp curves—all geometric features contributing to the occurrence of single-vehicle crashes.

- A number of socioeconomic characteristics may explain part of the crash rates on low-volume roads. Obviously, older vehicles are less safe than newer vehicles, and the age of the vehicle is closely tied to a variety of social factors. The data here show that the age of the vehicle is inversely proportional to the single-vehicle crash involvement and proportional to two-vehicle crash involvement. Although newer vehicles are safer and have added safety features, compared with older vehicles, they also could be viewed as a means to reduce the safety margins set by the drivers. This is particularly true for the younger drivers in single-vehicle crashes. These facts could be presented within a driver education program where the potential perils of new vehicles could be demonstrated. Older vehicles present the other end of the problem where antiquated vehicles still drive on secondary, low-volume roads. Vehicle inspection programs may be an added countermeasure where vehicles with safety-related deficiencies could be identified.

National Cooperative Highway Research Program Project

Accident Mitigation Guide for Congested Rural Two-Lane Highways (NCHRP Report 440)

While the NCHRP project had several tasks and objectives, its primary purpose was the creation of an *Accident Mitigation Guide for Congested Rural Two-Lane Highways* (*1*). The *Accident Mitigation Guide* was to be developed to provide assistance to the transportation practitioner in identifying and designing projects to improve safety on congested rural and exurban two- and three-lane highways. A synopsis of the material in the *Accident Mitigation Guide* is provided in Table 3-1.

Chapters 3 to 6 of the *Accident Mitigation Guide* contain the bulk of information. They discuss countermeasures that are appropriate for congested rural and exurban two- and three-lane highways. Each countermeasure section starts with an overview, such as a brief discussion on the need for adequate recovery distance along a roadway. This discussion is then followed by three subsections: Accident Experience, Countermeasures, and Effectiveness of Countermeasure. Accident Experience contains available information on the types of accidents and/or the frequency of accidents for the situation. Appropriate countermeasures for use are discussed next. This discussion presents general information about countermeasures, techniques that are used, and examples. The final subsection discusses the known effectiveness of the countermeasures. In some cases, the effectiveness of a countermeasure is well known, such as the addition of shoulders. In other cases, the effectiveness is suspected or not known.

To select the roadway projects that would be investigated as part of the research, a preliminary list of potential improvements were developed and included with a mailout survey. Respondents indicated which improvements have been implemented and where. The panel for the research project provided additional guidance on which types of improvements should be targeted during the selection process. For example, previous research has demonstrated the benefits of passing lanes and turn lanes. Therefore, the efforts were focused on other types of treatments, such as rumble strips and traveler information. The roadway projects included in the *Accident Mitigation Guide* illustrate the types of improvements that have actually been implemented by state and local highway agencies that are less costly than widening the roadway to four lanes. Table 3-1 (see section on Chapter 7: Examples of Safety Improvements in Table 3-1) includes a list of the projects.

Role of Congestion in Accident Experience

An investigation to determine the role of congestion in traffic accidents on two-lane highways was undertaken in the research (*4*). The investigation used traffic volume and accident data for selected two-lane highway sites in five states. Accident frequencies, accident rates, accident severity distributions, and accident type distributions were determined for the sites in each state as a function of traffic operational level of service (LOS). The conclusions of this evaluation were:

- There is no clearly defined relationship between accident rate per million vehicle-kilometers and level of service. Different trends were found in different states, and no definitive conclusions could be reached.
- The proportion of fatal and injury accidents increases as congestion increases under daytime conditions. The proportion of fatal and injury accidents is lowest at LOS A (45.0 percent), is higher for LOS B through E (53.6 percent), and is highest for LOS F (69.1 percent).
- The proportion of multiple-vehicle accidents increases and the proportion of single-vehicle accidents falls as congestion increases for LOS B through E under daytime conditions. The trend of increasing multiple-vehicle accidents with increasing congestion is primarily due to increases in the proportions of rear-end and sideswipe collisions as congestion increases.

Table 3-1. Synopsis of Material in the *Accident Mitigation Guide for Congested Rural Two-Lane Highways*.

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 is discussed in the following sections: traffic control devices and rumble strips. **Chapter 4: Roadside Countermeasures.** The condition of the roadside can affect accident frequency and severity, especially when considering the high percentage of accidents, 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 Advanced Traveler Information System; Innovative Electronic Advanced Warning System; Centerline Rumble Strips and Inverted Profile Thermoplastic Edgelines; 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 Advanced 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.

These findings provide guidance for congested two-lane highway sites. First, although there is no clear relationship of accident rate per vehicle-kilometer to congestion level, accident frequencies clearly increase with increasing traffic volume. Therefore, congested sites are likely to have more accidents than uncongested sites, and installation of accident countermeasures are likely to have higher safety benefits. For example, a countermeasure that generally reduces accidents by 20 percent will reduce more accidents at a congested site than at an uncongested site. Second, congested sites have a greater proportion of severe accidents than uncongested sites. This increases both the seriousness of the safety problem at congested sites and the potential benefits of safety countermeasures. Third, as congestion increases, the occurrence of multiple-vehicle accidents becomes more and more predominant. In setting priorities for improvement, this implies that roadside improvements (which generally address single-vehicle run-off-road accidents) are potentially desirable at any site—congested or uncongested—while roadway improvements that address multiple-vehicle accidents become increasingly important as congestion increases. At congested sites, priority should definitely be given to countermeasures with the potential to reduce rear-end and sideswipe collisions such as intersection turn lanes, two-way left-turn lanes, and passing lanes.

Findings from the NCHRP Project

The *Accident Mitigation Guide* provides one comprehensive document that a practitioner can use to investigate several potential countermeasures for improving safety and/or operations on rural or exurban two- and three-lane highways. The investigation of implemented countermeasures found the following:

- Lower-cost treatments can be highly successful in reducing accidents and/or improving operations along congested rural two-lane highways.
- Public participation played a significant role in the development and selection of countermeasures at several sites.
- Information on the selection and installation of a treatment is not always well documented. In addition, detailed before-and-after studies of the effectiveness of a treatment are also sparse. There were some cases, however, where the documentation of a treatment was comprehensive.
- Several of the potential treatments were part of other, larger roadway improvement projects; therefore, it was difficult to isolate the effects of the lower-cost improvement from the effects of the other treatments.
- Several of the treatments were viewed as temporary measures to improve safety and/or operations until the funds could be allocated to widen the roadway to four lanes.

Roadway Safety Guide (*5*)

The Federal Highway Administration developed a guide which was:

> "...designed to provide local elected officials and other community leaders with basic information on improving roadway safety in their communities. Written for nonengineers, it is designed to be a hands-on, user-friendly document, providing community leaders with:
> - strategies they can use right away to begin making roads safer;
> - basic information to improve roadway safety in cooperation with state and local transportation departments, highway engineers, highway safety officials, Safe Communities groups, and other safety programs; and
> - clear descriptions of key funding and decision-making processes that affect roadway safety.
>
> The Guide is available on the Roadway Safety Foundation website, www.roadway.org, with updates to assist users in their ability to respond to emerging roadway safety problems."

The report, *Roadway Safety Guide for Local Decision Makers and Community Leaders,* includes the following chapters:
1. Getting Started: How to Identify Roadway Safety Problems
2. Choosing Countermeasures: Best Practices
3. Getting It Done
4. Getting Help

Low-Cost Methods for Improving Traffic Operations on Two-Lane Roads: Informational Guide (*6*)

This report is an informational guide for highway agencies on the use of low-cost improvements to alleviate operational problems on two-lane highways. The guide addresses both passing and turning improvements that can be constructed for a lower cost than construction of a continuous four-lane highway. The passing improvements presented include passing lanes, climbing lanes, short four-lane sections, turnouts, shoulder driving, and shoulder-use sections. The turning improvements included are intersection turn lanes, shoulder bypass lanes, and two-way left-turn lanes.

Technology in Rural Transportation "Simple Solutions" (*7*)

This report contains information on simple solutions identified during the rural outreach project. The goal was to identify and describe proven, cost-effective, "low-tech" solutions for rural transportation-related problems or needs. Research and interviews with local level transportation professionals were used to identify examples of technology applications. More than 50 "simple solutions" were identified and a subset of these solutions was selected for further investigation. Details gathered included descriptions of the benefits of the technology, the expected implementation process, the potential issues associated with each technology, and each technology's role in a larger scale, fully integrated rural intelligent transportation system.

Prediction of the Expected Safety Performance of Rural Two-Lane Highways (*8*)

The report presents an algorithm for predicting the safety performance of a rural two-lane highway. The accident prediction algorithm consists of base models and accident modification factors for both roadway segments and at-grade intersections on rural two-lane highways. The base models provide an estimate of the safety performance of a roadway or intersection for a set of assumed nominal or base conditions. The accident modification factors adjust the base model predictions to account for the effects on safety for roadway segments of lane width, shoulder width, shoulder type, horizontal curves, grades, driveway density, two-way left-turn lanes, passing lanes, roadside design and the effects on safety for at-grade intersections of skew angle, traffic control, exclusive left- and right-turn lanes, sight distance, and driveways. The accident prediction algorithm is intended for application by highway agencies to estimate the safety performance of an existing or proposed roadway. The algorithm can be used to compare the anticipated safety performance of two or more geometric alternatives for a proposed highway improvement. The accident prediction algorithm includes a calibration procedure that can be used to adapt the predicted results to the safety conditions encountered by any particular highway agency on rural two-lane highways. The algorithm also includes an Empirical Bayes procedure that can be applied to utilize the safety predictions provided by the algorithm together with actual site-specific accident history data.

Safety Improvements for Low-Volume Rural Roads (*9*)

The justification of safety improvements for low-volume rural roads has been difficult. Roadblocks of a primarily economic nature have prevented the improvement of many features associated with this type of road, features which have been known to have adverse safety implications for many years. In this report, traditional methods of developing a safety index for these roads have been explored and found unsuitable. These methods include the correlation of crash rates with specific roadway features and the location where atypical number of accidents occur. Neither of these approaches in general are of value on low-volume (ADT $\leq$1000) rural roads. The combination of two relatively new concepts for safety improvements is recommended as a result of this study. They are "process-based improvements" and "low-cost safety improvements." For example, one "process" is to eliminate all hazardous concrete culvert headwalls in a district. The "low-cost" aspect relates to either breaking the headwall off at ground level or building up the soil of the roadside to the level of the headwall top surface.

CHAPTER 4

VEHICLE CRASHES ON ON-SYSTEM, LOW-VOLUME, RURAL TWO-LANE HIGHWAYS IN TEXAS

A study on vehicle crashes using Texas DPS crash and TxDOT roadway inventory databases was conducted. The study was performed to partially address the following questions pertaining to on-system, low-volume, rural roads:

(1) How often do crashes occur?
(2) Where do crashes occur?
(3) What types of crashes occur more often?

The chapter will summarize key results from the vehicle crash study.

Addressing the first two questions is as important as addressing the third question for several reasons. Because of the lack of resources and a vast highway system that needs to be maintained, operated, and improved, highway engineers continue to have to juggle available resources to make incremental safety improvements. This often requires them to make difficult decisions on the trade-off between cost and safety and other operational objectives. Under this premise, retrofitting the entire low-volume system at once with certain potential "low-cost" improvements may still be infeasible to do. Thus, knowing where to improve and how to prioritize and schedule the improvement is equally important in addressing the safety problems of low-volume roads (*10*).

The occurrences of vehicle crashes are quite random and sporadic across the road network (*11*, *12*). 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 this study, vehicle crashes were examined at three levels of aggregations: state level, district level, and county level.

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 average daily traffic (ADT) volumes and area type (i.e., rural versus urban). They are:

- Rural two-lane with ADT less than or equal to 2000 vehicles per day,
- Rural two-lane with ADT between 2000 and 6000 vehicles per day,
- Rural two-lane with ADT greater than 6000 vehicles per day,
- Urban two-lane with ADT less than or equal to 2000 vehicles per day,
- Urban two-lane with ADT between 2000 and 6000 vehicles per day, and
- Urban two-lane with ADT greater than 6000 vehicles per day.

The district-level analysis was to shed light on the potential time-trend and 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 later 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.

County-level analysis was intended to provide more details on the spatial distribution of crashes. It also identified counties that the project team could visit within other tasks. For example, based on county crash rates, the project team selected counties with very high rates and those with low rates but similar number of centerline miles for further investigation. Chapter 5 presents the findings from the site-level crash evaluation.

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 their high non-reporting rates. Because of these concerns, the analysis in this study was conducted with KAB crashes only. Also, for those not familiar with TxDOT, the Department is currently structured into 25 geographic districts that are responsible for highway development. The state's 254 counties are divided among the districts. District offices divide their work into area offices and areas into maintenance offices. Texas' variety of climates and soil conditions places differing demands on highways, so design and maintenance, right-of-way acquisition, construction oversight, and transportation planning are primarily accomplished locally.

STATE-LEVEL ANALYSIS

The two-lane roadways in Texas were divided into rural or urban and then into three ADT groups (less than or equal to 2000 ADT, between 2000 and 6000 ADT, and more than 6000 ADT). While working with the crash database, it was 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 the intersection 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). The KAB crash frequencies, million vehicle miles traveled, KAB crash rates, and centerline miles for the six ADT/area type groups are presented in Table 4-1 for three years from 1997 to 1999. Observations that can be made from the table follow:

- 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.
- 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 VMT than traveling on a multilane roadway.

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

Table 4-1. Texas On-System, Two-Lane Highways.

	ADT Group	KAB Crashes	MVMT	KAB/100 MVMT	Centerline Miles
	1999				
Rural	ADT≤2000 ADT = 2 to 6000 ADT > 6000	4824 4902 2356	10,561 12,967 6496	45.7 37.8 36.3	45,674 10,268 2031
Urban	ADT≤2000 ADT = 2 to 6000 ADT > 6000	205 1046 2697	197 1420 5,086	104.1 73.7 53.0	446 976 1114
	All Two-Lane (w/Crashes Double Count) All Two-Lane (No Crashes Double Count) All On-System	16,030 13,909 44,606	36,727 141,450	43.6 31.5	60,509 73,772
	1998				
Rural	ADT≤2000 ADT = 2 to 6000 ADT > 6000	4822 4675 2202	10,587 12,838 6015	45.5 36.4 36.6	45,865 10,209 1906
Urban	ADT≤2000 ADT = 2 to 6000 ADT > 6000	195 1044 2872	211 1465 5159	92.4 71.3 55.7	478 998 1112
	All Two-Lane (w/Crashes Double Count) All Two-Lane (No Crashes Double Count) All On-System	15,810 13,777 44,355	36,275 138,927	43.6 31.9	60,568 73,724
	1997				
Rural	ADT≤2000 ADT = 2 to 6000 ADT > 6000	4976 4622 2210	10,744 12,192 6008	46.3 37.9 36.8	46,629 9711 1917
Urban	ADT≤2,000 ADT = 2 to 6000 ADT > 6000	202 1210 3069	227 1615 5557	89.0 74.9 55.2	524 1117 1218
	All Two-Lane (w/Crashes Double Count) All Two-Lane (No Crashes Double Count) All On-System	16,173 14,111 45,050	36,343 131,312	44.5 34.3	61,116 72,792

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

Appendix J contains the statistical characteristics of vehicle crashes for the three ADT groups within the rural and urban environment. These statistics are based on three years of crash records from 1997 to 1999. Frequencies and distributions of KAB crashes are shown by injury severity, whether they are intersection-related, 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, and object struck. Table 4-2 lists observations from these distributions (with focus on the row percent, i.e., the third value in each group as shown in Appendix J):

Table 4-2. Characteristics of Crashes within Development/ADT Groups.

Category	**Observation**
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-lanes.
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-lanes. 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).
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.
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 percent of KAB for each ADT group for crashes on curves with a degree of curvature of 4 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 in rural low-volume roads is a major factor responsible for their higher KAB crash rates. Previous research has also found that horizontal curves experience a higher crash rate than tangents on rural two-lane highways (*13*).
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).

Table 4-2. Characteristics of Crashes within Development/ADT Groups (continued).

Category	**Observation**
Lighting Conditions	Considerably higher percentages of the KAB crashes occurred on dark, not lighted, 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, not lighted, conditions while only 27 percent of the KAB crashes in the urban low-volume area occurred under similar lighting conditions.
Surface Conditions	About 14 to 16 percent of all KAB crashes regardless of area type or ADT occurred under wet/muddy/snowy conditions.
Month-of-Year	Crashes occurred quite uniformly throughout the year with May, July, and October having slightly higher percentages of crashes.
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 is on Friday, lowest generally on Sunday, and uniform for the rest of the days.
Time-of-Day	The higher percentages of KAB crashes occurred between 3 pm and 7 pm for all development/ADT groups.
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 increase (42 percent for 2-6000 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 accidents 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).

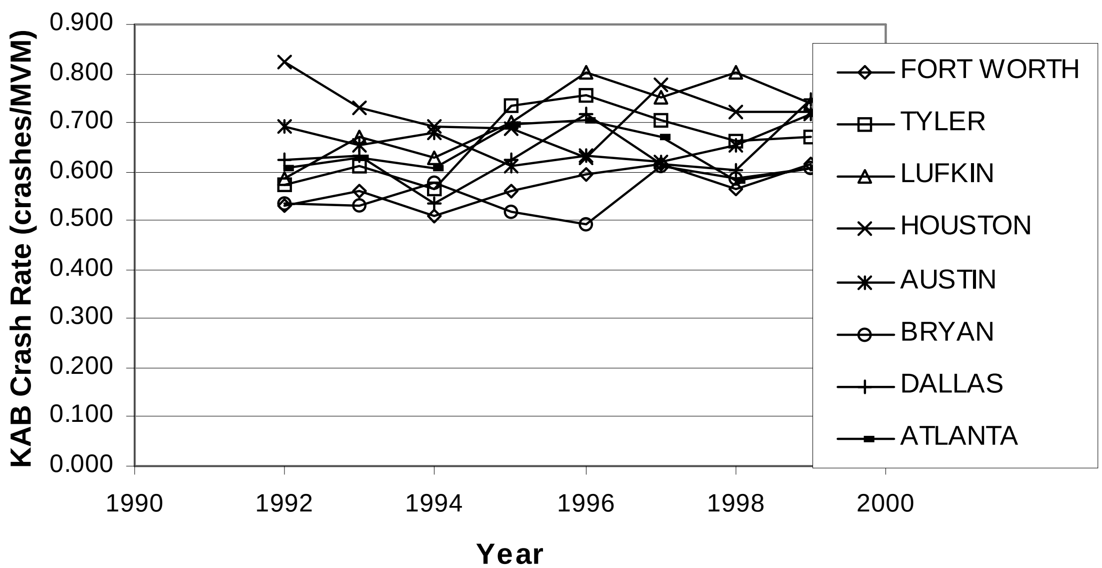
DISTRICT-LEVEL ANALYSIS

Figure 4-1 shows KAB crash rates on on-system, low-volume (less than or equal to 2000 ADT), rural two-lane highways for each TxDOT district from 1992 to 1999. Based on these rates, the districts were grouped into three "rate groups."

- **High-Rate Group:** Atlanta, Austin, Bryan, Dallas, Ft. Worth, Houston, Lufkin, and Tyler;
- **Mid-Rate Group:** Beaumont, Brownwood, Corpus Christi, Paris, Pharr, San Antonio, Waco, Wichita Falls, and Yoakum; and
- **Low-Rate Group:** Abilene, Amarillo, Childress, El Paso, Laredo, Lubbock, Odessa, and San Angelo.

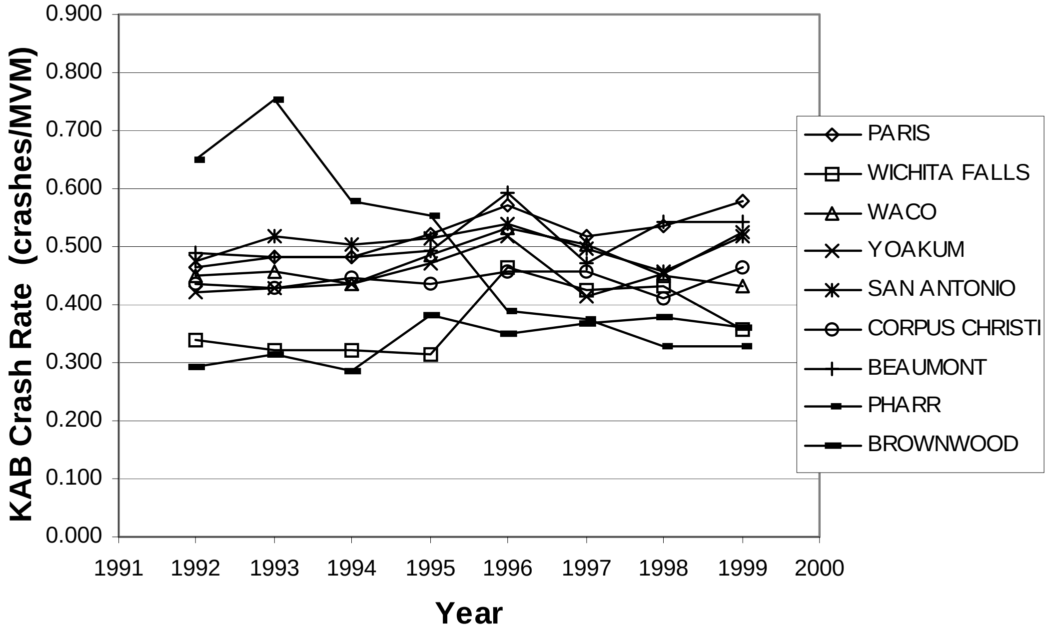
Figure 4-2 shows the location of the rate groups in the state. Several interesting observations could be made with regards to the crash-rate time series shown in Figure 4-1:

- The Lufkin District has one of the highest KAB rates in the previous four years. The Dallas District had a large increase in its KAB crash rate between 1998 and 1999.
- The eight districts in the High-Rate Group have higher than average rates consistently throughout each of the nine years while the eight low-rate districts consistently have below-average rates throughout the same period.
- Pharr District shows a significant drop in crash rate in and after 1996 while Wichita Falls experienced a jump in crash rate in and after 1996.
- The overall KAB crash rate was about 0.4 crashes per million vehicle miles (MVM). The High-Rate Group has an average rate of about 2.5 times higher than that of the Low-Rate Group.

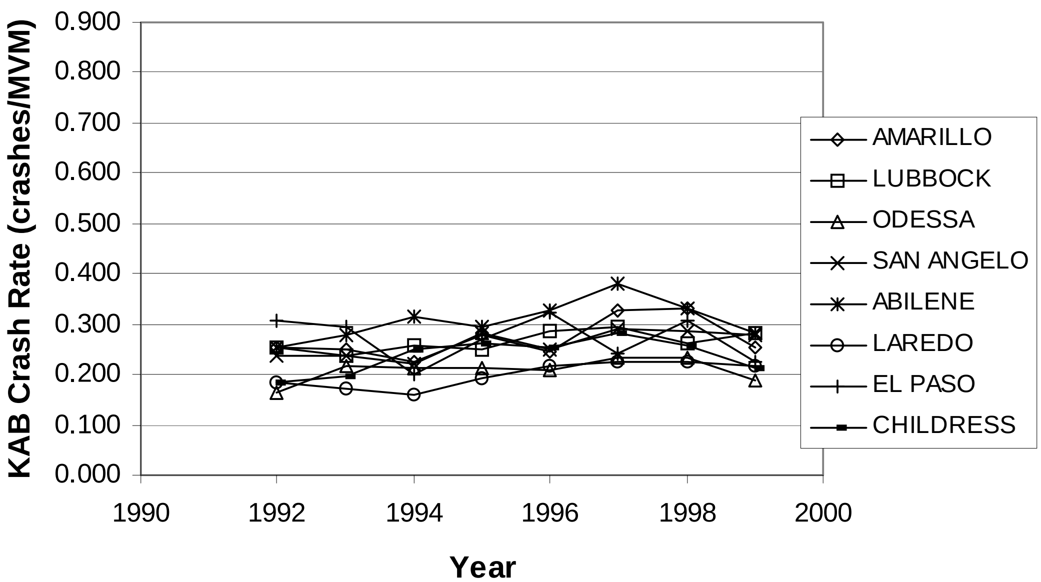


A. High-Rate Group.

Figure 4-1. KAB Crash Rates (Per Million Vehicle Miles Traveled) by District, 1992 to 1999, On-System, Low-Volume, Rural Two-Lane Highways.



B. Mid-Rate Group.



C. Low-Rate Group.

Figure 4-1. KAB Crash Rates (Per Million Vehicle Miles Traveled) by District, 1992 to 1999, On-System, Low-Volume, Rural Two-Lane Highways (continued).

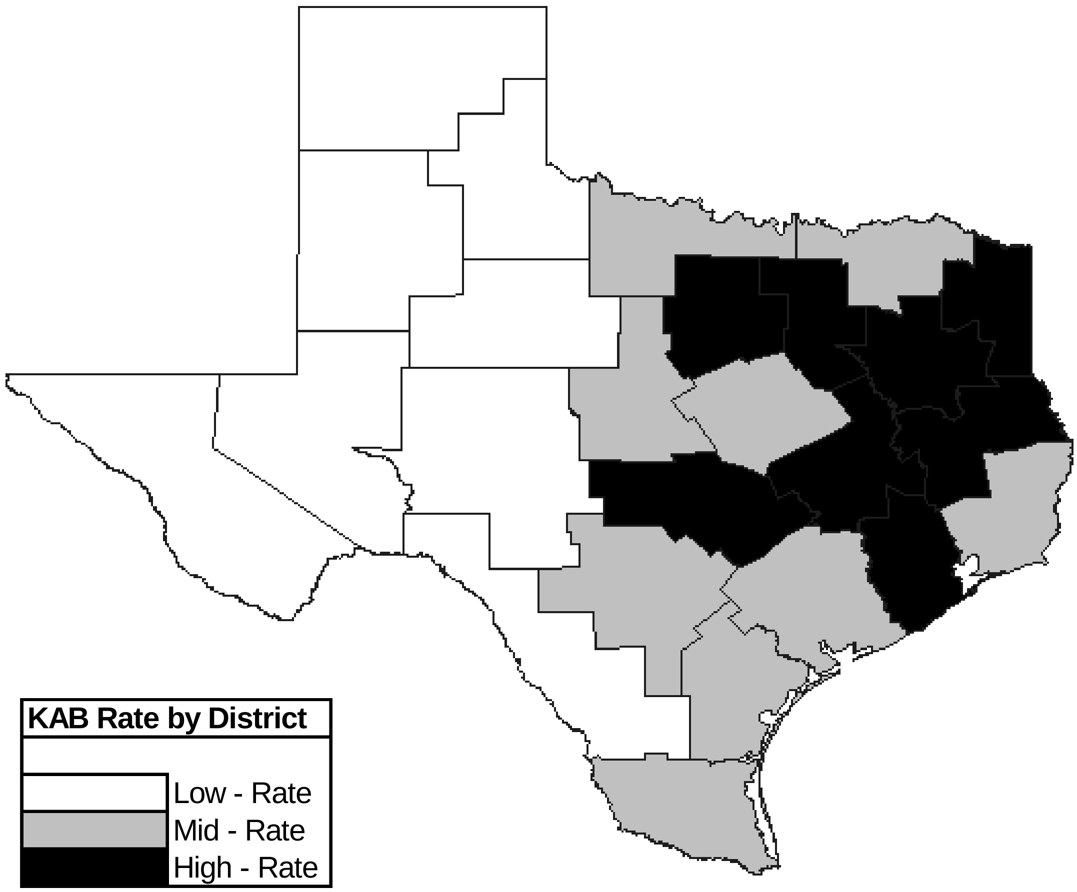


Figure 4-2. Location of Crash Rate Groups in Texas.

Appendix K contains the statistical characteristics of vehicle crashes for the three district groups. 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. The frequencies and distributions of KAB crashes are presented in similar groups as used for the state-level data. Table 4-3 lists observations from these distributions (with focus on the row percent, i.e., the third value in each group).

Table 4-3. Characteristics of Crashes within KAB Rate Groups.

Category	Observation
Injury Severity	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 is much higher than the Low-Rate Group (24 percent) and Mid-Rate Group (31 percent). This 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 with 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 with 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 under wet pavement than the Low-Rate Group (14.3 versus 10.1 percent). The Low-Rate Group had a higher percentage of crashes occurring on 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.

Table 4-3. Characteristics of Crashes within KAB Rate Groups (continued).

Category	Observation
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 tree/shrub are important characteristics of the High-Rate Group.
Other Factor	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).

COUNTY-LEVEL ANALYSIS

The county-level analysis was intended to provide more details on the spatial distribution of crashes. It was also intended to provide an indication on which counties the project team may want to visit or select when conducting more detailed engineering analyses. Seven years of crash records and road inventory data from 1992 to 1999 were examined for each county.

Figure 4-3 shows the number of centerline miles by county (averaged over the seven-year period). The 37 counties with the highest number of centerline miles are listed in Table 4-4. Figure 4-4 presents KAB crash rates by county (in crashes per 100 MVM), and the 45 counties with the highest rates are listed in Table 4-5. The darker the shading in Figure 4-3, the higher the crash rate. The figure illustrates that higher KAB crash rates are present in the eastern portion of the state.

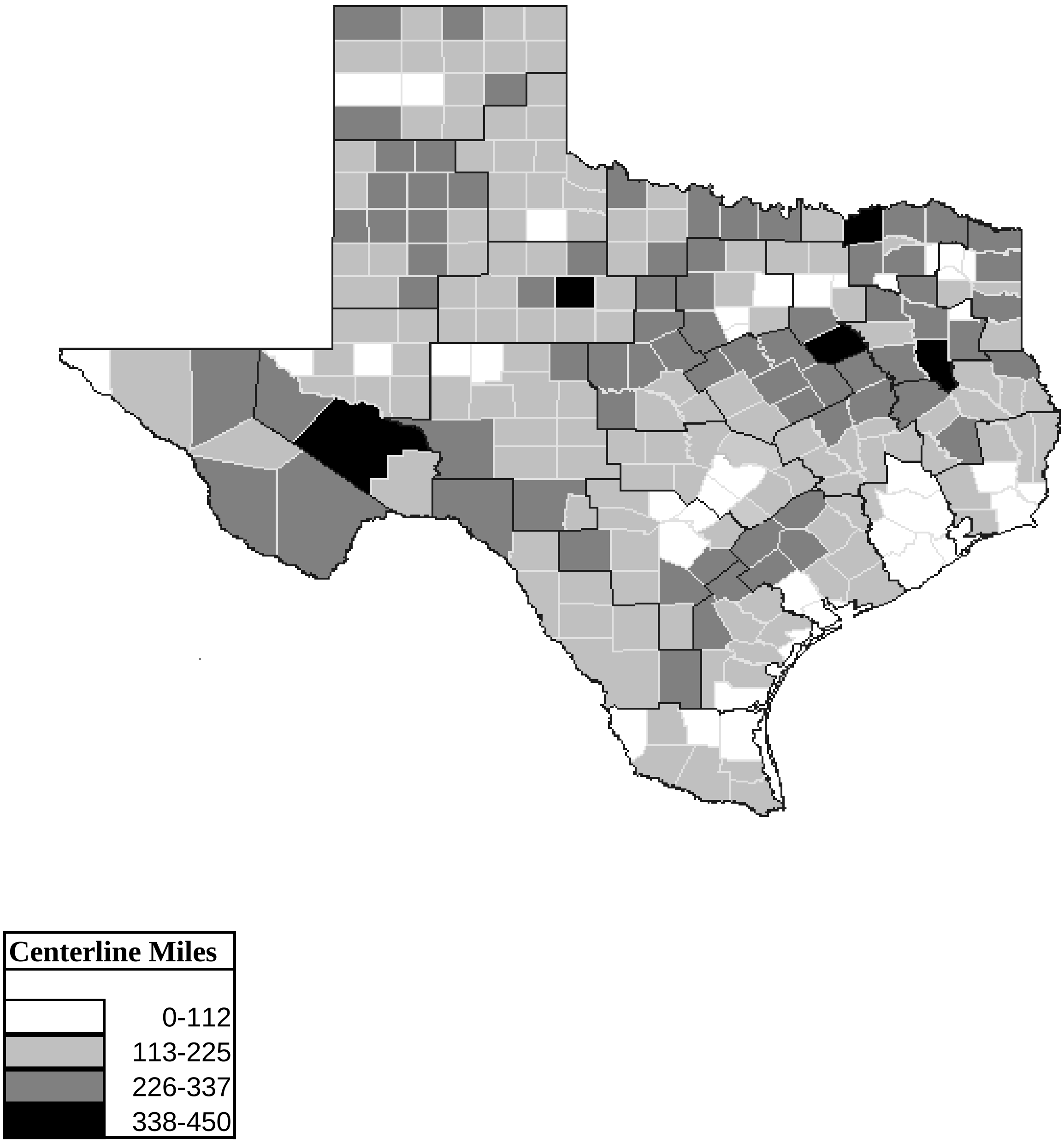


Figure 4-3. Centerline Miles by TxDOT County for On-System, Low-Volume, Rural Two-Lane Highways (average for 1992 to 1999).

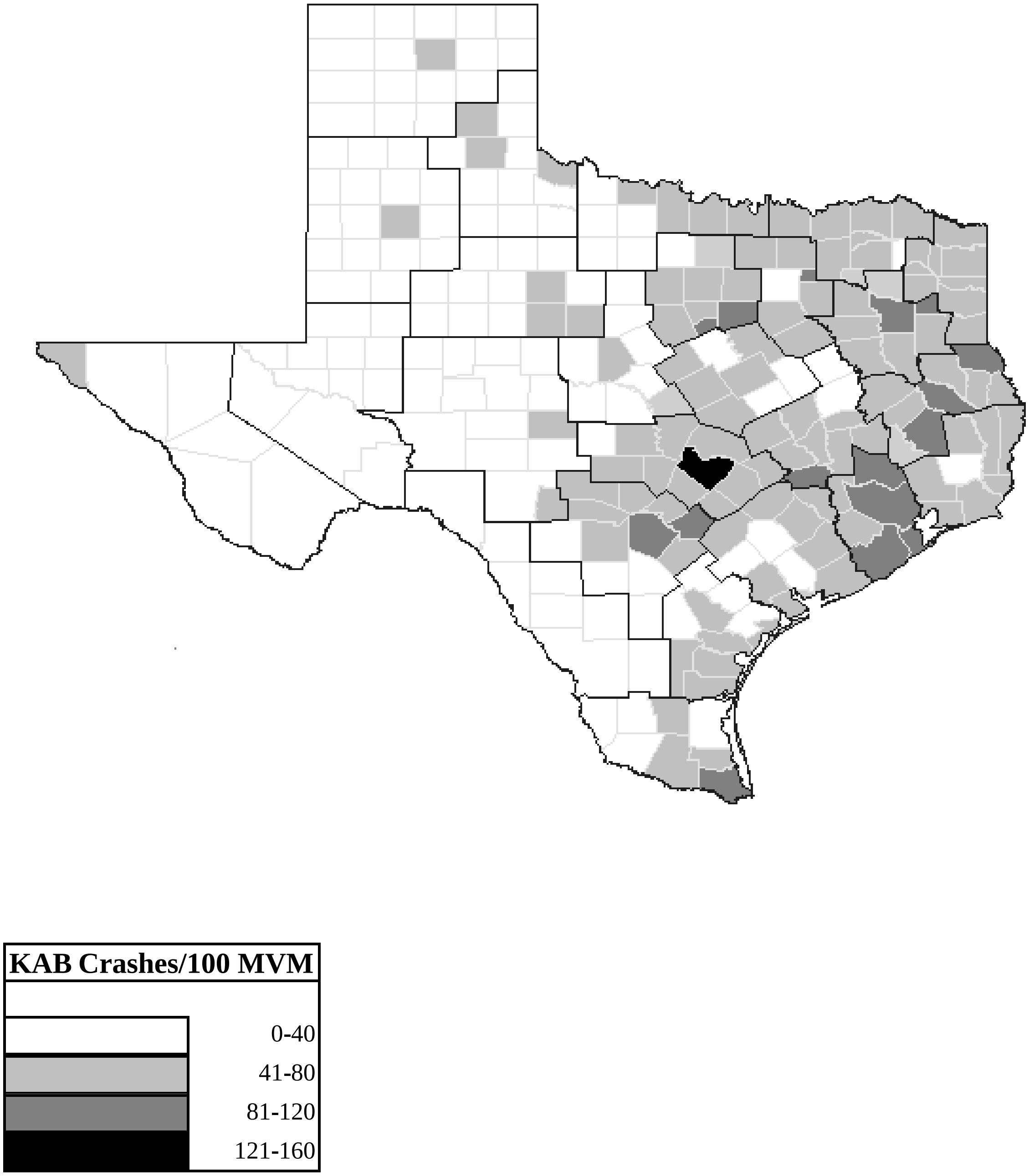


Figure 4-4. KAB Crashes/100 MVM by TxDOT County for On-System, Low-Volume, Rural Two-Lane Highways (average for 1992 to 1999).

Table 4-4. Top 37 Counties with the Most Centerline Miles (8-year Averages) (On-System, Low-Volume, Rural Two-Lane Highways, 1992-1999).

County Name	County Number	District Name	Centerline Miles
Pecos	186	Odessa	449
Fannin	75	Paris	378
Cherokee	37	Tyler	366
Jones	128	Abilene	343
Navarro	175	Dallas	341
Rusk	201	Tyler	336
Lamar	139	Paris	328
Hill	110	Waco	327
Red River	194	Paris	317
Cass	34	Atlanta	317
Hunt	117	Paris	317
Houston	114	Lufkin	304
Gonzales	90	Yoakum	303
Wood	250	Tyler	303
Lamb	140	Lubbock	302
Young	252	Wichita Falls	299
Eastland	68	Brownwood	295
Bosque	18	Waco	291
Karnes	129	Corpus Christi	290
Van Zandt	234	Tyler	288
Fayette	76	Yoakum	287
Runnels	200	San Angelo	287
Hale	96	Lubbock	286
Anderson	1	Tyler	283
Limestone	147	Waco	282
Floyd	78	Lubbock	280
Clay	39	Wichita Falls	280
Reeves	195	Odessa	278
Commanche	47	Brownwood	277
Brewster	22	El Paso	277
Coleman	42	Brownwood	276
Montague	169	Wichita Falls	275
Lynn	153	Lubbock	272
Shelby	210	Lufkin	272
Atascosa	7	San Antonio	271
Lubbock	152	Lubbock	271
Ellis	71	Dallas	271

Table 4-5. Top 45 Counties with the Highest KAB Crash Rate per MVMT. (Low-Volume, Rural Two-Lane Highways, 1992-1999).

County Name	County Number	District Name	Centerline Miles	KAB Crash Rate
Travis	227	Austin	37	1.508
Harris	102	Houston	3	1.183
Somervell	213	Fort Worth	55	1.097
Angelina	3	Lufkin	195	1.083
Rockwall	199	Dallas	53	1.070
Gregg	93	Tyler	50	1.023
Montgomery	170	Houston	86	0.919
Washington	239	Bryan	167	0.889
Brazoria	20	Houston	52	0.866
Smith	212	Tyler	227	0.855
Bexar	15	San Antonio	66	0.846
Polk	187	Lufkin	225	0.838
Galveston	85	Houston	7	0.834
Shelby	210	Lufkin	272	0.832
Johnson	127	Fort Worth	136	0.831
Guadalupe	95	San Antonio	169	0.822
Cameron	31	Pharr	220	0.804
Lee	144	Austin	117	0.800
Williamson	246	Austin	215	0.797
Camp	32	Atlanta	86	0.787
Hood	112	Fort Worth	85	0.780
Harrison	103	Atlanta	253	0.776
Kendall	131	San Antonio	104	0.773
Orange	181	Beaumont	41	0.769
Burnet	27	Austin	171	0.767
Nacogdoches	174	Lufkin	216	0.765
Bastrop	11	Austin	166	0.728
Upshur	230	Atlanta	210	0.724
Kerr	133	San Antonio	161	0.720
Burleson	26	Bryan	157	0.718
Kaufman	130	Dallas	206	0.712
Henderson	108	Tyler	225	0.707
Nueces	178	Corpus Christi	142	0.692
San Jacinto	204	Lufkin	177	0.686
Hays	106	Austin	56	0.684
Bandera	10	San Antonio	153	0.682
Mclennan	161	Waco	238	0.682
Titus	225	Atlanta	89	0.681
Walker	236	Bryan	155	0.678
Rusk	201	Tyler	336	0.673
Victoria	235	Yoakum	107	0.668
Bell	14	Waco	203	0.655
Waller	237	Houston	126	0.645
Collin	43	Dallas	225	0.642
Hunt	117	Paris	317	0.642

SUMMARY OF FINDINGS

This study found the following for the three questions asked at the beginning of the chapter:

(1) How often do crashes occur?

In 1999, there were 45.7 KAB crashes/100 MVMT on low-volume, rural two-lane highways. For all on-system roads, the rate was 31.5 KAB/100 MVMT. 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 ($\leq$2000 ADT), rural two-lane highways.

(2) Where do crashes occur?

More KAB crashes occurred in eastern counties (see Figure 4-3) than western counties. The crash rates revealed that a vehicle traveling on a two-lane road, whether in an urban or rural environment, has a greater likelihood of being involved in a KAB crash per VMT than traveling on a multi-lane highway.

(3) 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, non-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:

- treatments that either decrease the number of vehicles from leaving the roadway, especially on tight horizontal curves or that better communicate the nature of the curve;
- improvements to reduce the number of nighttime crashes;
- treatments that reduce crashes at driveways; and
- improvements to minimize severity of crashes if a vehicle leaves the road.

CHAPTER 5

EVALUATION OF CRASHES AT ROADWAY LEVEL

When the accident rates by county were plotted, a definite pattern of areas with high rates versus areas with lower rates emerged (see Figure 4-2). 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 more narrow 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 SELECTION

The two counties with the highest average KAB rates on low-volume, rural two-lane highways for 1992 to 1998 were identified: 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. Because the number of miles that would be considered low volume will change as cities develop and expand, the data for the most recent year available (1998) were used to identify counties. Martin County with 185 miles of low-volume, rural two-lane roads was matched to Angelina County (189 miles). Travis County with 22 miles was matched to El Paso County (35 miles). Figure 5-1 shows the location of the four counties, and Figure 5-2 includes pictures of one of the study sites within each county.

Another advantage to the Travis County and El Paso County pair is that both counties include medium-sized, growing cities. Travis County is home to Austin, and El Paso County is home to the city of El Paso. The growth of these cities is causing increased traffic volumes on rural two-lane roadways. Therefore, in addition to El Paso County having centerline miles similar to Travis County, they both share characteristics common to an area undergoing development. The city of Lufkin is the population center of Angelina County while Martin County is a predominantly rural county in the Odessa District, which has one of the lowest KAB rates.

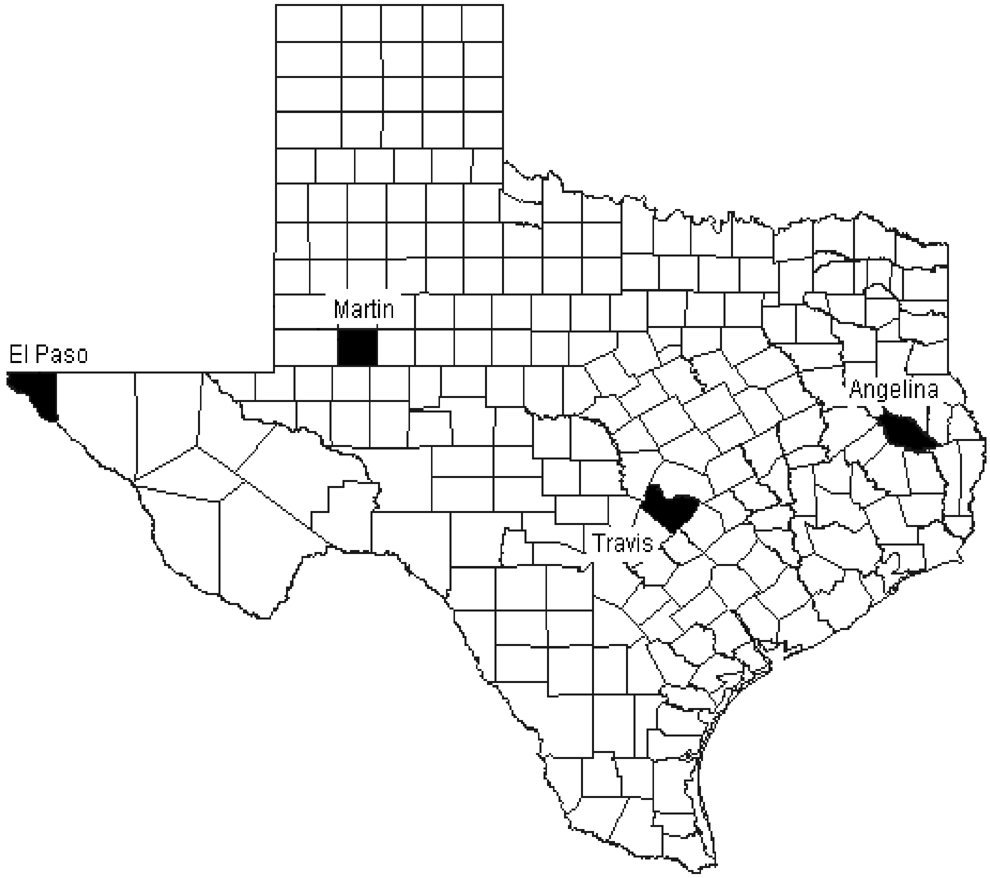


Figure 5-1. Counties in Texas Selected for Analysis.

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. These locations typically occurred either near an intersection or interchange with a higher functional class road or near a town. 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 was retained so that a similar number of miles would be available between El Paso and Travis Counties. Table 5-1 lists the sections used in the analysis, along with their lengths, yearly ADTs, vehicle miles traveled, and three-year crash totals.

Martin County

Angelina County

El Paso County

Travis County

Figure 5-2. Samples of Study Sites in Four Texas Counties.

DATA COLLECTION

Two primary sources of data were collected for this evaluation: site characteristics data and crash record data.

Crash Records

TxDOT maintains the crash records for the state using information provided by the Department of Public Safety (DPS). A copy of the electronic crash data files is also available within the Texas Transportation Institute. 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. During the initial evaluation of the crash data, it was determined that crashes at an intersection are only assigned to one road. If the roads are two different classes (i.e., Interstate, US, SH, or FM), the crash is assigned to the higher-class road. If the roads are of the same class, the crash is assigned to the lower-numbered road. Since nearly all of the control sections within this study are high-numbered FM roadways, the crashes at intersections were almost always assigned to the crossing road. Therefore, the number of crashes initially included in the analysis was undercounted.

Characteristics of the crashes assigned to the cross road for each intersection with our study sites were obtained and used within the analysis. To allow comparison between the crashes on the sections selected for this evaluation and all crashes on low-volume, rural two-lane highways (see Chapter 4), this study examined KAB crashes only.

Table 5-1. Sections Selected for Field Investigation.

Ctrl Sect	Route	Length (mi)	ADT	MVMT	Number of Crashes [a]						KAB/ MVMT
					N	C	B	A	K	KAB	
ANGELINA COUNTY											
336-9	FM 1669	1.8	213	0.4	0	0	2	0	0	2	4.8
390-4	FM 1270	6.0	210	1.4	0	0	0	2	0	2	1.5
1874-2	FM 2021/ FM 3521	3.7	687	2.8	6	2	4	4	1	9	3.2
1874-1	FM 2021	8.5	876	8.2	5	6	21	7	1	29	3.6
2115-1	FM 2251	5.4	1317	7.8	3	0	7	3	1	11	1.4
Totals		25.4		20.5	14	8	34	16	3	53	2.6
MARTIN COUNTY											
1871-2	FM 2002	6.0	106	0.7	0	0	0	0	0	0	0.0
1638-2	FM 829	15.8	387	6.7	0	0	0	1	0	1	0.1
494-3 (B)	SH 137	12.0	1269	16.7	1	0	3	0	0	3	0.2
Totals		33.8		24.1	1	0	3	1	0	4	0.2
EL PASO COUNTY											
2-3 (C-D)	SH 20	7.9	1350	11.7	0	0	3	1	0	4	0.3
674-2	FM 76	5.6	1991	12.2	0	0	3	1	0	4	0.3
2-15	FM 1109	4.1	1433	6.4	0	0	0	0	0	0	0.0
2326-1 (C)	FM 2529	5.0	4188	22.9	0	0	0	0	0	0	0.0
Totals		22.6		53.3	0	0	6	2	0	8	0.2
TRAVIS COUNTY											
2210-1	RM 2322	4.6	2106	10.6	8	3	3	1	1	5	0.5
2718-1	RM 2769	7.3	2313	18.5	2	4	11	1	1	13	0.7
1378-1	RM 1431	9.8	907	9.7	0	0	4	1	0	5	0.5
Totals		21.7		38.8	10	7	18	3	2	23	0.6

[a] N= Non-Injury
C = Possible Injury
B = Non-Incapacitating
A = Incapacitating
K = Fatal
KAB = Fatal, Incapacitating, or Non-Incapacitating

Site Characteristics Data

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 were collected at each site by driving the site and recording data using video or noting characteristics on a pre-developed data collection sheet (see Table 5-2 for a list of the information collected). The first round trip was a simple observation trip to become familiar with the site and take note of any unique elements. On the second trip, a video record of the entire length of the control section was made. While one technician was driving through the site, the second technician used a camcorder to record the view through the front windshield to obtain a driver's point of view of the roadway. A third round trip was made to fill out the sections of the worksheet for roadside environment, roadside development, and traffic control devices. A fourth round trip was used to count driveways and intersections on both sides of the road, and to count vertical curves and advisory speeds. Depending on the access density or the terrain, it was sometimes necessary to divide these tasks between two round trips. A final trip through the site provided the opportunity to stop and measure lane and shoulder widths and take pictures of both directions of the control section.

Table 5-2. List of Data Collected within the Site Characteristics Worksheet.

Date: Route: City/County: Control Section:	Beginning Feature: Ending Feature: Length: Direction 1: NB SB EB WB

• Roadside environment (measured for Directions 1 and 2 at both 2 ft and 10 ft from pavement):
  • No fixed objects
  • Yielding objects only
  • Combo of yielding and isolated rigid objects
  • Isolated rigid objects only
  • Many or continuous rigid objects
• Roadside development
  • Trees
  • Farmland
  • Residential
  • Commercial
  • Park/School/Campus
	• Number of access points along section (driveways and intersections)
	• Lane width (by direction)
	• Shoulder type and width (by direction)
	• Total pavement width
	• Number of traffic signals and stop signs
	• Posted speed limit
	• Number of advisory speeds (and values)
	• Presence of pavement markings
	• Notes of any sight distance restrictions, unusual features, and unique characteristics

DATA ANALYSIS

Crash Records

Table 5-3 contains the KAB crash data from the crash database for the study sites, grouped by county. The total statewide numbers are included for comparison; these data reflect 14,742 KAB crashes on rural two-lane highways with less than 2000 ADT from 1997 to 1999. The 1999 statewide KAB rate for low-volume, rural two-lane highways was 0.46 crashes per million vehicle miles traveled. The crash rates for the control sections driven in the four counties varied from 0.15 in El Paso County to 2.58 in Angelina County (see Figure 5-3). 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.

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). Figure 5-4 shows the distribution of crashes by where they occurred with respect to an intersection for the state of Texas and for the four counties combined. Figure 5-5 shows the distribution of accidents on the roadways within each county. There were

Table 5-3. Crash Data for 1997-1999 for Control Sections, by County and Statewide.

	Angelina		Martin		El Paso		Travis		Total		Statewide	
	Num	%	Num	%	Num	%	Num	%	Num	Pct	Num	%
Overall Accidents	53		4		8		23		88		14622	
Intersection-Related Accidents												
Intersection	21	40	4	100	2	25	5	22	32	36%	2248	15
Intersection-Related	2	4	0	0	0	0	1	4	3	3%	1346	9
Driveway Access	4	8	0	0	1	13	2	9	7	8%	1269	9
Non-Intersection	26	49	0	0	5	63	15	65	46	52%	9759	67
First Harmful Event												
Pedestrian	0	0	0	0	0	0	0	0	0	0%	145	1
Another vehicle in transport	28	53	4	100	3	38	8	35	43	49%	4548	31
RR Train	0	0	0	0	0	0	0	0	0	0%	35	0
Parked Car	1	2	0	0	0	0	0	0	1	1%	72	0
Pedalcyclist	1	2	0	0	0	0	0	0	1	1%	71	0
Animal	0	0	0	0	0	0	0	0	0	0%	637	4
Fixed Object	16	30	0	0	4	50	11	48	31	35%	4739	32
Other Object	0	0	0	0	0	0	0	0	0	0%	44	0
Overturned	6	11	0	0	0	0	4	17	10	11%	4209	29
Other non-collision	1	2	0	0	1	13	0	0	2	2%	122	1
Injury Severity												
Fatal (K)	3	6	0	0	0	0	2	9	5	6%	1344	9
Incapacitating (A)	16	30	1	25	2	25	3	13	22	25%	4348	30
Non-incapacitating (B)	34	64	3	75	6	75	18	78	61	69%	8930	61
Number of Vehicles Involved												
1	23	43	0	0	4	50	15	65	42	48%	9992	68
2	27	51	4	100	2	25	8	35	41	47%	4393	30
3	2	4	0	0	1	13	0	0	3	3%	222	2
4	1	2	0	0	1	13	0	0	2	2%	12	0
Light Conditions												
Daylight	33	62	4	100	4	50	11	48	52	59%	8338	57
Dark - No Street Lights	18	34	0	0	3	38	10	43	31	35%	5344	37
Dark - Street Lights	2	4	0	0	1	13	2	9	5	6%	389	3
Dawn	0	0	0	0	0	0	0	0	0	0%	269	2
Surface Conditions												
Dry	46	87	3	75	8	100	22	96	79	90%	12539	86
Wet	7	13	1	25	0	0	1	4	9	10%	1909	13
Weather Conditions												
Clear	46	87	3	75	8	100	22	96	79	90%	13054	89
Raining	7	13	1	25	0	0	1	4	9	10%	1057	7
Degree of Curve												
Unknown	0	0	0	0	1	13	1	4	2	2%	601	4
No curve	34	64	4	100	6	75	15	65	59	67%	8853	61
0.1-1.9	6	11	0	0	0	0	0	0	6	7%	695	5
2.0-3.9	3	6	0	0	0	0	3	13	6	7%	1384	9
4.0-5.9	3	6	0	0	0	0	1	4	4	5%	1195	8
6.0 or higher	7	13	0	0	1	13	3	13	11	13%	1894	13

almost an equal number of intersection (21) and non-intersection (26) crashes in Angelina County. Fifteen of the 23 crashes in Travis County were non-intersection crashes, as were five of the eight crashes in El Paso County. All four crashes in Martin County were intersection crashes. As a group, the sites selected for this study have more intersection or driveway-related accidents than most low-volume, rural two-lane highways in Texas.

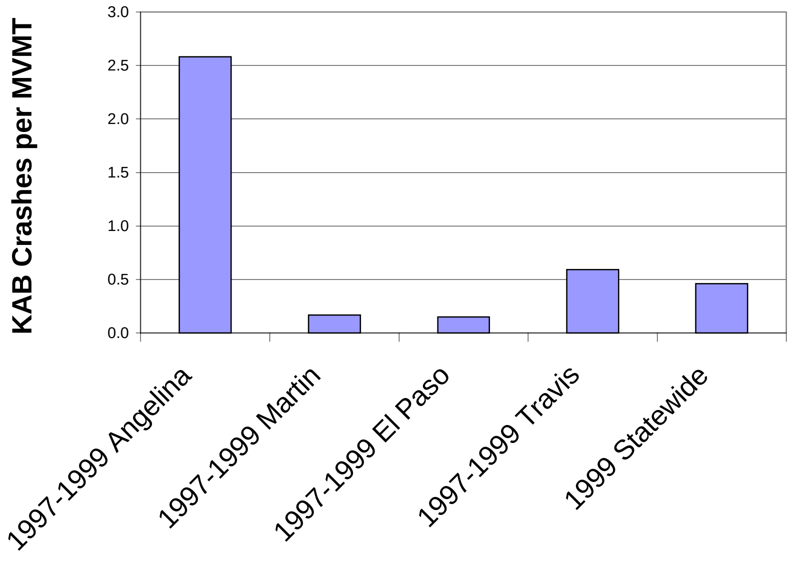
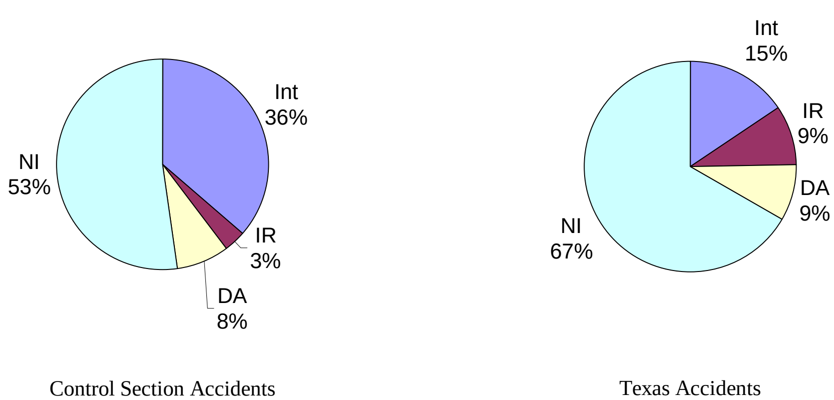


Figure 5-3. KAB Rates for Selected Roadways.



(Int = Intersection, NI = Non-Intersection, IR = Intersection-Related, DA = Driveway Access)

Figure 5-4. Distribution of Crashes by Intersection Influence.

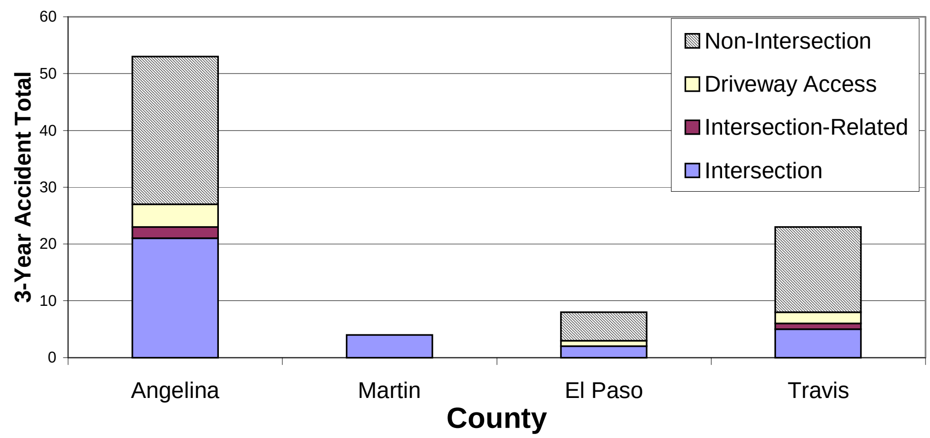
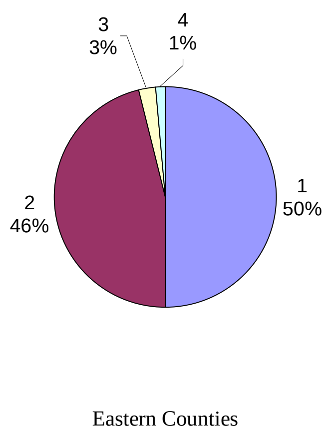


Figure 5-5. Crashes for Roadways by Intersection Influence.

Along with having the majority of the crashes associated with intersections, the selected roadways had more of their crashes involving more than one vehicle (see Figure 5-6) and the first harmful event was, in most cases, striking another vehicle. Figure 5-7 shows the distribution of first harmful event codes by different counties and the distribution for all roads studied and for the state. The counties in the west show that the majority of the crashes involved two or more vehicles (67 percent). Crashes in the two eastern counties (Angelina and Travis) were split almost evenly between one- and two-vehicle crashes. Crashes in the two western counties (Martin and El Paso) were predominantly multi-vehicle crashes. All four crashes in Martin County were two-vehicle collisions at intersections. For all low-volume, rural two-lane highways only 26 percent of the crashes involved two or more vehicles.



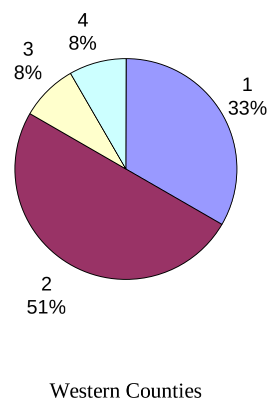
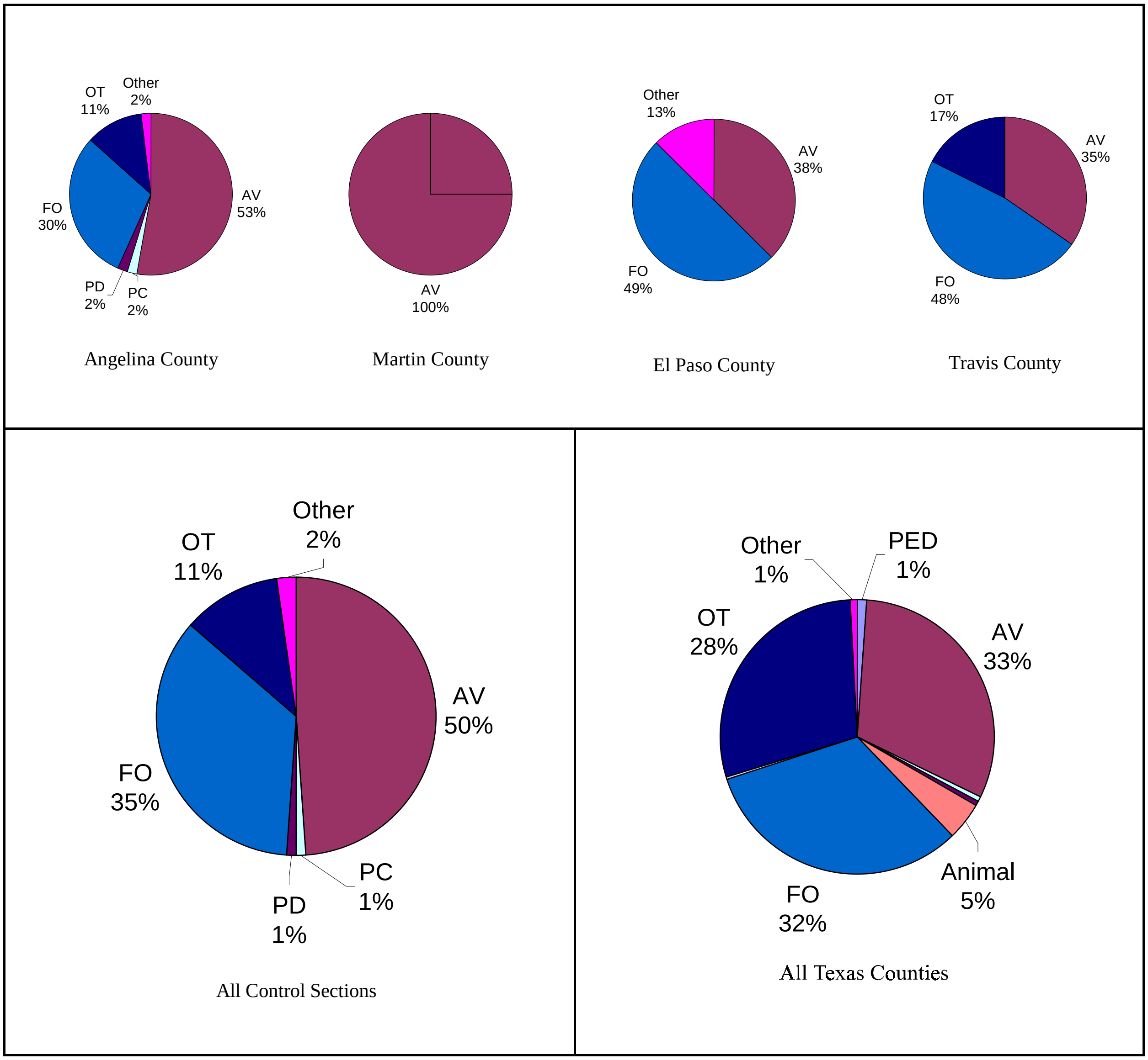


Figure 5-6. Crashes by Number of Involved Vehicles.

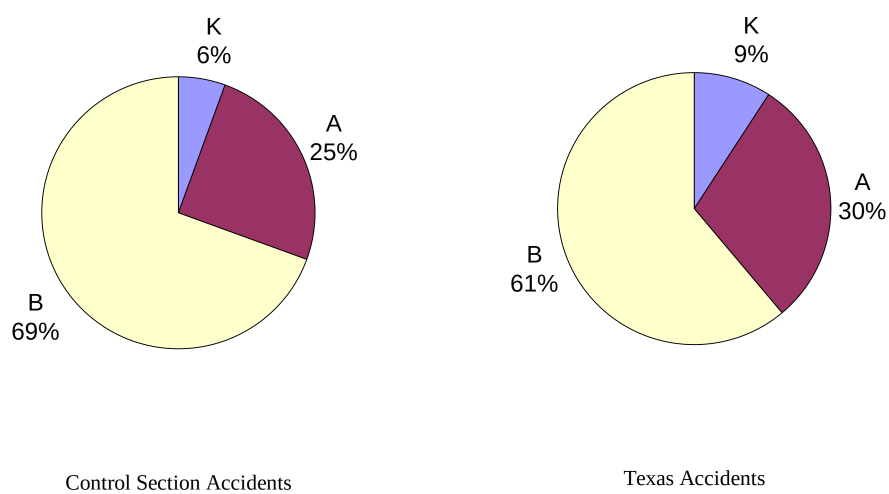


(OT = overturned, FO = fixed object, PD = pedalcyclist, PC = parked car, AV = another vehicle in transport)

Figure 5-7. First Harmful Event.

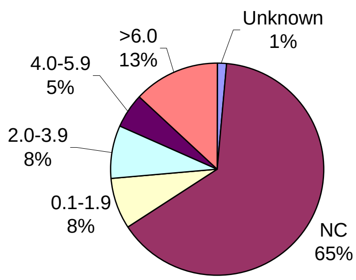
The primary accident type in Angelina County was recorded as colliding with another vehicle; more than half the crashes were of this type (see Figure 5-7). A third of the crashes were fixed-object crashes, and 11 percent involved overturned vehicles. Travis County crashes were divided into the same three 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 (see Figure 5-7). 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.

The level of injuries were similar between the selected roadways and the state. Between 60 and 80 percent were non-incapacitating. Figure 5-8 illustrates the distribution of injuries. 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 (see Figure 5-9). 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.

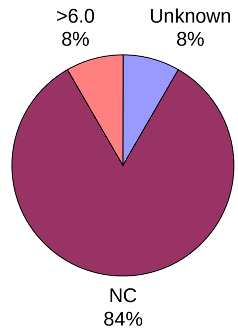


(K = Fatal, A = Incapacitating, B = Non-incapacitating)

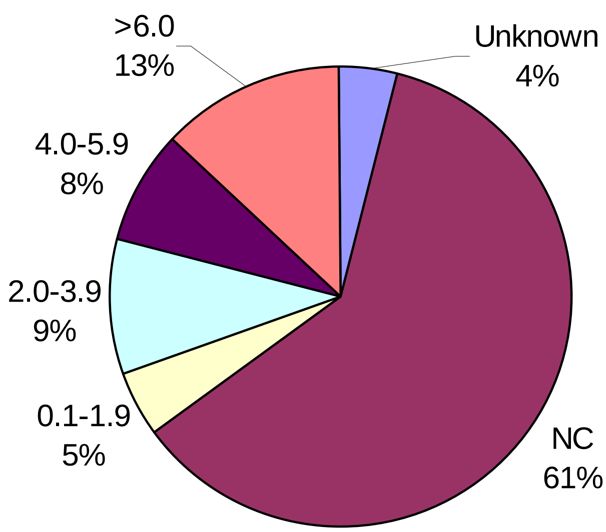
Figure 5-8. Injury Severity Level.



Eastern Counties



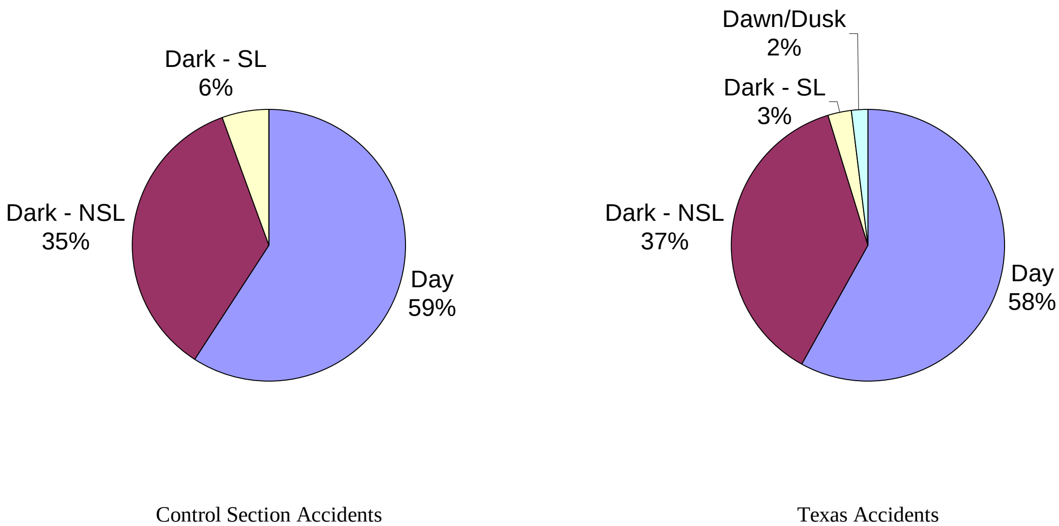
Western Counties



All Texas Counties

Figure 5-9. Crashes by Degree of Curvature (NC = no curve).

Over half of all control section crashes occurred in daylight hours, reflecting the trend in each individual county except for Martin County (see Table 5-3) 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 (see Figure 5-10).



(SL = street lights, NSL = no street lights)

Figure 5-10. Light Conditions.

Site Characteristics Data

The site characteristics data collected from field visits were entered into a spreadsheet for further examination. The sections with more than two lanes were eliminated along with sections with ADTs much greater than 2000. Those sections near 2000 ADT were retained.   The site characteristics data shown in Table 5-4 include the portions of the control section that have two lanes divided into the subsections that most closely approximated the traffic counting stations with less than 2000 ADT.

Table 5-4 contains the site characteristics data for the control sections used as study sites, grouped by county. Total length is the combined length of all control sections from the county included in the analysis. The average roadside environment score is based on a five-point scale, used for the area within 2 ft and within 10 ft 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 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.)

Table 5-4. Site Characteristics for Control Sections Used as Study Sites, Grouped by County.

Geometric Values		Angelina	Martin	El Paso	Travis
Total Length (mi)		25.4	33.8	22.6	21.7
Number of Vertical Curves per mile		1.2	0.4	0.1	2.7
Min Lane Width (ft)		9.0	11.5	10.0	11.6
Max Lane Width (ft)		10.7	12.1	12.8	13.2
Average Roadside Environment Score (scale of 1 to 5, with 1=no fixed objects, 5=many or continuous rigid objects)					
	Dir 1 < 2 ft	1.4	1.0	3.0	5.0
	Dir 1 < 10 ft	2.6	1.3	5.0	5.0
	Dir 2 < 2 ft	1.4	1.0	4.5	5.0
	Dir 2 < 10 ft	2.4	1.3	5.0	5.0
Predominant Roadside Development					
	Dir 1	Trees	Farmland	Farmland	Trees
	Dir 2	Trees	Farmland	Farmland	Trees
Driveway Density (driveways per mile)					
	Dir 1	9.8	2.3	4.9	4.7
	Dir 2	8.7	2.8	3.3	8.2
	Total	18.5	5.1	8.2	12.9
Roadway Density (intersections per mile)					
	Dir 1	1.4	0.8	1.3	0.6
	Dir 2	1.7	0.9	0.7	0.8
	Total	3.0	1.7	2.0	1.3
Access Density (driveway density + roadway density)					
	Dir 1	11.2	3.1	6.2	5.2
	Dir 2	10.4	3.7	4.0	9.0
	Total	21.6	6.9	10.2	14.2
Average Shoulder Width (ft)					
	Dir 1	0.0	5.5	4.5	1.0
	Dir 2	0.0	5.7	4.8	1.2
Min Pavement Width (ft)		18.0	31.8	26.6	24.8
Max Pavement Width (ft)		23.0	41.1	36.9	30.5
Median Width		0	0	0	0
Traffic Control Values					
Number of Signals per mile		0	0	0.0	0.1
Number of RR Crossings per mile		0.0	0	0	0
Number of Stop Signs per mile		0.5	0.1	0.3	0.0
Min Posted Speed Limit (mph)		40	70	35	45
Max Posted Speed Limit (mph)		55	70	55	55
Number of Advisory Speed Limits		13	0	7	31
Advisory Speed Limits per mile		0.5	0	0.3	1.4
Min Advisory Speed Limit (mph)		20	None	10	20
Max Advisory Speed Limit (mph)		50	None	35	50

Predominant roadside development was determined by the technicians during their drive-throughs; 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 edgeline 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.

Table 5-4 shows the following patterns between the eastern counties and the western counties:

- The number of vertical curves per mile are much higher in the eastern counties (1.2 to 2.7 vertical curves/mi) than the western counties (0.1 to 0.4 vertical curves/mi).
- The average roadside environment score, particularly within 2 ft of the roadway has a similar trend—the eastern counties (1.4 to 5.0) have a higher roadside environment score 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.
- 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 5-2)
- Access density is also very different between east (14.2 to 21.6 access points/mi) and west (6.9 to 10.2 access points/mi), 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).
- Shoulders were much wider, on average, in western counties (4.5 to 5.7 ft) than eastern counties (0.0 to 1.2 ft) as were total pavement widths (26.6 to 41.1 ft in the west versus 18.0 to 30.5 ft in the east).
- The number of advisory speeds posted on the study sites were much higher in the east (44) than in the west (7).

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.

SUMMARY OF FINDINGS

In the four counties studied for this task, two (Angelina and Travis) were counties with high KAB rates, and two (Martin and El Paso) were counties with lower KAB rates and that had a similar number of miles of low-volume, rural two-lane highway. Angelina County had the highest KAB crash rate as well as the highest number of crashes overall. Among the four counties, there is a distinct difference between eastern counties and western counties. The eastern counties had the higher crash totals and rates, and they contained all of the fatal crashes considered in this study. In general, sites in the eastern counties had less driver-friendly characteristics, with more horizontal and vertical curves, narrower lanes and/or shoulders, less forgiving roadside development, higher access density, and higher roadside development scores. Eastern counties also had more crashes at intersections than western counties.

CHAPTER 6

SUMMARY AND CONCLUSIONS

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 vehicles per day. These low-volume rural roadways carry less than 8 percent of the total vehicle miles on state-maintained (or on-system) highways and have approximately 11 percent of the total on-system vehicle crashes. These roadways also have relatively more severe injuries when vehicle crashes do occur. For example in 1999, about 26 percent of the Texas on-system crashes are KAB crashes (i.e., fatal, incapacitating injury, and non-incapacitating injury), while over 40 percent of the crashes on low-volume on-system roads in 1999 were KAB crashes.

A project using the Texas DPS crash and TxDOT roadway inventory databases was conducted to identify the common types of crashes on low-volume, rural two-lane highways. In 1999, there were 45.7 KAB/100 MVMT on low-volume, rural two-lane highways. For all on-system roads, the rate was 31.5 KAB/100 MVMT. Therefore, a driver on a low-volume, rural two-lane highway is more likely to be involved in a crash than the average for all Texas roads. The data also showed that a driver is more likely to be in a crash on a two-lane highway than on a multi-lane highway. In general, crashes on low-volume, rural two-lane highways occur between intersections, by a single vehicle running off the road. Crashes on curves and in dark, non-light conditions are more common on low-volume, rural two-lane highways than on urban roads.

The project also demonstrated that more KAB crashes occurred in eastern counties than western counties. A sample of counties was selected to investigate which regional characteristics are associated with high- and low-crash rates. The two counties within Texas with the highest average KAB rates for 1992 to 1998 were identified. Both of these counties were located in the eastern portion of the state. They were matched with counties in the western portion of the state that had a similar number of low-volume, rural two-lane highway miles. The eastern counties had the higher crash totals and rates, and they contained all of the fatal crashes considered in this study. In general, sites in the eastern counties had less driver-friendly characteristics, with more horizontal and vertical curves, narrower lanes and/or shoulders, less forgiving roadside development, higher access density, and higher roadside development scores. Eastern counties also had more crashes at intersections than western counties.

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

- treatments that either decrease the number of vehicles from leaving the roadway, especially on tight horizontal curves, or that better communicate the nature of the curve;
- improvements to reduce the number of nighttime crashes;

- treatments that reduce crashes at driveways; and
- improvements to minimize severity of crashes if a vehicle leaves the road.

To obtain information about the types of treatments being used on these types of facilities, a mailout survey was distributed to the TxDOT districts and to other states. Notable differences between Texas responses and responses from other states include the following:

- For clear zone treatments, Texas had a much higher percentage for making culverts traversable than other states.
- For wildlife control, other states use signs and reflectors more than Texas.
- For additional lane improvements, other states use passing lanes and climbing lanes more than Texas.
- For pavement surface treatments, other states use centerline, edgeline, and intersection rumble strips more than Texas.
- For pavement markings, Texas uses thicker thermoplastic pavement markings and raised pavement markings more than other states.
- For sign improvements, other states use more advance intersection signs, diamond chevrons signs, beacons on stop signs, and in-rail reflectors than Texas.
- For other types of treatments, other states use more illumination than Texas.

The most frequently used treatments in Texas from all categories include:

- safety appurtenances,
- mowing,
- traversable culverts,
- delineators,
- advance curve signing,
- advance stop signs,
- raised pavement markers,
- tree removal,
- headwall removal,
- advance intersection signage,
- side slope flattening,
- pavement edge maintenance,
- pavement marking reapplication,
- additional pavement markings, and
- clear zone improvements.

The appendices of this report provide summaries of the effectiveness of various treatments as identified from the literature.

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For low-volume, two-lane rural highways in Texas, about 67 percent of crashes occur at non-intersection locations. The top three categories used to indicate the first harmful event for a crash on these types of roadways were: fixed object (32 percent), other vehicle (32 percent), and overturned (28 percent). The statistics for fixed object and overturned categories support the need for keeping the vehicle on the roadway. A technique available for warning a driver that the vehicle is leaving the lane is rumble strips. A technique for helping to keep a vehicle on the roadway is to provide wider shoulders (see Appendix C). Rumble strips are raised or grooved patterns placed on the pavement surface of a roadway or travel way. Their purpose is to provide motorists with an audible and vibrational warning that their vehicle has partially or completely left the lane.

RUMBLE STRIPS

As reported on one of their websites, a primary goal for the Federal Highway Administration is to reduce the number and severity of single-vehicle, run-off-road (ROR) crashes while preserving safe use of the roadway by bicyclists and pedestrians. Roadway improvements that address the run-off-road issue include better geometric design, increased skid resistant roadway surfaces, more durable pavement markings, and more visible roadside signs. In recent years, several state transportation agencies and toll road authorities have also installed and evaluated the effects of shoulder rumble strips (SRS) on off-road crashes, particularly on rural freeways. The results of these evaluations have been overwhelmingly positive. FHWA has issued a Technical Advisory to provide information on the state-of-the-practice for the design and installation of shoulder rumble strips and to encourage their use on appropriate rural segments of the National Highway System (*1*). The Technical Advisory provides guidance on the design of the rumble strips and considerations for where to install them. Their recommendations on using rumble strips on roads other than freeways in rural areas follow:

> Because there are a significant number of ROR crashes on non-freeway facilities such as rural multilane and two-lane roadways, the FHWA recommends the use of shoulder rumble strips on those roadways for which an engineering study suggests that the number of these crashes would likely be reduced by the installation of shoulder rumble strips. In some cases, countermeasures, such as improved signing and markings, increased pavement skid resistance, or other roadway improvements, may be more appropriate than rumble strips or used in conjunction with them. When rumble strips are recommended, the following guidelines should be followed to the maximum extent practical:
>
> - Standard milled rumble strips, installed as close to the edgeline as practical, should be used when an 8-ft (2.4 m) clear shoulder width remains available after installation of the rumble strip.
> - A modified design should be used when the remaining available clear shoulder width is less than 6 ft (1.8 m) wide and the road is used by cyclists. The most recent studies indicate a milled depth of approximately 3/8 inch (10 mm) provides reasonable warning to most motorists while not being unduly dangerous to cross on a bicycle when necessary. Some states have also used narrower strips (i.e., less than 16 inches [400 mm] perpendicular to the direction of traffic) successfully. Others, as noted above, have

adopted a gap spacing to allow a cyclist to cross into the travel lane and back without having to cross directly over the rumble strips.

- Rumble strips should not normally be used when their installation would leave a clear shoulder pathway less than 4 ft (1.2 m) wide for bicycle use.

The use of edgeline rumble strips has greatly increased in recent years. Several documents demonstrate their effectiveness or investigate alternative designs for bicyclists or other concerns. The use of centerline rumble strips on two-lane rural highways has also been implemented at certain locations. Following is a summary of information available on edgeline and centerline rumble strips.

EDGELINE RUMBLE STRIPS

Rumble strips warn motorists that they are leaving or about to leave the lane. 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 edgeline rumble strip on a two-lane highway.

Shoulder rumble strips have proven to be an effective way of warning drivers that they are leaving, or about to leave, the roadway. Studies have shown that shoulder rumble strips are effective against ROR/fixed object and ROR/rollover type crashes. Nationwide, ROR crashes account for approximately one-third of all traffic fatalities, with about two-thirds of these ROR fatalities occurring in rural areas. It has been estimated that 40 to 60 percent of these crashes are due to driver fatigue, drowsiness, or inattention (*2*).

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

- Rumble strips are estimated to reduce the rate of ROR crashes between 15 and 70 percent on the FHWA website *Rumble Strips* (*3*).
- Data from the New Jersey Turnpike shows 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 (*3*).
- The Pennsylvania Turnpike also saw a decrease in ROR crashes on their multilane facilities as reported in a 1997 publication. Reductions of about 100 crashes per year are attributed to their rumble strips (*4*).
- Caltrans conducted an evaluation of the safety effects of continuous rumble strips on asphalt shoulders (*5*) 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 1985 FHWA study (*6*) included a detailed analysis of 10 sites. ROR crashes decreased by 20 percent while rates on comparable control sites increased by 9 percent.

- A 1999 FHWA analysis (*7*) presented the results for two separate studies of continuous shoulder rumble strips (CSRS). The Illinois study involved comparisons of 55 treatment sites to 55 control sites. This study showed an 18.3 percent reduction in single-vehicle, run-off-road crashes and a 13 percent reduction in single-vehicle, run-off-road injury crashes. Also, Illinois rural roadway data were collected and showed a reduction of 21.1 percent in single-vehicle, run-off-road crashes. Another study conducted in California posted results showing a 7.3 percent reduction in single-vehicle, run-off-road crashes, but it included a 13.4 percent standard deviation implying insignificant results. This report also presented evidence showing a 23.6 percent increase in crashes among fatigued and drowsy drivers, but this too included a high standard deviation (20.6 percent).
- A 1998 study (*8*) compared total run-off-road crashes before and after the installation of CSRS and produced substantial results (see Table A-1).
- A 1999 study by Griffith (*9*) extracted data from California and Illinois and estimated the safety effects of continuous rolled SRS on freeways. The results from the analysis estimated that continuous SRS 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 A-2 as a summary of the associated crash reductions for shoulder rumble strips.

Table A-1. Before and After Data for Rumble Strips in New York State (*8*).

Year	Total ROR Crashes	Total Injuries	Total Fatalities	Million Vehicle Miles Traveled
Before and During Rumble Strip Installation				
1991 1992 1993	557 566 588	358 407 328	17 17 8	6744 7612 7792
After Rumble Strip Installation Completed				
1996 1997	161 [74]* 74 [88]	113 [72] 54 [87]	4 [75] 1 [95]	8512 8692
* Numbers in [ ] represent percent reduction in crashes from 1991				

Table A-2. Shoulder Rumble Strips Studies and Associated Crash Reductions (*2*).

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

Studies have also examined the effects on bicyclists for various shoulder rumble strips designs. FHWA (*2*) provides the following summaries for two recent studies:

- Moeur tested 28 bicyclists (5 basic, 17 skilled, and 6 experienced) in a 2000 Arizona field study by having them ride over various skipped SRS sections to determine acceptable skip patterns. It was determined that 12-ft (3.7 m) skips in ground-in SRS pattern would acceptably permit bicyclists to cross at high speeds (speeds were assumed to be between 23 to 28 mph or 37 and 45 km/h). Either 40- or 60-ft (12.2 or 18.3 m) cycles for the skip pattern were determined acceptable.
- The objective of a Pennsylvania project performed in 2000 was to develop new SRS configurations that decrease the level of vibration experienced by bicyclists while providing an adequate amount of stimulus to alert inattentive or drowsy drivers. Six configurations were tested by 25 intermediate and advanced bicyclists. The researchers recommended the adoption of two new bicycle-tolerable rumble patterns, one for non-freeway facilities operating near 55 mph (88 km/h) and the other for those operating at 45 mph (72 km/h).
- In 2001, the California Department of Transportation performed a study of various SRS designs. Six test vehicles, ranging from a compact automobile to large commercial vehicles, were used to collect auditory and vibrational data while traversing the SRS. Fifty-five bicyclists of various skill levels and ages evaluated the SRS designs. The recommendation of the study was to replace the existing rolled SRS design with a milled SRS design that is 1 ft (300 mm) in transverse width and 5/16 ± 1/16 inches (8 ± 1.5 mm) in depth on shoulders that are at least 5 ft (1.5 m) wide. For shoulders less than this width, the installation of raised/inverted profile thermoplastic was recommended.
- A 2001 study in Colorado developed recommendations based on the input of 29 bicyclists as well as vibrational and auditory data collected in four different types of vehicles. Of the 10 styles tested, those that provided the most noticeable vibrational and auditory stimuli to the vehicle were rated worst by bicyclists.

The benefit-cost ratio for rumble strips has been estimated in two recent studies. A 1999 report (*9*) 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 (*8*) 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.

CENTERLINE AND EDGELINE RUMBLE STRIPS

In addition to using edgeline 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 (*1*) 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." FHWA is seeking candidate sites for a nationwide study on the treatment. NCHRP Report 440 (*10*) reported on three sites where both edgeline and centerline rumble strips are being used. A summary of those three sites follows.

Centerline Rumble Strips and Inverted Profile Thermoplastic Edgelines for a California State Route

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. In the previous nine years, the average number of fatal crashes was 2.7 per year. In 1995, the number of fatal crashes was six with a total of 14 people killed. Financial constraints limited the options for improvements such as expanding the highway to a four-lane divided roadway or widening the shoulders. Caltrans looked for improvements that could correct driver behavior in a manner that would reduce the fatal head-on crashes. The following were installed as part of the project:

- Double yellow stripes were replaced with a rumble strip (to provide an audible and vibratory warning) and raised profile thermoplastic traffic striping (to enhance nighttime visibility and provide both audible and vibratory warning for straying motorists). In addition, yellow retro-reflective pavement markers were also installed between the rumble strip and raised profile thermoplastic. The spacing between the double yellow stripes was increased to 28 inches (71.1 cm) to accommodate the 16 inches (40.6 cm) used for the ground-in rumble strip, the 4 inches (10.1 cm) for each thermoplastic stripe, and the yellow retro-reflective markers. Figure A-1 shows a sample of the treatment.
- Solid yellow centerline stripes in one direction (no passing sections) were replaced with raised profile thermoplastic striping.
- Markers were added to the center of the roadway in passing sections to provide audible warning to motorists crossing the center of the road.
- Inverted profile thermoplastic striping with rumble strips was placed on shoulders with a minimum width of 6 ft (1.8 m). Shoulder widths less than 6 ft (1.8 m) received inverted profile thermoplastic striping only. A minimum of 4 ft (1.2 m) of unobstructed shoulder was preserved to accommodate bicycle traffic.
- Black non-reflective pavement markers were placed in the intervals between stripes in the two-lane passing zones to increase the rumble effect.
- The concrete bridges on the project received raised profile and inverted profile thermoplastic striping on the centerline where double yellow striping existed. Inverted profile thermoplastic striping was placed at the edge of the travel way. No ground-in rumble strips were constructed on the bridges.

Figure A-1. Example of Shoulder and Centerline Rumble Strips.

The installation of the pavement treatments was completed in November 1996. The estimated cost of the work in January 1996 was $789,000. Crash data for the roadway segment was available for 25 months after the installation of the treatment. In addition, 34 months of before data were obtained. The 23.5-mi (37.8 km) segment experienced fewer crashes in the after period than 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 only included one fatal crash. The distribution of crash types (e.g., head-on, rear-end, etc.) and primary cause (e.g., improper turn, speeding, etc.) remained relatively constant between the two periods. This limited crash review indicates that rumble strips could be an effective treatment in reducing crashes.

Rumble Strips along with Other Treatments

A principal highway that connects an interstate to small towns has become a commuter and recreational route. Recreational travel is expected to increase and is particularly pronounced on summer, fall, and holiday weekends. Commuting is a relatively new use of the highway. The advent of the interstate and the growth of commercial development in the northern suburbs of a major city have made the small towns a reasonable commute. As these towns develop as residential communities, the peak-period commuter traffic demands placed on the road is expected to increase. The large and increasing recreational and commuting traffic have focused attention on the capacity and safety of the highway.

Both the crash and severity rates for the highway are generally below average when compared to the sections of roadway within the metropolitan area with similar design characteristics. However, when compared to statewide averages, the rates on the highway are slightly higher than the average. Table A-3 summarizes the three-year crash totals for 1991-1993.

Table A-3. Crash Totals for 1991-1993.

Crash Type	Number	% of Total Reported
Rear-end	116	43
Sideswipe – same direction	23	9
Approach turn	18	6
Right angle	49	18
Ran off road – left side	16	6
Sideswipe – opposite direction	8	3
Head-on	11	4
Ran off road – right side	30	11
Type not reported	153	--
TOTAL	**424**	**100**

The high percentage of rear-end crashes suggests that a disproportionately high level of direct access is being provided by the highway, which is in conflict with the high overall travel speeds on the roadway. The high level of direct access between adjacent land uses and the highway is a product of both the historic growth pattern of the corridor and the lack of parallel routes through large segments of the corridor.

A number of short-term improvements were made to the highway to address safety concerns. These include the installation of traffic signals and channelization at two intersections, right-turn and right-turn/bypass lanes, one left-turn lane, raised pavement markers on horizontal curves, and centerline and edgeline rumble strips.

The rumble strip work was completed in the fall of 1995 at a cost of $54,000. Approximately 15 mi (24.2 km) were treated. The DOT completed a two-year before-and-after study of the crashes within the rumble strip areas. Table A-4 presents a summary of the before and after crashes listed by crash type at two sections along the highway where rumble strips were installed. While some crash types decreased, 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).

Table A-4. Crash Summary (Rumble Strip Installations).

Type of Crash	Number of Crashes			
	Section 1		Section 6	
	Before[a]	After[b]	Before[a]	After[b]
Rear-end	13	16	7	2
Sideswipe - passing	6	6	3	1
Sideswipe - opposing	2	1	1	1
Left turn	3	2	1	1
Off road - left	7	4	1	0
Off road - right	8	5	3	2
Right angle	9	3	2	6
Head-on	2	2	0	2
Others	30	9	29	8
TOTAL	**80**	**48**	**47**	**23**

[a] 11/01/93 to 10/31/95 (24 months)
[b] 11/01/95 to 10/31/97 (24 months)

Rumble Strips, Lane Striping, and Guardrail Installations

A highway that connects a major northwestern city and nearby suburbs and small cities serves as a high-volume commuter route. 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. Previous investigation into the crash characteristics of the roadway showed that several of the crashes were opposite-direction crashes, which suggests that they were due to passing maneuvers. 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

Figure A-2. Example of Installed Rumble Strips.

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. Figure A-2 shows a sample of the rumble strips.

The treatments were constructed between July 28, 1995, and September 29, 1995. The DOT provided crash data for one year before and one year after the installation of the treatments. Table A-5 presents a summary of the before and after crashes listed by crash severity and type for the section. A crash reduction of 23 percent was experienced between the two years of data with most of the crash reduction being from a decrease in rear-end crashes.

Table A-5. Crash Summary (Rumble Strip Installation).

Type of Crash	**Number of Crashes**	
	Before[a]	**After[b]**
Property Damage	53	45
Injury	46	31
Fatal	2	2
TOTAL	**101**	**78**
Alcohol Related	11	9
Fixed Object	25	20
Rear-End	36	25
Opposite Direction	16	12
Entering at Angle	4	3
Overturn	5	5
Hazardous Material	0	0
Pedestrian	0	1
Other	4	3
TOTAL	**101**	**78**

[a]7/28/94 to 7/27/95 (12 months)
[b]9/29/95 to 9/28/96 (12 months)

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Appendices A and C discuss treatments that can be used to minimize run-off-road crashes. Appendix A provides information on rumble strips, and Appendix C discusses the benefits of wider shoulders. Once a vehicle has left the roadway, 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. In addition to crash frequency, the severity of crashes involving specific roadside obstacles is also important.

A 1978 FHWA study by Perchonok et al. analyzed crash characteristics of single-vehicle crashes, including crash severity related to types of objects struck (*1*). For non-rollover fixed-object crashes, the obstacles associated with the highest percent of injury occurrences are, in order: bridge or overpass entrances, trees, field approaches (i.e., ditches created by driveway), culverts, embankments, and wooden utility poles. Actual percent injuries and fatalities of these crashes are shown in Table B-1. Obstacle types with the lowest crash severity include small sign posts, fences, and guardrails (*1*).

Table B-1. Severest Injury by Object Struck in Non-Rollover Crashes (*1*).

Object	Crash Sample Size	Percent Injured	Percent Killed
Bridge/Overpass Entrance	88	75.0	15.9
Tree	667	67.9	7.2
Field Approach	75	66.7	1.3
Culvert	231	62.3	6.1
Embankment	406	57.6	4.4
Wood Utility Pole	598	51.2	2.3
B/O Siderail	82	51.2	2.4
Rock(s)	73	49.3	1.4
Ditch	368	48.9	1.1
Ground	153	48.4	3.3
Trees/Brush	255	38.4	2.0
Guardrail	284	31.7	1.8
Fence	325	24.3	0.3
Small Sign Post	76	22.4	1.3
Total	**3681**	**50.8**	**3.6**

A separate analysis was also conducted for severity of crashes involving ditches. The authors found that ditches which were 3 ft (0.9 m) or deeper were associated with a higher percent of injury crashes (61 percent) when compared to crashes involving ditches 1 to 2 ft (0.3 to 0.6 m) deep (54 percent injury). Percent fatal crashes were about the same for each depth category (i.e., about 5 percent for both the 1- and 2-ft [0.3 and 0.6 m] group and the 3-ft-plus [0.9 m plus] group).

RECOVERY DISTANCE

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. 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. Design options for the treatment of these features have been generally considered in the following order:

- 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., edgeline) where there is a reasonable chance for an off-road vehicle to safely recover (*2*). 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 on two-lane congested roadways. Recommended roadside recovery distances (or clear zones) can be obtained from the *Roadside Design Guide* (*3*). 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.

Along a roadway section, the roadside recovery distance may vary considerably. The recovery distance for a roadway section can be determined by taking an average of measurements (e.g., 3 to 5 measurements per mi [2 to 3 per km] on each side of the road). Roadside recovery distances of 0 to 30 ft (0 to 9.2 m) are generally recorded.

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 edgeline) where roadside improvements are proposed, crash reduction factors may be found in Table B-2. 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 B-2. Crash Reduction Factors Due to Increasing Roadside Clear Recovery Distance (2).

Amount of Increased Roadside Recovery Distance, m (ft)	Percent Reduction in Related Crash Types* (%)
1.5 (5)	13
2.4 (8)	21
3.1 (10)	25
3.7 (12)	29
4.6 (15)	35
6.2 (20)	44
*Related crash types = run-off-road, head-on, and sideswipe	

SIDE SLOPES

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. Existing guidelines for acceptable side slopes have historically been based on computer simulations and observations of controlled vehicle test runs on various slopes as well as on "informed" judgments.

Figure B-1 shows a relationship between single-vehicle crashes and field-measured side slopes. As shown in Figure B-1, 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 (*2*).

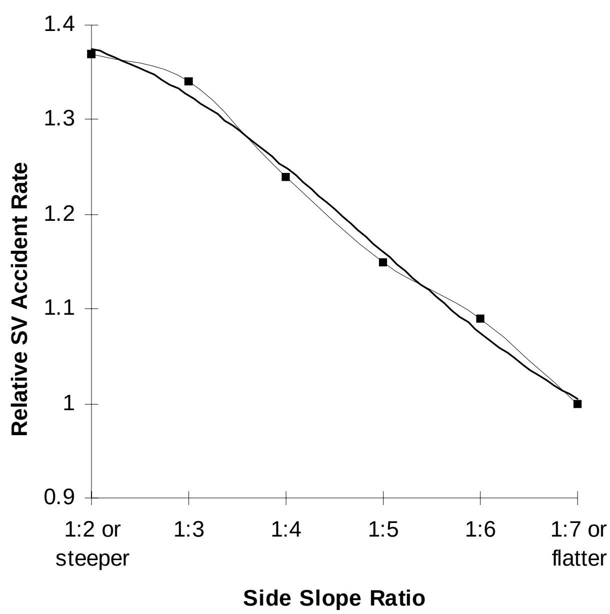

Figure B-1. Plot of Single-Vehicle (SV) Crash Rate for a Given Side Slope to Single-Vehicle Crash Rate for a Side Slope of 1:7 or Flatter (*2*).

In fill sections, side slopes that are 1:4 or flatter are generally desirable. When side slopes are 1:4 or flatter, motorists encroaching on the side slope can generally stop their vehicles or slow them enough to recover safely (as long as the appropriate recovery distance, free of obstacles, has been provided). Side slopes between 1:3 and 1:4 are traversable, but most motorists will be unable to stop or return to the roadway easily. In these sections, a runout area (see Figure B-2) may be required at the toe of the non-recoverable slope of the recovery area. Side slopes that are greater than 1:3 are considered to be critical because a vehicle that leaves the roadway is likely to overturn on such side slopes. If a side slope steeper than 1:3 begins closer to the traveled way than the suggested clear zone distance, a barrier might be warranted if the slope cannot be flattened easily. See AASHTO's *Roadside Design Guide* (*3*) for information on warranting barriers for side slopes.

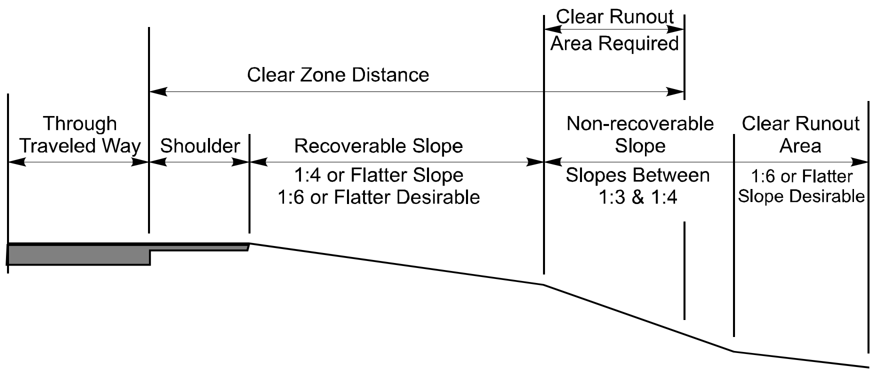

Figure B-2. Example of a Side Slope Design in a Fill Section (3).

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. On the other hand, a steep, rough-sided rock cut should normally begin outside the clear zone or be shielded. A rock cut is normally considered to be rough-sided when the face will cause excessive vehicle snagging rather than provide relatively smooth redirection. Warrants for the use of a roadside barrier in conjunction with cut slopes can be found in the AASHTO *Roadside Design Guide*.

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. The AASHTO *Roadside Design Guide* gives preferred fore slopes and back slopes for basic ditch configurations. Cross sections that fall in the shaded region of each of the figures are considered to be traversable by errant vehicles. Ditch sections that fall outside the shaded region are considered less desirable and their use should be limited where high-angle encroachment can be expected, such as on the outside of a relatively sharp horizontal curve. Types of improvements to ditches with cross sections needing improvements and located in vulnerable areas include the following: reshape the ditch to conform to a more "forgiving" design, convert ditch to a closed drainage system using culverts and pipes, and shield ditch to traffic using a traffic barrier.

Figure B-1 shows the relationship used to develop crash reductions matching various side slope flattening projects. The percent reductions are presented in Table B-3 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 (*2*). These reductions assume that the roadside slope to be flattened is relatively clear of rigid obstacles.

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 (*2*). The FHWA study found that side slopes of 1:5 or flatter are needed to significantly reduce the incidence of rollover crashes (i.e., not 1:4, as is often assumed) (*2*).

Table B-3. Effect (%) of Side Slope Flattening on Single-Vehicle and Total Crashes (*2*).

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.								

ROADSIDE OBSTACLES

Trees

Trees become potential obstructions by virtue of their size and location in relation to vehicular traffic. Generally, a single tree with a trunk diameter greater than 5.9 in (150 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. The reader is referred to AASHTO's *Roadside Design Guide* (*3*) for more information about the warranting and design of roadside barriers for protecting trees.

Tree crashes can be reduced based on crash reductions shown in Table B-4. For example, 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 (*4*).

Table B-4. Percent Reductions in Specific Types of Obstacle Crashes Due to Clearing/Relocating Obstacles Further from the Roadway (*4*).

Increase in Obstacle Distance (IOD)* m (ft)	Trees (%)	Mailboxes, Culverts, & Signs (%)	Guardrails (%)	Fences/Gates (%)
0.9 (3)	22	14	36	20
1.5 (5)	34	23	53	30
2.4 (8)	49	34	70	44
3.1 (10)	57	40	78	52
4.0 (13)	66	N.F.*	N.F.	N.F.
4.6 (15)	71	N.F.	N.F.	N.F.

*Notes:
N.F. = generally not feasible to relocate obstacles to specified distances.
IOD = amount of increase in obstacle distance from roadway.
This table is appropriate only for obstacle distances of 30 ft (9.1 m) or less and only on two-lane rural roadways.

Culvert Headwalls

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:

- Eliminate non-essential drainage structures.
- Design or modify drainage structures so they are traversable or present a minimal hazard to an errant vehicle.
- 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* (*3*) should be consulted for details on the design of these structures.

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 (see discussion of side slope in an earlier section). Crash reductions which correspond to placement of culvert headwalls further from the roadway are shown in Table B-4. For example, a 40 percent reduction in culvert hits is expected for culverts located 15 ft (4.6 m) from the road compared to 5 ft (1.5 m) (i.e., a 10-ft (3.1 m) difference in distance) (*4*). Other useful information on drainage structures is contained in the *Roadside Design Guide* (*3*).

Ross et al. (*5*) developed preliminary guidelines for minimum spacing of driveways on high speed roadways (see Table B-5). 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 B-5. Tentative Spacing Guidelines for Multiple Driveways (*5*).

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

Sign Support and Placement

Roadside signs can be divided into three main categories: overhead signs, large roadside signs, and small roadside signs. Each sign type requires a different hardware and safety treatment. Because overhead signs generally require massive support systems that cannot be made breakaway, they should be installed on or relocated to nearby overpasses or other structures, where possible. If it is not possible to locate the supports outside the clear zone, overhead supports are to be shielded with an appropriate barrier. Large roadside signs may be defined as those greater than 53.8 ft^2 (5 m^2) in area. They typically have two or more support poles that can be made breakaway. The basic concept of the breakaway support is to provide a structure that will resist wind and ice loads, yet fail in a safe and predictable manner if struck by a vehicle. Small roadside signs may be defined as those supported on one or more posts and having a sign panel area of less than 53.8 ft^2 (5 m^2). Although not perceived as a significant obstruction, small signs can cause significant damage to impacting automobiles. The most common methods for making base supports for small roadside signs breakaway include the following: base bending or yielding sign supports, fracturing sign supports (e.g., wood, steel posts, or steel pipes connected at ground level to a separate anchor), and slip base designs. AASHTO's *Roadside Design Guide* (*3*) should be consulted on how to design breakaway supports for roadside signs.

Sign placement is largely a function of readability to drivers, so in some respects signs should not be placed too far from the road. Even though sign posts represent a roadside obstacle, sign placement must be within the driver's cone of vision to be useful. Where practical, the use of breakaway sign posts is highly desirable to minimize the severity of impacts between motor vehicles and the posts. Where not practical, the sign should be relocated further from the pavement edge. The percent reductions in sign crashes are given in Table B-4 for various distances of the signs from the roadway.

Mailboxes

AASHTO's *A Guide for Erecting Mailboxes on Highways* (generally called the *Mailbox Guide*) (*6*) contains information on mailbox supports and their location on the roadside. The following guidelines should be used for installing mailbox supports:

- Mailbox supports, which should be considered as nominal, are 3.9 inches by 3.9 inches (100 mm by 100 mm) or 3.9 inches (100 mm) diameter wood posts, or a metal post with a strength no greater than a 2.0 inches (50 mm) diameter standard strength steel pipe, embedded no more than 23.6 inches (600 mm) into the ground. For example, a single 0.4-lb/ft (3.0 kg/m) U-channel support would be acceptable under this structural limitation. Mailbox supports should not be set in concrete unless the support design has been shown to be safe by crash tests.
- Mailbox-to-post attachments should ideally prevent mailboxes from separating from their supports under vehicle impacts. The *Mailbox Guide* contains information on attachments that prevent their separation (*6*).
- Multiple mailbox installations should meet the same criteria as single mailbox installations. Multiple support installations should have their supports separated a minimum distance equal to three-fourths of their heights above ground. This will reduce interaction between adjacent mailboxes and supports.

While relocating mailboxes further from the road would be expected to reduce the frequency of mailbox crashes, such relocation is not practical in many situations. A more promising alternative, which would affect crash severity but not crash occurrence, would be to make use of mailboxes with less rigid posts or breakaway design in place of the heavy steel, wooden posts, or multiple posts (*4*). Recent research has documented the injury reduction from breakaway mailbox posts (*7*).

Guardrail

Guardrail is installed along roadways to shield a vehicle from striking a more rigid obstacle or from rolling down a steep embankment. When installed, guardrail is generally positioned at the greatest practical distance from the roadway to reduce the incidence of guardrail impacts. Thus, it is not often feasible to relocate guardrail further from the roadway along a section unless some flattening of the roadside occurs. However, when it is feasible to flatten roadsides to a relatively mild slope (e.g., 1:5 or flatter) with appropriate removal of obstacles, then guardrail should be removed since the guardrail itself presents an obstacle which vehicles can strike. The crash reductions in Table B-4 for guardrail placement illustrate the crash benefits from relocating guardrail (*4*).

Russell et al. (*8*) developed guidelines for the use of guardrail on low-volume roads in Kansas. Low-volume roads were defined as roads with ≤400 ADT. The Kansas Department of Transportation (KDOT) wanted guidelines for using guardrail on low-volume roads in Kansas based on a cost-effectiveness analysis from adapting the microcomputer program ROADSIDE. KDOT was only interested in guidelines for three types of roadside obstacle: 1) culvert-straight wings; 2) culvert-flared wings; and 3) culvert-pipe/headwall. Conditions considered were offset distance, ADT, speed, and ditch depth.

Fences and Gates

Fences and gates are sometimes placed by private property owners just beyond the highway right-of-way and can present a hazard to run-off-road vehicles. As shown in Table B-4, the effect of relocating fences is a 20 percent crash reduction for 3 ft (0.9 m) of relocation, 44 percent for 8 ft (2.4 m) of relocation, and 52 percent for 10 ft (3.1 m) of relocation. Unfortunately, having fences relocated further from the roadway could require that an agency purchase more right-of-way along a route, which could be quite expensive (*4*).

Utility Poles

Utility poles represent a significant hazard on two-lane rural highways. Significant reduction in crashes on two-lane rural roadways can be achieved by reducing, eliminating, or protecting utility poles. Motor vehicle collisions with utility poles result in approximately 10 percent of all fixed-object fatal crashes annually. The frequency and severity of crashes with utility poles is affected by three factors:

- the number of utility poles per mile (pole density),
- the proximity of the poles to the edge of the travel way (pole offset), and
- the nature of their design (i.e., whether they are breakaway or unyielding).

Because most utility poles are generally *privately owned* and only *installed* on publicly owned right-of-way, they are often not under the direct control of the public agency, complicating the implementation of effective countermeasures.

Several options exist for reducing crash frequency and severity with *existing* utility poles, including the following:

- placing utility lines underground,
- increasing the lateral pole offset,
- increasing pole spacing,
- installing breakaway utility poles, and
- placing barriers around utility poles.

A site-specific benefit/cost analysis can be performed to decide which corrective measure is most cost-effective at a specific high crash-frequency location.

Placing Utility Lines Underground

This countermeasure involves removing the utility poles and burying the utility lines underground. Theoretically, placing the utility lines underground should eliminate 100 percent of the run-off-road/fixed-object crashes where the first harmful event is striking a utility pole. However, the true level of effectiveness of placing the utilities underground will depend on the number and proximity of other fixed objects in the roadway clear zone. Overall crash frequency is likely to be unaffected by placing utilities underground because vehicles are likely to be striking other fixed objects in the right-of-way. In one study, fatal crashes were reduced 38 percent as a result of burying the utilities underground; however, injury crashes increased 1.5 percent (*6*).

Increasing Lateral Pole Offset

As with other fixed objects in the right-of-way, the most desirable solution for correcting crashes is to locate the poles where they are least likely to be struck. This countermeasure is aimed at reducing utility pole crashes by increasing the distance a vehicle has to travel before striking a utility pole. Relocating poles farther from the roadway will generally reduce the frequency of utility pole crashes. Table B-6 (*9*) shows the reduction in utility pole crash frequency as a result of increasing the offset of utility poles from the pavement edge. There is no conclusive evidence to support that pole relocation will have a significant effect on the severity of utility pole crashes.

Reducing the Number of Poles

Utility pole spacing varies widely based on the type of lines. For telephone and small electric lines, pole spacing generally ranges about 100 ft (31 m). For larger voltage power lines (more than 69 KV), spacings are commonly 500 ft (152 m) apart or more. One way to reduce crash frequency is to reduce the number of poles (or pole density) in a given section of roadway.

There are a number of different strategies available for reducing the number of poles in the right-of-way, including the following:

- Increase the spacing between poles.
- Use the same poles to carry multiple utilities (e.g., to carry both telephone, electric lines, and luminaries).
- Place poles on only one side of the street instead of both sides.
- Selectively remove or relocate a limited number of poles from hazardous locations (i.e., intersections and horizontal curves).

A practical limitation to this strategy is that reducing the number of poles will likely require larger, more rigid poles to support more or heavier utility lines. This can be costly and the larger poles could have an adverse effect on crash severity if a vehicle should strike a pole.

Figure B-3 can be used to estimate the reduction in utility pole crash frequency as a result of reducing the number of poles (or pole density) in the right-of-way. The amount of the reduction can be found by entering the nomograph with the two different pole densities and given pole offset.

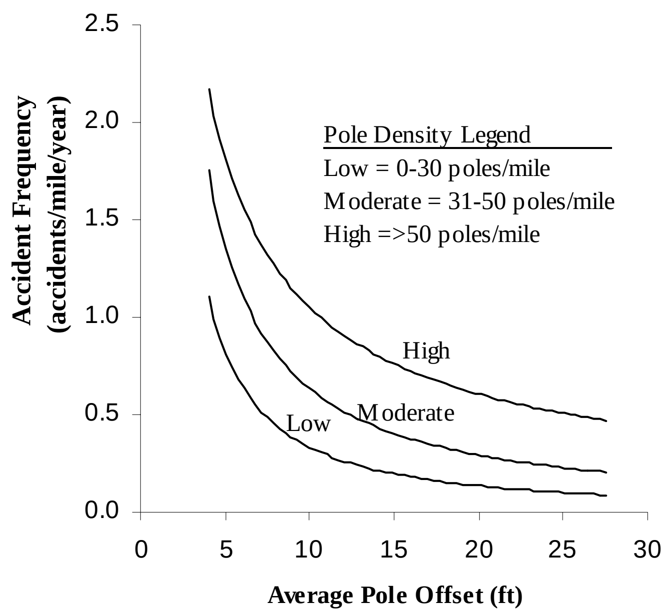

Figure B-3. Relationship Between Frequency of Utility Pole Crashes and Pole Offset for Three Levels of Pole Density (*9*).

Installing Breakaway Utility Poles

Using a breakaway design should be considered where poles have to be placed in vulnerable locations that cannot economically be removed or related. Examples of where breakaway poles might be effective include the following:

- gore areas,
- the outside of sharp curves, and
- opposite the intersecting roadway at T-intersections.

Details of both the breakaway utility pole and guy-wire connection designs are contained in Federal Highway Administration Report No. FHWA/RD-86/154, *Safer Timber Utility Poles* (*10*).

Placing Barriers Around Utility Poles

In those locations where it is not feasible to relocate and reduce the number of utility poles, shielding selected poles with guardrails or crash cushions may be warranted (of particular note are the massive supports used for major electrical transmission lines within the clear zone or in other vulnerable locations). The reader should use the AASHTO *Roadside Design Guide* for more information on the types and warrants for installing roadside barriers.

Table B-6. Reduction in Utility Pole Crashes Due to Pole Relocation for Roadway Sections.

Pole Offset Before Relocation, ft (m)	Expected Percent Reduction in Utility Pole Crashes (%)										
	Pole Offset After Relocation, m (ft)										
	6 (1.8)	7 (2.1)	8 (2.4)	9 (2.7)	10 (3.1)	11 (3.4)	12 (3.7)	13 (4.0)	14 (4.3)	15 (4.6)	20-30 (6.1-9.2)
4 (1.2)	30	42	49	55	60	63	69	70	72	73	77
5 (1.5)		36	43	50	56	59	65	67	69	70	74
6 (1.8)			27	36	43	48	55	57	60	62	67
7 (2.1)				22	31	37	46	48	52	54	59
8 (2.4)					22	29	39	42	45	48	55
9 (2.7)						18	30	33	37	40	48
10 (3.1)							22	25	30	33	42
11 (3.4)								18	24	27	36
12 (3.7)									11	15	25
13 (4.0)										11	22
14 (4.3)											17

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Roadway cross section includes the width of the travel way, the width and type of each lane, the width and type of shoulders, the cross slope of the pavement, and the slope of the side slopes. The American Association of State Highway and Transportation Officials (AASHTO) has set geometric values for roadway features by functional classification. These values are presented in *A Policy on Geometric Design of Highways and Streets*, commonly known as the *Green Book* (*1*). The following is a summary of research findings presented in NCHRP Report 440 (*Accident Mitigation Guide for Congested Rural Two-Lane Highways)* (*2*) and from other sources on widening the lane or shoulder, passing improvements, and two-way left-turn lanes (TWLTL).

WIDEN LANE OR SHOULDER

Travel lanes are the portion of the highway intended for use by through traffic. The lane width of a two-lane road is measured from the centerline of the highway to the edgeline, or to the boundary between the travel lanes and the shoulder. Shoulders are the portion of the highway immediately adjacent to, and outside of, the travel lanes. Shoulders are typically designed and intended to accommodate occasional use by vehicles but not continual travel. Part or all of the shoulder may be paved. The lane and shoulder widths plus the median width comprise the total roadway width. 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.

Numerous studies have been conducted in recent years to determine the effects of lane width, shoulder width, and shoulder type on crash experience; however, few of them were able to control for roadside condition (e.g., clear zone, side slope), roadway alignment, and other factors which, together with lane and shoulder width, influence crash experience. Because lane and shoulder width logically affect some crash types (e.g., run-off-road, head-on) but not necessarily other crash types (e.g., angle, rear-end), there is a need to express crash effects as a function of those related crash types.

Those crash types that research has shown that can be affected directly by lane and shoulder width improvements include the following:

- head-on,
- run-off-road/fixed object,
- run-off-road/rollover,
- same direction sideswipes, and
- opposite direction sideswipes.

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 (*3*). 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.” If a user knows only the number of total crashes on the section, Table C-1 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.

Table C-1. Factors to Convert Total Crashes to Related Crashes on Two-Lane Rural Roads (*3*).

ADT (vpd)	Terrain Adjustment Factors		
	Flat	Rolling	Mountainous
500	.58	.66	.77
1000	.51	.63	.75
2000	.45	.57	.72
4000	.38	.48	.61
7000	.33	.40	.50
10000	.30	.33	.40
Note: Related crashes include run-off-road, head-on, opposite-direction, and same-direction sideswipe.			

Table C-2 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.

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 C-2. Percentage of Crash Reduction of Related Crash Types for Lane Widening Only (*3*).

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

An expert panel 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 on safety for two-lane highways with

ADTs over 2000 veh/day (*3*, *4*). Table C-3 illustrates the recommendations of that expert panel expressed as crash modification factors (or relative crash frequencies). For example, the crash modification factor of 1.50 for 9-ft (2.8 m) lanes in Table C-3 implies that a two-lane highway with 9-ft (2.8 m) lanes would be expected to experience 50 percent more crashes of the type specified than a two-lane highway with 12-ft (3.7 m) lanes. In using Table C-3, it should be assumed that the safety performance of lane width less than 9 ft (2.7 m) is the same as that shown for 9-ft (2.8 m) lanes, and that the safety performance for lanes over 12 ft (3.7 m) wide is the same as that shown for 12-ft (3.7 m) lanes. Interpolation between the values shown in Table C-3 is encouraged.

Research results concerning reductions in related crashes due to widening paved or unpaved shoulders are listed in Table C-4. For example, widening 2-ft (0.6 m) gravel shoulders to 8 ft (2 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 reduce approximately 49 percent of the related crashes (*3*). It should be noted that the predicted crash reductions given in Tables C-3 and C-4 are valid only when the roadside characteristics (side slope and clear zone) are reestablished as before the lane or shoulder widening.

Table C-3. Crash Modification Factors for Lane Width on Rural Two-Lane Highways (*3*).

Lane Width, ft (m)	Crash Modification Factor [a]
9 (2.8)	1.50
10 (3.1)	1.30
11 (3.4)	1.15
12 (3.7)	1.00

[a]Relative crash frequency for run-off-road, head-on, and opposite-direction sideswipe crashes.

Table C-4. Percentage of Crash Reduction of Related Crash Types for Shoulder Widening Only (*3*).

Shoulder Widening per Side, ft (m)	Percent 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.

The expert panel discussed above also found the Zegeer et al. study to be the most reliable assessment of the effect of shoulder width on safety for two-lane highways with ADTs over 2000 veh/day (*3*, *4*). Table C-5 illustrates the recommendations of that panel for the effect of shoulder width on safety expressed as crash modification factors. Table C-6 shows similar results for the effect of shoulder type. Interpolation within these tables is encouraged, but extrapolation beyond their limits is not.

The crash modification factors for lane width, shoulder width, and shoulder type can be combined by multiplying them together. For example, the crash modification factor for a combination of 11-ft (3.4 m) lanes and 4-ft (1.2 m) gravel shoulders can be determined as:

$$(1.15)(1.15)(1.01) = 1.34$$

This implies that a two-lane highway with 11-ft (3.4 m) lanes and 4-ft (1.2 m) gravel shoulders would experience 34 percent more related crashes than a two-lane highway with the nominal condition of 12-ft (3.7 m) lanes and 6-ft (1.8 m) paved shoulders.

Table C-5. Crash Modification Factors for Shoulder Width on Rural Two-Lane Highways (*4*).

Shoulder Width, (ft) m	Crash Modification Factor [a]
(0) 0	1.50
(2) 0.6	1.30
(4) 1.2	1.15
(6) 1.8	1.00
(8) 2.4	0.87

[a] Relative crash frequency for run-off-road, head-on, and opposite-direction sideswipe crashes.

Table C-6. Crash Modification Factors for Shoulder Types on Two-Lane Highways (*4*).

Shoulder Type	Crash Modification Factor [a]							
	Shoulder Width, ft (m)							
	0 (0)	1 (0.3)	2 (0.6)	3 (0.9)	4 (1.2)	6 (1.8)	8 (2.4)	10 (3.1)
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.00	1.01	1.01	1.02	1.02	1.03
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06	1.07
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11	1.14

[a] Relative crash frequencies for run-off-road, head-on, and opposite-direction sideswipe crashes.

Other studies have also examined the benefits of widening pavements. Table C-7 provides percent reductions in total, single-vehicle, and head-on crashes due to widening pavements or adding full-width paved shoulders. Although sample sizes are small in certain cells, these results support the findings in other studies in terms of the beneficial effects of lane and shoulder widening, the types of crashes reduced, and the relative magnitude of the effects of widening.

Table C-7. Summary of Crash Reductions for Pavement Widening Projects (*5*, *6*).

Type of Project	Expected Percent Reduction in Crashes			
	ADT Range (vpd)	Total Crashes	Single-Vehicle Crashes	Head-On Crashes
Widening 20- to 24-ft (6.1 to 7.3 m) pavement to 28 ft (8.5 m)	0-3000	16.0 (C)	22.0 (C)	45.0 (C)
Widening 18- to 24-ft (5.5 to 7.3 m) pavement to 32 ft (9.8 m)	<5000	35.0 (C) (s)	49.0 (C) (s)	48.0 (C) (s)
Widening 18- to 24-ft (5.5 to 7.3 m) pavement to 40 ft (12.2 m)	>5000	29.0 (C) (s)	22.0 (C) (s)	51.0 (C) (s)
Adding full-width paved shoulders to two-lane roads	1000-3000 3000-5000 5000-7000	27.0 (T) (s) 12.5 (T) 17.6 (T) (s)	55.0 (T) (s) 21.4 (T) (s) 0.0 (T)	Unknown Unknown Unknown

Notes:
(C) = values from the Rinde study (*5*) in California
(T) = values from the Turner et al. (*6*) study in Texas
(s) = significant at the 95 percent level of confidence for (C) sites and 90 percent confidence level for the (T) sites.
The single-vehicle and head-on crash percentages for California were adjusted by 4 to 6 percent to account for external effects and are now on the same basis as total crashes. These values are only for two-lane rural roads.

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 (*7*). The percent reduction factors determined for single-vehicle crashes are listed in Table C-8. The reduction factors were estimated based upon regression equations of approximately 1400 mi (2254 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:

- Surface width has no demonstrable effect on multi-vehicle crash rate on rural, two-lane, farm-to-market roads with AADTs up to 1500.
- Surface widening can reduce single-vehicle crash rate on rural, two-lane, farm-to-market roads with AADTs up to 1500.
- While surface widening can reduce single-vehicle crash rate on rural, two-lane, farm-to-market roads with AADTs in excess of 400, such action is not warranted (i.e., not cost beneficial) at AADTs below 1000.

Table C-8. Single-Vehicle Crash Reduction Factors (%) Associated with Surface Widening in Three ADT Categories (7).

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)	7	13	19	25
	20 (6.1)		7	13	19
	22 (6.7)			7	13
	24 (7.3)				7
701 to 1000	18 (5.5)	12	23	32	41
	20 (6.1)		12	23	33
	22 (6.7)			13	24
	24 (7.3)				13
1001 to 1500	18 (5.5)	14	27	38	49
	20 (6.1)		15	28	40
	22 (6.7)			16	30
	24 (7.3)				17

PASSING IMPROVEMENTS

A majority of two-lane highways carry relatively low-traffic volumes and experience few operational problems; however, some higher volume two-lane highways experience safety and operational problems. Often such problems can be related to inadequate geometry (steep grades, poor sight distance) and the lack of passing opportunities (due to heavy oncoming traffic and/or poor sight distance). While a major reconstruction project may be used to reduce the problem (e.g., widening to a four-lane facility or major alignment changes), other lower cost alternatives have been used successfully to reduce crash operational problems.

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

- passing lanes,
- climbing lanes,
- short four-lane sections,
- turnouts, and
- shoulder use sections (i.e., shoulders are used as driving lanes).

These countermeasures are illustrated in Figure C-1.

The need for passing opportunities on a two-lane road arises when the demand for passing opportunities exceeds their supply. The supply of passing opportunities on a two-lane road depends on the availability of passing sight distance and gaps in the opposing traffic stream. When the demand exceeds the supply, traffic platoons develop and grow as faster vehicles catch up with slower ones and are unable to pass. Passing lanes and use of shoulders and turnouts by slow vehicles can increase the opportunity for the faster vehicles to pass the slower vehicles.

A passing lane is an added lane provided in one or both directions of travel on a conventional two-lane highway to improve passing opportunities. This definition includes passing lanes in level or rolling terrain, climbing lanes on grades, and short four lane sections. The length of the added lane can vary from 1000 ft (305 m) to as much as 3 mi (5 km). When passing lanes are provided at an isolated location, their function is generally to reduce delays at a specific bottleneck, and the location of the passing lane is dictated by the needs of the specific traffic operational problem encountered. When passing lanes are provided to improve overall traffic operations over a length of road, they are often constructed systematically at regular intervals (*8*).

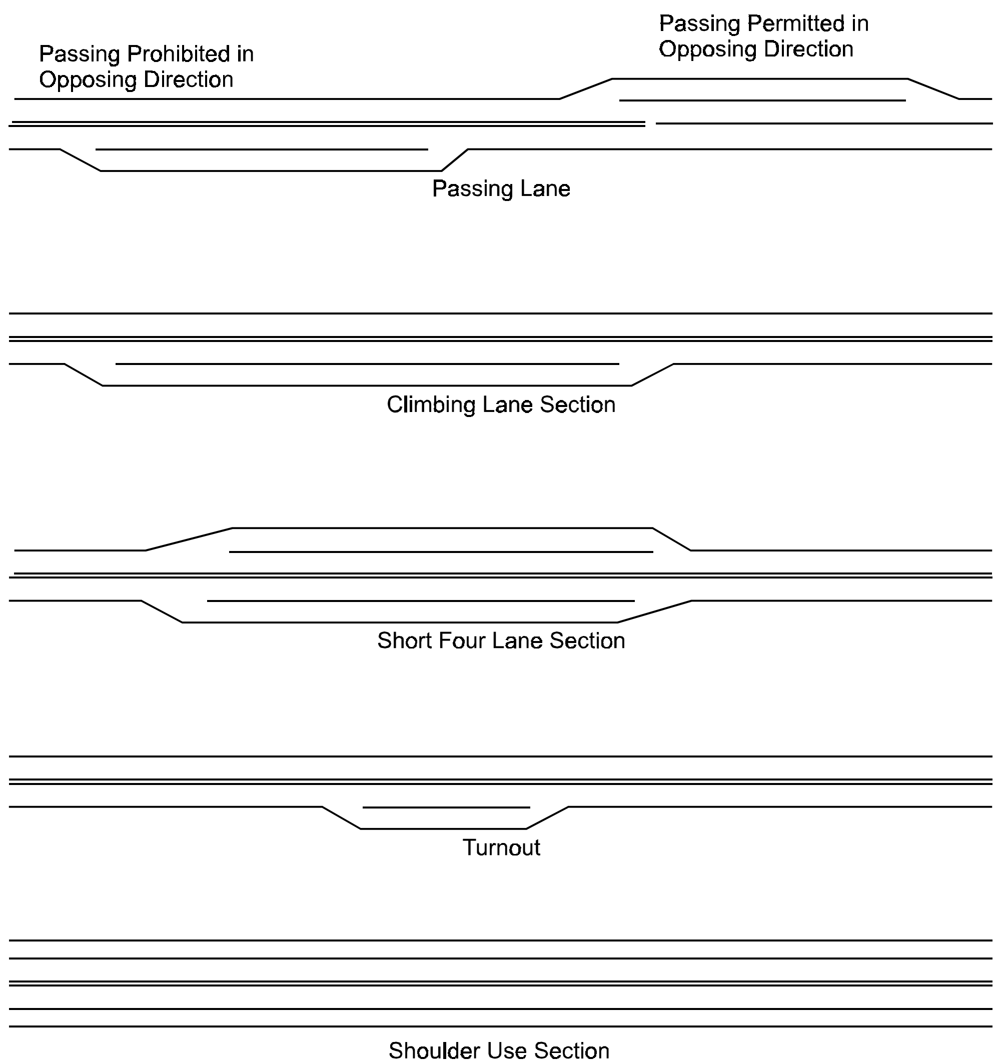

Figure C-1. Typical Operational Treatments Used on Two-Lane Highways (*8*).

A turnout is a widened, unobstructed shoulder area on a two-lane highway that allows slow-moving vehicles to pull out of the through lane to permit following vehicles to pass. Turnouts are relatively short, generally less than 600 ft (190 m) in length. They have been used most widely in the western United States; however, they are applicable to any winding or mountainous two-lane highway with limited passing opportunities (*8*).

The primary purpose of the shoulder on a two-lane highway is to provide a stopping and recovery area for disabled or errant vehicles. In some parts of the United States there is a long-standing custom where adequate paved shoulders are provided for slow-moving vehicles to move to the shoulder when another vehicle approaches from the rear and return to the travel lane after the vehicle has passed. Shoulder driving can provide great operational flexibility for two-lane highways; however, this option may not be appropriate at all locations because driving on the shoulder is illegal in most states.

An approach for allowing the use of paved shoulders by slow-moving vehicles is to permit the practice at selected sites designated by specific signing. Signs are placed at both the beginning and end of the highway section where shoulder use is allowed. This approach results in a highway agency encouraging shoulder use by slow-moving vehicles only where it has been established that additional passing opportunities are needed and where the shoulder is structurally adequate to handle the anticipated traffic loads. In some cases, the use of the shoulder is restricted to daylight hours only.

Table C-9 summarizes the results of a research study that examined how sections of highway 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 (*8*, *9*). 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 C-9 may not apply to low-volume two-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 *Informational Guide* by Harwood and Hoban (*8*).

TWO-WAY LEFT-TURN LANE

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. TWLTLs have been used for many years on urban and suburban arterial streets with commercial development 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.

Table C-9. Crash Reductions Related to Five Design Alternatives, as Compared to a Basic Two-Lane Road Design (*8*, *9*).

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

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.

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 (*10*). Comparable crash reduction effectiveness was found by Harwood and St. John (*9*) 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 (*9*). 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.

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Roadway alignment includes straight sections, horizontal curves, roadway grades, and vertical curves. The American Association of State Highway and Transportation Officials (AASHTO) has set geometric values for roadway features by functional classification. These values are presented in *A Policy on Geometric Design of Highways and Streets,* commonly known as the *Green Book* (*1*). Traffic control devices, such as signs and markings, can also assist in creating a roadway that performs well and safely. Information on these devices is presented in the *Manual on Uniform Traffic Control Devices (MUTCD)* (*2*).

Research has been conducted to evaluate the safety of various alignments. In some cases, these efforts have identified definitive relationships between design values and safety. The findings have allowed the development of crash reduction estimates that would be expected due to related roadway safety improvements. In other cases, the evidence only provides an estimate or suggestions of how to improve a roadway. The findings from these different studies provide results that can be used to improve the design of rural two-lane highways.

HORIZONTAL ALIGNMENT

Crash studies indicate that horizontal curves experience a higher crash rate than tangents, with rates ranging from one and a half to four times greater than tangent sections (*1*, *2*, *3*). Past research has identified a number of traffic, roadway, and geometric features that are related to the safety of horizontal curves. These factors include the following *(3)*:

- traffic volume on the curve and traffic mix (e.g., percent trucks);
- curve features (degree of curve, length of curve, central angle, superelevation, presence of spiral, or other transition curves);
- cross-sectional curve elements (lane width, shoulder width, shoulder type, and shoulder slope);
- roadside hazard on the curve (clear zone, side slope, rigidity, and types of obstacles);
- stopping sight distance on curve (or on curve approach);
- vertical alignment on horizontal curve;
- distance to adjacent curves;
- presence/distance from curve to the nearest intersection, driveway, bridge, etc.;
- pavement friction;
- presence and type of traffic control devices (signs and delineation); and
- others.

Previous studies show clearly that sharper curves are associated with higher crash rates than milder ones (*4*, *5*, *6*, *7*). The types of crashes generally found to be more represented on curves compared to tangents included more severe (fatal and A-type injury) crashes, head-on and opposite-direction sideswipe crashes, fixed-object and rollover crashes, crashes at night, and crashes involving drinking drivers. Based on a larger sample of 10,900 horizontal curves in Washington State, the distribution of curve crashes by severity and type were determined as shown in Table D-1.

Of all the factors that affect the design of horizontal curves, the degree of curvature is the best predicted of the crash potential (*4*, *8*). Simply stated, flatter curves (i.e., curves with low degrees of curvature) are more likely to have fewer crashes than sharper curves.

Geometric countermeasures that are used to improve safety along horizontal curves include the following:

- curve flattening,
- roadway widening on curves,
- superelevation improvements, and
- roadside improvements on curves.

Traffic control devices used at horizontal curves include delineation treatments and curve warning signs. These treatments are discussed in the following traffic control devices section. Information on roadside improvements is provided in Appendix B.

Table D-1. Summary of Crash Statistics on Washington State Curve Sample (*5*).

Variable	Frequency	Percentage
Total crashes	12,123	100.0
PDO crashes	6500	53.6
Injury crashes	5359	44.2
Fatal crashes	264	2.2
People injured	8434*	N/A
People killed	314*	N/A
Head-on crashes	517	4.3
Opposite-direction sideswipe crashes	468	3.9
Fixed-object crashes	5045	41.6
Rollover crashes	1874	15.5
Same-direction sideswipe	139	1.1
Rear-end both moving	303	2.5
Other collision types	3777	31.2
Dry-road crashes	6914	57.0
Wet-road crashes	2609	21.5
Snowy/icy road crashes	2600	21.4
Daylight crashes	6828	56.3
Dark, dawn, dusk crashes	5295	43.7

* These are numbers of **people** injured or killed, and not the number of crashes in which someone was injured or killed.

Curve Flattening

Curve flattening refers to reconstructing a horizontal curve to make it less sharp (i.e., a larger radius value or a lower degree of curve). The IHSDM (Interactive Highway Safety Design Model) crash prediction model for two-lane highways uses the following equation to determine the expected crash frequency of a horizontal curve relative to a tangent roadway:

$$AMF = \frac{1.55L_c + \frac{80.2}{R} - 0.0125}{1.55L_c}$$

Where:

AMF = crash modification factor
L_c = length of horizontal curve (mi)
R = radius of curvature (ft)
S = 1 if spiral transition curve is present or 0 if spiral transition curve is not present

This equation is based on the result of Zegeer et al. (*5*). In applying this equation to a curve with a spiral transition, L_c represents the length of the circular portion of the curve. When a curve is flattened (i.e., when its radius is reduced) but its central angle remains the same, the length of the curve increases. This must be considered when evaluating the expected effect of curve-flattening projects. The expected crash rate of the longer curve with larger radius should be compared to the shorter, sharper curve plus two tangent sections on either end.

Roadway Widening on Curves

Wider lanes and shoulders on curves are also associated with a reduction in curve-related crashes. Percent reductions in total crashes are given in Table D-2 for improvements involving widening lanes and/or shoulders on horizontal curves (*5*). From the left column of the table, the user should select the amount of lane or shoulder widening that is proposed for the project.

Table D-2. Percent Reduction in Crashes Due to Lane and Shoulder Widening on Horizontal Curves (*5*).

Total Amount of Lane or Shoulder Widening, ft (m)		Percent Crash Reductions (%)		
Total	**Per Side**	**Lane Widening**	**Paved Shoulder Widening**	**Unpaved Shoulder Widening**
2 (0.6)	1 (0.3)	5	4	3
4 (1.2)	2 (0.6)	12	8	7
6 (1.8)	3 (0.9)	17	12	10
8 (2.4)	4 (1.2)	21	15	13
10 (3.1)	5 (1.5)	—	19	16
12 (3.7)	6 (1.8)	—	21	18
14 (4.3)	7 (2.1)	—	25	21
16 (4.9)	8 (2.4)	—	28	24
18 (5.5)	9 (2.7)	—	31	26
20 (6.1)	10 (3.1)	—	33	29

The columns in Table D-2 provide the expected percent reduction in total crashes for widening lanes, paved shoulders, and unpaved shoulders, respectively. For example, assume a 20-ft

(6.1 m) roadway (i.e., two 10-ft (3.1 m) lanes with no shoulder) is to be widened to 22 ft (6.7 m) of paved surface with 8-ft (2.4 m) gravel shoulders (i.e., 16 ft (4.9 m) total of shoulder widening). From Table D-2, these improvements would reduce curve crashes by 5 percent (due to lane widening) and 24 percent due to widening unpaved shoulders by 2.4 m (8 ft). Note that the 5 percent and 24 percent crash reduction values cannot merely be added numerically. The proper procedure for combining two or more crash reduction factors is discussed in Zegeer et al. (*5*).

Superelevation Improvements

Superelevation is the amount of "banking" or cross-slope of a horizontal curve. A number of studies have attempted to link superelevation to crash causation. One study by Zador et al. noted deficiencies in available superelevation at fatal crash sites compared with nearby control sites (*9*). In the 1991 FHWA study, a small but significant crash effect of too little superelevation was noted (*5*). The authors concluded that curve sites with a superelevation "deficiency" have significantly worse crash experience than curves with a proper amount of superelevation. The superelevation deficiency, e_D, is defined as the difference between the recommended superelevation according to the *Green Book* (*1*), (e_R), and actual superelevation (e_A) or $e_D = e_R - e_A$.

Table D-3 shows the percent reduction in total curve crashes due to improving superelevation. To illustrate the use of the table, assume the actual superelevation (e_A) on a curve is 0.04 and the AASHTO recommended superelevation (e_R) for a particular curve design is 0.06. This corresponds to a superelevation deficiency e_D of 0.02. According to Table D-3, which is a modification of the Zegeer et al. (*3*) results by the expert panel that developed the IHSDM crash prediction algorithm (*10*), a horizontal curve with a superelevation deficiency of 0.02 would experience 6 percent more crashes than a similar horizontal curve with no superelevation deficiency.

Table D-3. Crash Modification Factor for Superelevation Deficiency on Two-Lane Highway Horizontal Curves (*10*).

Superelevation Deficiency	Crash Modification Factor
0.00	1.00
0.01	1.00
0.02	1.06
0.03	1.09
0.04	1.12

It should be noted that the 1991 study also investigated the safety effect of too much superelevation. No adverse effects were found based on available data. Current design policy is implemented with an assumed upper limit on superelevation for areas with snow and ice. The presumption is that excess superelevation produces sliding down the curve under low-speed conditions and hence increases crash potential. While this condition could theoretically occur at low-speed curve locations with sharp curvature and a high rate of superelevation, no evidence was found of any such significant adverse safety effects.

VERTICAL ALIGNMENT

The vertical alignment selected for a highway is a compromise between existing terrain, safety, and construction cost. It is described by both vertical lines or grades and vertical curves including the sags and crests. The design of crest vertical curves is influenced by the difference between the grades and the stopping distance selected for the roadway. Stopping sight distance is the sight distance available on a roadway that would permit a below-average operator or vehicle traveling at or near the design speed of the roadway to stop before reaching a stationary object in its path. For crest vertical curves, the sight distances are determined for drivers to see over the top of the hill to objects on the other side. For sag vertical curves, the sight distances are determined for drivers seeing at night from the vehicles' headlights.

Table D-4 shows that downgrade crashes are more frequent and result in higher percentages of injuries and fatalities than upgrade crashes. Also, injury and fatality rates on vertical curves are higher than on level or upgrade locations. The crash rate for downgrades is 63 percent higher than for upgrades, assuming that upgrades have as much vehicular traffic as downgrades (*11*).

Table D-4. Crash Frequency and Severity by Vertical Alignment (*11*).

Vertical Alignment	Number of Crashes	Percent of Total Crashes	Percent Injured	Percent Fatal
Level	2001	34.6	53.6	4.7
Upgrade	943	16.3	55.6	3.9
Downgrade	1533	26.5	58.4	5.1
Up on crest	373	6.5	59.5	6.0
Down on crest	461	8.0	62.6	5.9
Up on sag	258	4.5	57.8	6.3
Down on sag	211	3.7	61.7	6.8
Total Known	5780	100.0		
Unknown	2192			
Total	7972			

The elements of vertical alignment that are believed to influence safety include the steepness and length of grade and the vertical curve design. Geometric countermeasures for vertical alignment include minimizing the effects of slower moving vehicles by providing opportunities to pass and increasing sight distance on or minimizing hazards within a vertical curve. Information on providing passing opportunities is presented in Appendix C. Information on grade and on sight distance on crest vertical curves follows.

A recent study by Miaou developed a crash modification factor for the effect of vertical grade on crash frequency on rural two-lane highways (*12*). This factor, shown in Table D-5, is equivalent to an increase in crash frequency of 1.6 percent per percent grade. The crash modification factors shown in Table D-5 have been incorporated in the IHSDM crash prediction algorithm (*10*).

Table D-5. Crash Modification Factors for Grade of Roadway Sections (*10*).

Grade (%)				
0	2	4	6	8
1.00	1.03	1.07	1.10	1.14
Note: This factor can be expressed as an effect of 1.6 % per percent grade.				

Recent studies on vertical curves found:

- Crash rates on rural two-lane highways with limited stopping sight distance are similar to the crash rates on all two-lane rural highways (*13*).
- Vertical curves with stopping distances less than 311.5 ft (95 m) had more crashes than vertical curves with very long stopping sight distances. The largest increase in crashes occurred at the study sites that had the shortest stopping sight distances (*14*).
- Stopping sight distances ranging from 328 to 426.5 ft (100 to 130 m) did not affect crash rates unless an intersection was within the limited sight distance section (*15*).

Thus, for the range of conditions studied, limited stopping sight distance does not appear to cause a safety problem. The following recommendations regarding the safety effects of limited stopping distance were made (*13*):

- Many design criteria are based on parameters associated with the interaction between drivers, vehicles, and roadways. The resultant design criteria should be greater than or equal to the minimum requirements for safety.
- Based on the literature and on this study, the minimum stopping sight distance for safe operations and a 56 mph (90 km/h) speed is somewhere between 311.7 to 361 ft (95 to 110 m). The values are less than the minimum design values in the 1994 AASHTO *Green Book*; therefore, the AASHTO stopping sight distance represents acceptable values for design. The threshold for safe operations may increase when hazards, such as intersections or horizontal curves, are located within the limited stopping sight distance section.
- Because there are no apparent safety benefits from providing stopping sight distances longer than 360 ft (110 m) (when other hazards are not present), improvements other than lengthening a limited stopping sight distance crest vertical curve may provide a more effective use of available funds.

TRAFFIC CONTROL DEVICES

An informed driver with sufficient time to respond to a situation can avoid making serious driving errors. Conversely, inadequate information or time to respond to a situation results in a high probability of an erratic maneuver and high potential for a crash. Thus, communicating clear and concise information that is timely and meaningful to drivers is essential to a safe driving environment. Signs, pavement markings, and delineators can provide drivers with additional information concerning the roadway such as unexpected or atypical situations. Delineation refers to any method of defining the roadway operating area for the driver (*16*). Delineation has been defined as one or more devices that regulate, warn, or provide tracking information and guidance to the driver. These devices include the following delineation materials: painted markings, thermoplastic and other durable markings, raised pavement markers, and post-mounted delineators. Warning signs are also considered part of the delineation system when used to complement standard delineation in special areas, such as horizontal curves. For this document, delineation techniques have been divided into signs; pavement markings, including both paint and thermoplastic markings; and delineators, such as raised pavement markers and post-mounted delineators.

The *Roadway Delineation Practices Handbook* (*16*) was developed to assist in making decisions about roadway delineation systems. The *Handbook* supplements the *MUTCD* (*2*) by offering implementation guidelines. The contents cover current and newly developed devices, materials, and installation equipment, and presenting each item's expected performance based on actual experience or field and laboratory tests. Individual chapters cover the characteristics of retroreflection and quality assurance, driver visibility needs, traffic points, preformed tapers, raised pavement markings and other marking materials, post-mounted delineators and other delineation devices, and administrative and management issues and practices.

Signs

A recent TxDOT study has 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 (*17*) . 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.

A 1980s study in Ohio examined the effectiveness of advisory speed signs used in conjunction with curve warning signs (*18*). The results of the test-driver study indicated that drivers, on the average, look about two times at a warning sign (fixation duration 0.5 to 0.6 seconds). 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 (*19*, *20*).

Pavement Markings

Pavement markings are used to provide regulations and warnings to the driver. They can be used either alone or to supplement the regulations or warnings of other devices such as traffic signs or signals. Longitudinal pavement markings are used to indicate lane lines and edgelines. Yellow is used to separate traffic in opposing directions while white is used to separate traffic flowing in the same direction or mark the right edge of the pavement. Whether the lines are solid or broken and wide communicates restrictions along the roadway. Markings are more effective at communicating this type of information than signs. Right- and left-side edgelines are recommended for all roadways with any substantial traffic volumes.

Pavement markings studies have examined the effectiveness of edgeline and centerline markings and whether there are benefits to using wider markings in certain areas. The use of illusion-creating markings has also been investigated along with unique markings selected to reduce speeds prior to a horizontal curve.

Edgeline and Centerline Markings

The use of 4-in (10.2 cm) edgelines significantly reduced the number of crashes as compared with those sites with no edgelines (*21*). The use of 4-in (10.2 cm) edgelines has also shown a significant reduction in the number of crashes at access points (i.e., driveways and intersections) (*22*). Adding edgelines and centerlines to roadways where no delineation has been provided reduced crashes by 36 percent in a 1970s study (*23*). Adding centerlines reduced crashes by 29 percent; adding edgelines to centerlines yielded an 8 percent reduction. A Kansas study involved control and treatment sites comprising 384 mi (618.2 km) of rural highway servicing between 550 and 3600 vehicles per day. Using these findings, it was determined that edgelines will yield benefits exceeding their costs if an average of one non-intersection crash occurs annually every 15.5 mi (25 km) of roadway (*24*).

Wide Markings

Several states have experimented with using 8-in (20.3 cm) edgelines to prevent run-off-road (ROR) crashes (*25*, *26*, *27*). In general, the effectiveness of 8-in (20.3 cm) edgelines to reduce run-off-road crashes is questionable. Their use is recommended for rural roadways where the pavement width is at least 24 ft (7.3 m), the shoulders are unpaved, and the average day traffic (ADT) is between 2000 and 5000 vehicles per day. Eight-inch edgelines are not recommended on two-lane, rural roads with the following exceptions:

- frequent heavy snowfall and use of deicing materials and abrasives that tends to deteriorate edgelines,
- pavement widths of less than or equal to 6.7 m (22 ft), and
- roads having paved shoulders over 1.8 m (6 ft) wide.

Eight-inch edgelines may be appropriate as a safety improvement when applied at spot locations such as isolated horizontal curves and approaches to narrow bridges.

Unique Markings

Transverse pavement markings have been tested to determine if drivers will slow down in advance to 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 observed during the baseline period (*20*). Another study (*28*) 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 D-1 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 (*29*).

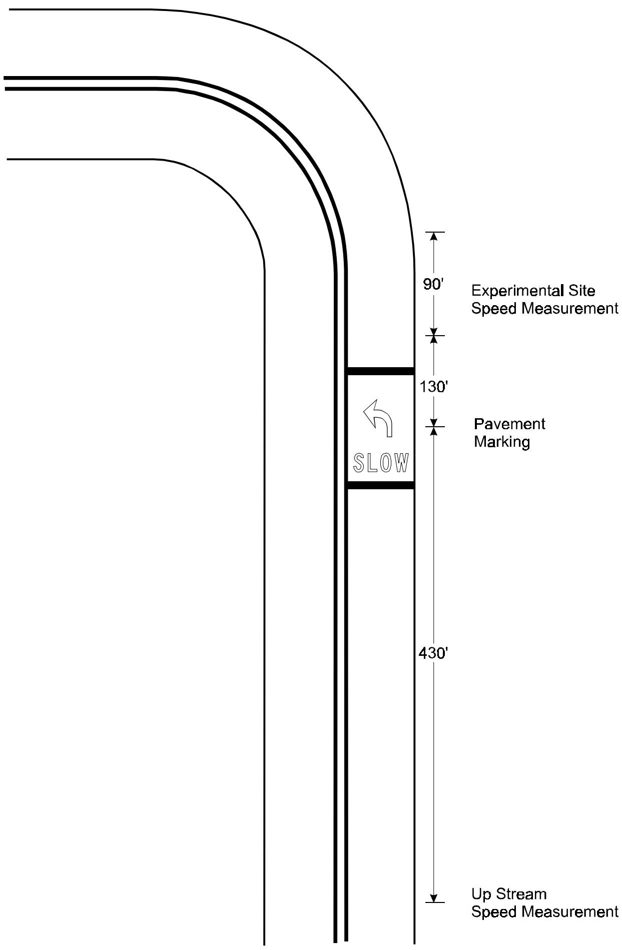

Figure D-1. Pavement Marking and Speed Measurement Locations for Retting and Farmer's Study (*29*).

Griffin and Reinhardt (*30*) reviewed the available literature on two illusion-creating pavement marking patterns. The markings were developed and used in the last 20 years to reduce traffic speeds and traffic crashes that result from driver inattention and habituation to high-speed driving. The marking patterns were the converging chevron pavement marking pattern and the transverse bar pavement marking pattern (most often used at the approaches to traffic circles). Based on a review of 10 different studies of the effects, the following was found:

- Most of the studies that were reviewed indicated that traffic speeds could be reduced by the application of transverse bar markings.
- Some studies suggested that the speed-reduction effectiveness of these patterns can be maintained for many months; others suggest the benefits of the markings are transitory and fade within a matter of days or weeks.
- When transverse bars were used in conjunction with pavement discontinuities (i.e., rumble strips), speed reduction was enhanced, but speed variability tended to increase.
- Transverse bar markings may reduce traffic speeds because the patterns may be functioning as a warning signal rather than from the illusion that drivers are traveling too fast.

Raised Pavement Markers

The application of raised pavement markers provides several benefits including increased delineation of the driving path of the roadway, increased ability to “track” the roadway, increased reflectivity under wet-weather conditions, and increased tactile and auditory warning to drivers when crossing the markers (*31*). Despite the clear advantages of RPMs, several studies have indicated an increase in nighttime crashes when RPMs are present (*32*, *33*, *34*), perhaps as a result of an increased sense of confidence in the driving task.

A study was performed to note driver responses to the application of raised pavement markers (RPM) by measuring changes in speed and encroachment distances into the opposing travel lane after varying the spacing intervals of the markers (*35)*. The RPM were spaced at a 40-ft (12 m) and 20-ft (6 m) spacing. The study used two rural minor arterial sites. The study recommended at least a 40-ft (12 m) spacing interval for the markings. They found that spacings below this value were shown to be no more effective in daylight conditions and are more costly and time consuming to install.

Delineators

Raised pavement markers (RPMs) can be used to show roadway alignment or to replace or supplement other pavement markings. The same principles that govern the use of painted markings are used for RPMs in terms of color, application, and configuration. The *MUTCD* (*2*) provides information on the pattern and spacing of RPMs. The *Roadway Delineation Practices Handbook* (*16*) presents figures to illustrate the principles that the *MUTCD* outlines and also specifically addresses the placement and spacing of RPMs for special situations.

Post-mounted delineators (PMDs) are light-reflecting devices mounted at the side of the roadway, in series, to show the roadway alignment. Their purpose is to outline the edges of the roadway and to accent critical locations. PMDs are usually mounted on posts 1.2 m (4 ft) above the pavement. Under normal atmospheric conditions (i.e., no fog, blowing snow, etc.), they should be visible at 1000 ft (305 m) when illuminated by the high beams of standard automobile headlights. In general, PMDs perform best on curves that are 7 degrees or less — for sharper curves, another form of extra delineation (such as chevrons) should be used. The *MUTCD* (*2*) provides standards for the following characteristics:

- mounting height,
- number,
- spacing,
- color of retroreflectors,
- criteria for retroreflective elements, and
- locations where use is required.

In tangent sections, PMDs should be placed 200 to 500 ft (61 to 153 m) apart in a continuous line not less than 2 ft (0.6 m) or more than 8 ft (2.4 m) outside the edge of the usable shoulders. Delineators should also be placed on the outside of curves having a radius of 1000 ft (305 m) or less. Recommended spacings for delineators on curves are given in the *MUTCD*. Three PMDs should be provided both before and after each curve, and the spacing should be such that at least three PMDs are always visible to the driver at one time. Generally, the spacing on curves should not exceed 300 ft (91.4 m) or be less than 20 ft (6.1 m). The *Roadway Delineation Practices Handbook* (*16*) provides information on typical installation of PMD horizontal curves.

Several researchers (*26*, *36*, *37*, *38*) 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 (*39*) suggest that neither edgelines 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 edgelines) 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 (*40*).

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 (*41*). 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.

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APPENDIX E: ROAD SURFACE CONDITION

Treatments used to decrease crashes associated with wet pavement include filling in pavement ruts, improving the skid resistance of a pavement, and warning the motorists of the slippery pavement.

PAVEMENT RUTTING

A study in Wisconsin was conducted to quantify how pavement rutting affects crash rates and to evaluate possible safety-based guidelines for the treatment of pavement rutting (*1*). Crashes were categorized as rut-related if the prevailing conditions could be potentially associated with the occurrence of hydroplanning. Rut depth measurements were average values for both directions of 1.1-mi (1.8 km) segments and represent the average elevation difference between the tire paths and the high point between them. The results of the statistical analyses indicated that the defined rut-related crash rate begins to increase at a significantly greater rate as rut depths exceed 0.3 inches (7.6 mm). A safety cost-effectiveness curve also demonstrated diminishing marginal returns when ruts less than 0.3 inches (7.6 mm) are filled. The conclusion was that it is economically justifiable in Wisconsin to treat pavements having rut depth measurements of 0.3 inches (7.6 mm) or greater.

SKID RESISTANCE IMPROVEMENTS

An example of a site where the skid resistance of a pavement was improved was presented in NCHRP Report 440 (*2*). A two-lane section of a rural highway located within a state park in northern California also separates two sections of four-lane freeway. The pavement width varies from 24 to 32 ft (7.3 to 9.8 m). The roadway is not a candidate for widening because of sensitive environmental considerations. It is a narrow windy road through an old growth redwood forest (see Figure E-1). The redwoods form a canopy over the roadway which causes the roadway to stay wet and slippery for a while following rain or condensed fog. In addition, the needles dropping from the trees also contributes to the slipperiness of the roadway. The goal of the treatment was to reduce wet pavement crashes.

Figure E-1. Two-Lane Rural Highway in an Old Growth Redwood Forest (*2*).

Open graded asphalt concrete (OGAC) has been used by Caltrans for improving wet weather skid resistance and minimizing hydroplaning. Caltrans Standard Specifications currently includes only a 3/8-inch (0.95 cm) maximum gradation specification. A 1-inch (2.54 cm) maximum gradation provided more voids for better drainage and, thus, better skid resistance by providing more voids than the 3/8-inch (0.95-cm) or ½-inch (1.27 cm) maximum OGAC standard mix. The 1-inch (2.54 cm) maximum OGAC mix was obtained from the Oregon Department of Transportation. According to Caltrans, the mix has been used extensively in Oregon and has been successful in reducing the number of crashes. Also, it was used on I-5 where the ADT exceeded 20,000 vehicles, and the pavement has held up well.

A 1-inch (2.54 cm) open graded asphalt concrete was used to reduce wet pavement crashes. 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. Caltrans believes that the treatment has been performing well. According to their before-and-after study, in the 13 months prior to installation they had 16 wet-pavement-related crashes. They have only had two crashes in the six months after installation. Additional data were gathered as part of this 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 only represented about 26 percent of the crashes on the segment.

WARNING DEVICES

The *MUTCD* (*3*) states that the Slippery When Wet sign may be 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.

FORETELL is being developed by the Federal Highway Administration as part of its rural intelligent transportation system (ITS) (*4*). Participants in the program include the state departments of transportation for Iowa, Missouri, and Wisconsin. It will provide via the Internet timely, detailed, and relevant weather-related road information needed by state highway managers and the public. The system works by collecting and combining raw weather information from many sources to provide the most recent and accurate weather data available. As of March 2001, FORETELL is in the demonstration phase and can only be accessed by program partners. Eventually the general public will be able to use FORETELL to access a wide range of weather and pavement condition information for any road or region.

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3. FHWA. *Manual on Uniform Traffic Control Devices.* Federal Highway Administration, Washington, D.C. (2001).

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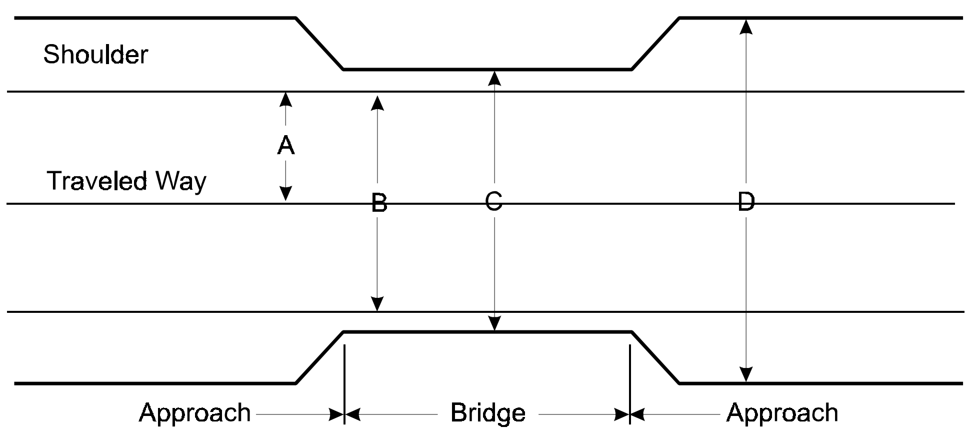
APPENDIX F: NARROW BRIDGE

Highway bridges are sometimes associated with crash problems, particularly rural highway bridges with narrow width, poor sight distance (e.g., just past a sharp horizontal curve), and/or poor signing and delineation. Numerous studies have analyzed the effects of various traffic control devices (e.g., signs and markings) on crashes and on vehicle operations such as vehicle placement on the bridge. However, research is scarce on the effects of bridge geometrics on crash experience.

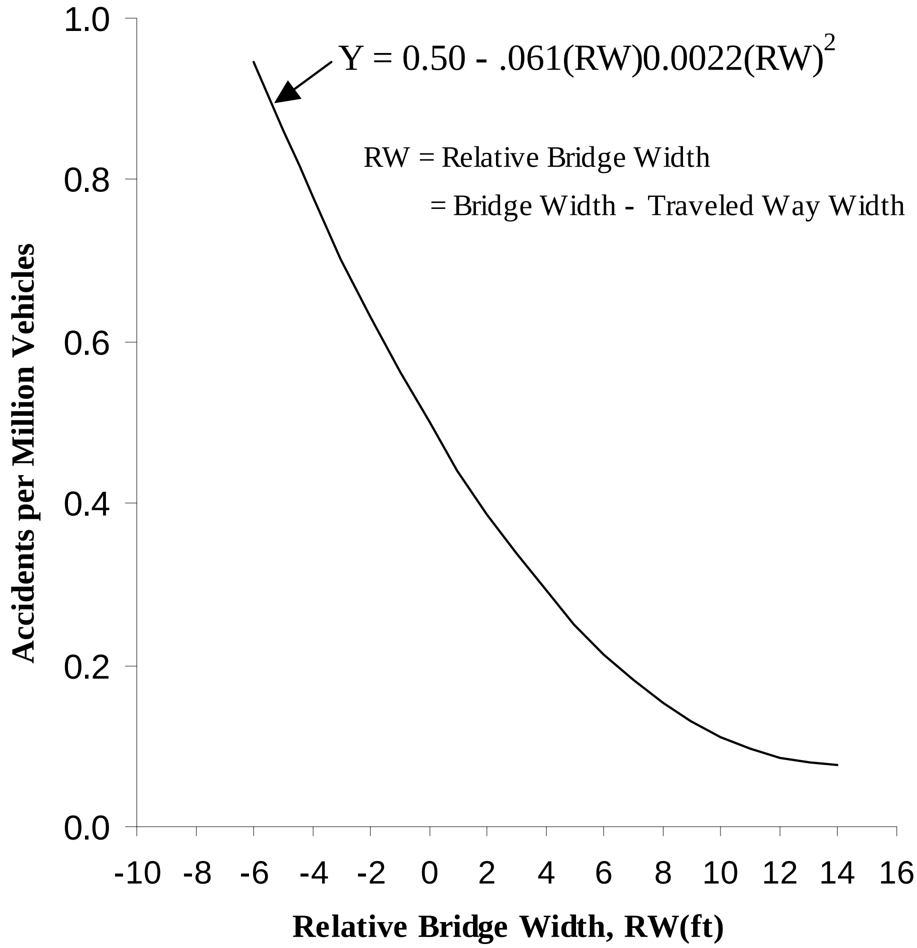
The features, which are of the most importance in terms of affecting bridge crash rates are the bridge width and/or the width of the bridge in relation to the approach width. The best known crash relationship with bridge width was developed in a 1984 study by Turner (*1*). Based on crashes at 2087 bridges on two-lane roads in Texas, a crash model was developed as a function of "relative bridge width" (RW), which is defined as the bridge width (C) minus the width of the traveled way (B) (see Figure F-1).

According to Turner's crash model, as shown in Figure F-2, the number of crashes per million vehicles decreases as the relative bridge width increases (*1*). This relationship indicates that it is desirable to have bridge widths at least 6 ft (1.8 m) wider than the traveled way. In other words, shoulders of 3 ft (0.9 m) or more should be provided on each side of the bridge.
The relationship shown in Figure F-2 is currently the best information available on the topic; however, the reader should note that the study did not include bridges with no crashes. If these bridges would have been included, a different relationship may have been found.



Where: **A = Lane Width**
B = Traveled Way Width
C = Bridge Width
D = Approach Roadway Width
RW = Relative Bridge With
RW = Bridge Width (C) - Traveled Way Width (B)

Figure F-1. Key Elements at a Bridge Site (*1*).



1 ft = 0.305 m

Figure F-2. Crash Rate by Relative Width (*1*).

Listed below are potential countermeasures identified as a means of reducing crash frequency and severity at bridges.

UPDATE BRIDGE RAILING

All bridge structures are required to have some type of bridge railing in place to prevent vehicles from running off the edge of a bridge or culvert. Bridge railing differs from roadside barriers in that they are generally an integral part of the structure (i.e., physically attached), and they are designed to have virtually no deflection when struck by an errant motorist.

APPENDIX F: NARROW BRIDGE

According to the *Roadway Design Guide* (*2*), bridge rails designed to AASHTO specifications *prior to* 1964 **may not** meet current specifications and may need retrofitting. Retrofit designs may be needed to do the following:

- Increase the strength of the railing system.
- Provide longitudinal continuity.
- Reduce or eliminate undesirable effects of curbs or narrow walkways in front of the bridge rail.
- Eliminate snagging potential.
- Increase the height of the rail systems to accommodate higher profile vehicles.

Several options exist for retrofitting or updating bridge rail systems, and the reader should consult the *Roadway Design Guide* for more information on the design and implementation of these options.

INCREASE BRIDGE WIDTH

Although expensive, increasing the width of a bridge is another option available for correcting crash problems associated with bridges. It is desirable that a bridge be designed to provide a full, continuous shoulder so that a uniform clearance to the bridge sides is maintained. The uniform alignment created by maintaining the full shoulder widths enhances highway safety by reducing driver concern for and reaction with the structural elements of the bridge rail.

Crash reduction factors given in Table F-1 provide percent reductions in total crash rate expected due to widening shoulders on bridges. For example, assume that a bridge is 24 ft (7.3 m) wide with 10-ft (3.1 m) lanes and 2-ft (6 m) shoulders on each side. According to Table F-1, widening the bridge to 32-ft (9.8 m) (i.e., two 10-ft [3.1 m] lanes with two 6-ft [1.8 m] shoulders) would reduce the total bridge crash rate by 62 percent.

Note that values in Table F-1 assume that the lane width stays constant in the before-and-after condition. When the bridge lane width is increased, a conservative estimate of crash reduction would be to use Table F-1 and only include the amount of increased shoulder width. For example, when widening a 20-ft (6.1 m) bridge (two 10-ft [3.1 m] lanes and no shoulder) to a 30-ft (9.1 m) bridge (two 12-ft (3.7 m) lanes and two 3-ft (.9 m) shoulders), assume an increase in shoulder width from 0 to 3 ft (0 to .9 m) for at least a 42 percent "minimum" crash reduction. While the factors shown in Table F-1 are the best estimate available of the effect of bridge width on crashes, they should be used cautiously because of an important drawback of the study on which they are based. This study considered only bridges that experienced one or more crashes during the study period. Failure to include sites that experienced no crashes is a well-known source of bias in safety research.

Table F-1. Summary of Crash Reduction Factors Associated with Widening Shoulders on Bridges (*1*). [a]

Bridge Shoulder Width Before Widening, m (ft)		**Bridge Shoulder Width, m (ft) after Widening Each Side [Total of Both Sides in Brackets]**						
Each Side	Total of Both Sides	1.2 [0.6] (4 [2])	1.8 [0.9] (6 [3])	3.1 [1.2] (10 [4])	2.4 [1.5] (8 [5])	3.7 [1.8] (12 [6])	4.3 [2.1] (14 [7])	4.9 [2.4] (16 [8])
0 (0)	0 (0)	23	42	57	69	78	83	85
1 (0.3)	2 (0.6)	--	25	45	60	72	78	80
2 (0.6)	4 (1.2)	--	--	27	47	62	71	74
3 (0.9)	6 (1.8)	--	--	--	28	48	60	64
4 (1.2)	8 (2.4)	--	--	--	--	44	44	50

[a] Assume that the width of lanes on the bridge remains constant. Values in the table were derived based on the crash model developed by Turner on rural two-lane roads.

IMPROVE SIGNING AND DELINEATION

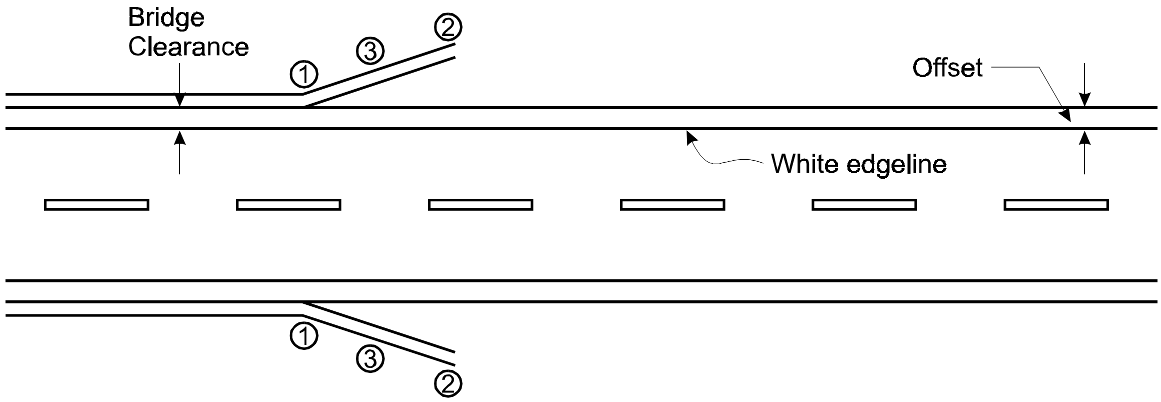
Controlled field studies were used to examine whether the amount and type of delineation provided at different bridge/culvert designs had an impact on drivers' comfort levels when approaching and crossing narrow bridges (*3*). Although researchers did not find a delineation technique that performed significantly better than the rest studied, they included recommended tapered edgeline/transverse marking arrangements. Figure F-3 shows the recommendation for roadways with edgelines, an offset-bridge clearance < 3.3 ft (1 m), and no lane width reduction across the bridge. They also included drawings for the following two cases: 1) roadways with edgeline offset > 3.9 ft (1.2 m) and offset bridge clearance > 3.3 ft (1 m) and 2) roadways without edgelines and approach width greater than the bridge width. The configurations are recommended for narrow bridge locations where a crash problem is known to exist or where other evidence suggests that drivers are not vacating the shoulder soon enough to avoid striking the bridge.

EXAMPLE OF A TREATMENT ON A NARROW BRIDGE

NCHRP Report 440 (*4*) discussed a treatment used on a narrow bridge in Missouri. A series of crashes prompted local residents to become concerned about the safety of a bridge located on a two-lane rural highway in the midwest (see Figure F-4). The bridge, carrying an average daily traffic of approximately 8000 vehicles with 7 percent trucks, was located on a highway that was becoming a premier route for truck drivers. Primarily, safety problems involved the narrow width of the bridge and the growing truck traffic. Specifically, the following situations were encountered at the bridge:

- drivers stopping at the bridge when a large vehicle was crossing, causing rear-end crashes;
- drivers encroaching the centerline of the bridge, causing sideswipe crashes; and

- left-turn traffic at lake roads located at the end of the bridge approaches, contributing to rear-end crashes.



Notes:
- Type 2 or Type 3 object marker.
- Type object marker if guardrail protection for bridge end is provided.
- Optional PMDs at 24.93- to 49.87-ft (7.6 to 15.2 m) spacings.

Figure F-3. Recommended Bridge Delineation for Roadways with Edgelines, Offset-Bridge Clearance of < 3.3 ft (1 m), and No Lane Width Reduction Across Bridge (*3*).

Figure F-4. Narrow Bridge (*2*).

Concerned citizens, organized by one of the motorists injured at the bridge, urged the department of transportation to replace the bridge. Lacking sufficient funds until a much later date, the department of transportation researched new products on the market and the latest technology applicable to this situation. Combining several different products to fit the situation, they created the Electronic Advanced Warning System currently in place. The Electronic Advanced Warning System was designed to 1) warn motorists of large vehicles crossing the bridge in the opposing lane and 2) warn motorists upstream of the bridge of vehicles stopped at the bridge.

Motorists are warned of large vehicles approaching in the opposing lane by a flasher on top of a "Caution" sign located at both ends of the bridge. Narrow beam microwave units, mounted on a post at either end of the bridge, detect vehicle direction and height. These units are set to detect approaching vehicles with a minimum height of 10 ft (3.1 m). Radio telemetry is utilized to activate the flasher on the opposite side of the bridge.

The second part of the Electronic Advanced Warning System was the installation of a "Be Prepared to Stop" sign with a flasher about 1200 ft (366 m) from both ends of the bridge. Using induction loop technology, an 80-ft (24.4 m) detection zone was created to detect stopped or slow-moving traffic. When these criteria are met, the flasher on the sign begins to flash, warning approaching traffic of the condition ahead.

The work was completed in February 1996 at an approximate cost of $33,000. This equipment, although somewhat susceptible to failure from lightning, has worked very effectively. The motorists seem to understand the function of the equipment and heed its warning. The traffic section believes this is an effective short-term solution with logical expectations and benefits. The department of transportation estimated the annual crash reduction realized by this countermeasure. These estimates are summarized in Table F-2.

Table F-2. Annual Crash Reduction for Treatment at Narrow Bridge (*4*).

Crash Type	**Estimated Reduction**	**Annual Number Crashes Before Improvement**		**Estimated Annual Reduction in Crashes**	
	%	**PDO**	**Fatal/Injury**	**PDO**	**Fatal/Injury**
Side Swipe	24	4.2	1.2	1.00	0.29
Rear End	24	0.8	1.0	0.19	0.24
Avoiding	24	1.2	0.2	0.29	0.05
Out of Control	24	0.4	0.8	0.10	0.19
Total Estimated Crash Reduction:				1.58	0.77

REFERENCES

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A major safety concern in rural areas is the result of speed differentials, generally due to vehicles slowing or stopped to make a turning maneuver at the intersection. For minor rural intersections, the effects of speed differential may be reduced greatly by flaring the intersection and permitting through traffic to bypass to the right of the vehicle waiting to make a left turn. Major rural intersections may need turn bays as a means of maintaining high operating efficiency and a safer environment. When a large number of turns need to be accommodated or when the intersection area is large and vehicles need additional guidance through the intersection, channelization may be considered.

Conflicts between turning vehicles and pedestrians and between turning vehicles and other vehicles approaching from the opposite direction can cause congestion delay and safety problems at intersections and driveway access points. Hummer et al. (*1*) used crash data for 1993 to 1995 for two selected counties in North Carolina to determine the types of collisions typically associated with rural intersections and driveways (see Table G-1). They found that rear-end crashes, which may include crashes involving turning vehicles, were the most common. Crashes involving left- or right-turn maneuvers represented 33 percent of the passenger car crashes and 34 percent of the truck crashes.

Table G-1. Collision Types at Rural Intersections (*1*).

Collision Type	Car		Truck	
	Number	Percent	Number	Percent
Rear End	1311	33	371	31
Angle	1249	31	345	29
Left Turn	1153	29	348	29
Right Turn	177	4	60	5
Backing	113	3	51	4
Other	16	0	10	1
TOTAL	4019	100	1185	100

An Ohio Department of Transportation study (*2*) determined the crash rates at unsignalized and signalized intersections with and without turn lanes. Table G-2 shows the significant differences in the crash rates for the different categories.

A 1975 Kentucky study (*3*) at yield-controlled intersections indicated that over half the crashes were rear-end collision while angle collisions were over half the crashes at stop signs (see Table G-3). Table G-3 also lists the results from a similar 1976 study, which used data from rural towns in Virginia but did not differentiate between crashes at yield signs and those at stop signs. The Virginia study also noted that crash rates at stop-controlled intersections were lower at those intersections having high traffic volumes (see Table G-4).

Table G-2. Crash Rates for Intersections with Signal Control and Left-Turn Lanes (*2*).

Type of Crash	Unsignalized		Signalized	
	No Left-Turn Lane	With Left-Turn Lane	No Left-Turn Lane	With Left-Turn Lane
Left Turns All Other	1.20 3.15 S	0.12 0.92 S	0.65 1.82 S	0.37 1.17
TOTAL	4.35 S	1.04 S	2.47 S	1.54 S
Crashes per million entering vehicles "S" denotes a difference that is statistically significant.				

Table G-3. Crash Types at Sign-Controlled Rural Intersections (*3*).

State	Control	Percent of All Crashes			Crash Rate (crashes per million entering vehicles)
		Rear End or Sideswipe	Right Angle	Other	
Kentucky	Yield Signs Stop Signs	56.2 29.6	22.5 51.9	21.3 18.5	Not available
Virginia	Stop and Yield signs	39	49	12	1.08

Table G-4. Relationship of Crash Rates to Traffic Volume Entering Stop-Controlled Intersections (*4*).

ADT	Crash Rate (crashes per million entering vehicles)
Less than 10,000 10,000 to 15,000 15,000 to 20,000 Over 20,000	1.12 1.05 0.97 0.52

LEFT-TURN LANE

The left-turn lane is generally the key auxiliary lane at an intersection. 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. It can also increase the distance downstream that the turning driver can see and will result in the driver being able to better judge the availability of gaps.

The AASHTO *Green Book* (*5*) 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. *Green Book* Exhibit 9-75 lists the traffic volumes where left-turn lanes should be considered. Additional information on left-turn treatments at intersections is included in NCHRP Synthesis 225 (*6*) and NCHRP Report 279 (*7*).

Providing adequate deceleration into a turn bay at an intersection will result in the smooth removal of a turning vehicle from the through lane. When the deceleration distance is too short, vehicles desiring to turn will be at a lower speed in the through lane (as they decelerate in anticipation of the turn bay) than the through vehicles. This differential in speeds can cause conflicts and crashes. Speed differential can also occur between a vehicle accelerating after a turn and the through vehicles in the same lane. Adequate deceleration and acceleration transition areas can improve operations and safety. Information on taper designs and deceleration/acceleration lengths for different grades or running speed assumptions is included in the *Green Book* (*5*).

The storage requirements for turn lanes is computed on the basis of the number of vehicles to be stored. The storage length should be sufficient to avoid the possibility of left-turning vehicles stopping in the through lanes. The storage length should also be sufficiently long so that the entrance to the auxiliary lane is not blocked by vehicles standing in the through lanes waiting for a signal change or for a gap in the opposing traffic flow.

At unsignalized intersections, the storage length, exclusive of taper, may be based on the number of turning vehicles likely to arrive in an average two-minute period within the peak hour (*5*). As a minimum requirement, space for at least two passenger cars should be provided; with over 10 percent truck traffic, provisions should be made for at least one car and one truck. The two-minute waiting time may need to be changed to some other interval that depends largely on the opportunities for completing the left-turn maneuver. These intervals, in turn, depend on the volume of opposing traffic.

A California study examined the difference in the effectiveness of the raised barrier protected left turn versus the painted left turn in rural areas (*8*). Both treatments provided a significant reduction in crash rates with relatively little difference between the types of treatment for rural areas (see Table G-5). The study's findings for the urban intersections indicated that the raised barrier protected left-turn lanes were much more effective than painted left-turn lanes. The study also compared crash reduction resulting from adding left-turn channelization at signalized and unsignalized intersections. The signalized intersections experienced an 18 percent reduction (from 1.00 to 0.82 crashes per million entering vehicles) while the unsignalized experienced a 50 percent reduction (from 1.16 to 0.58 crashes per million entering vehicles).

Table G-5. Crash Rates Before and After Adding Left-Turn Channelization at Unsignalized Intersections in Rural Areas (*8*).

	Raised Barrier Protected Left-Turn Lane			Painted Left-Turn Lane		
	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.

NCHRP Report 440 (*9*) presented a site where left-turn treatments were added to a two-lane roadway that has several world-class vineyards and restaurants that attract tourists. The roadway is a two-lane highway with shoulders on the roadway that are generally 4 to 8 ft (1.2 to 2.4 m) wide with a peak-hour volume of 2200 vehicles in 1983. The roadway is particularly congested on weekends because of the high number of visitors to the wineries. Queues often form behind vehicles waiting to make a left turn into the wineries. During the period between September 1, 1983, and August 31, 1986, there were 138 rear-end or left-turn-related crashes.

The construction project widened the roadway to include left-turn lanes at selected intersections (see Figure G-1) and a two-way turn lane on the north end of the project (see Figure G-2). The pavement was rehabilitated and widened to a 40-ft (12.2 m) cross section that included two 12-ft (3.66 m) lanes and two 8-ft (2.4 m) shoulders. In the vicinity of several intersections, the existing pavement was widened to 52 ft (15.9 m) to accommodate two 8-ft (2.4 m) shoulders, two 12-ft (3.7 m) through lanes, and one 12-ft (3.7 m) left-turn lane. In addition, all existing left-turn bays were brought up to the 52-ft (15.9 m) dimension. The improvements were anticipated to decrease the number of left-turn-related crashes in addition to reducing congestion and delay.

The work was completed in June of 1996 at a cost of $3.2 million. Crash data for the roadway segment were obtained for 29 months prior to installation and 30 months following installation. Before the left-turn treatments were installed, an average of 2.41 crashes per month occurred. Following installation, an average of 1.83 crashes per month occurred, representing approximately a 24 percent reduction in number of crashes. The type of primary collision factor associated with the crashes remained fairly constant between the two periods. The most common primary collision factor was speeding (36 percent of the before crashes and the after crashes), followed by failure-to-yield (19 percent of the before crashes and 15 percent of the after crashes), and improper turn (9 percent of the before crashes and 15 percent of the after crashes). It appears that the type of crashes did not change between the two periods; however, the total number of crashes did decrease.

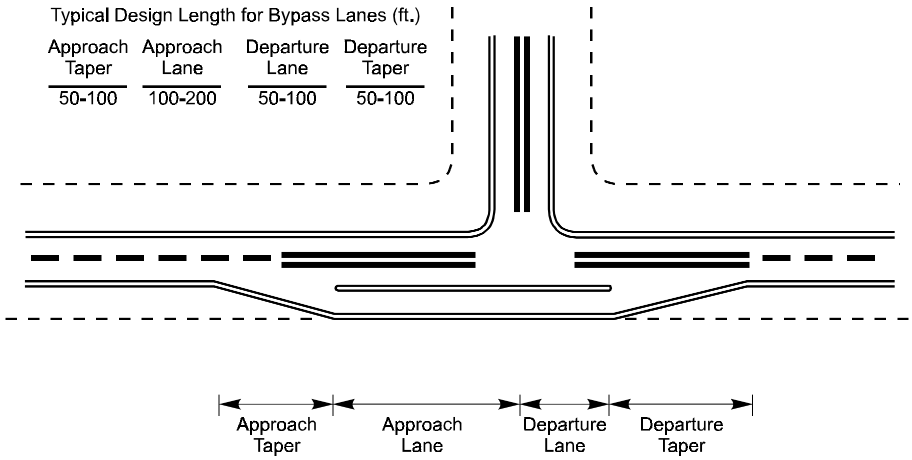
Figure G-1. Example of Left-Turn Lane (*9*).

Figure G-2. Example of Two-Way Turn Lane (*9*).

SHOULDER BYPASS LANES

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. The bypass lane may also be used at major driveways. Where an adequate paved shoulder is already available, installation of a shoulder bypass lane may be as simple as remarking the highway edgeline. Thus, provision of a shoulder bypass lane is often much less expensive than construction of a left-turn lane. At other locations, construction of a paved shoulder for use as a bypass lane may be justified either to improve traffic operations or reduce crash experience.

Figure G-3 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. The marking of a bypass lane encourages drivers to avoid unnecessary delay and assures that the maneuver is legal by designating a portion of the paved shoulder as part of the traveled way.



1 ft = 0.305 m

Figure G-3. Plan View of Typical Intersection with Shoulder Bypass Lane (*10*).

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 (*11*). Similarly, an Illinois study observed over 90 percent usage of shoulder bypass lanes by drivers who needed them (*12*). Even bypass lanes as short as 150 ft (46 m) were used effectively by drivers.

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 (*11*).

RIGHT-TURN LANE

Right-turn lanes can provide increased operational efficiency to an intersection, especially when there is a high volume of vehicles turning right. The design of the right-turn lane is very similar to the design of the left-turn lane. There should be adequate storage and a smooth taper into the lane.

Several publications provide advice on when to consider a right-turn lane. Some of the information is based on a benefit-cost analysis or on the safety effects of the turn lane. Most use operational effects to identify when a turn lane should be considered. Stover et al. (*13*) suggest that right-turn lanes be provided on uncontrolled intersection approaches when the average daily traffic on the intersecting roadway is 500 vehicles per day or greater. Glennon et al. (*14*) conducted a benefit-cost analysis and made assumptions about the operational and safety effects of right-turn lanes. The results of the analysis indicated that right-turn lanes are cost-effective at driveways when a) the driveway volume is at least 1000 vpd with at least 40 right turns into the driveway during peak periods, and b) the roadway ADT is at least 10,000 vpd and the roadway speed is at least 35 mph (56 km/h). Cottrell (*15*) developed guidelines using information obtained from a survey of state practices and field studies. The treatments considered were: a) no special treatment other than the radius, b) a taper, and c) a full-width lane.

McCoy et al. (*16*) developed guidelines for the use of right-turn lanes at access points on urban two-lane and four-lane roadways. The study was performed for the Nebraska Department of Roads. The guidelines compared the benefits and costs of right-turn lanes at uncontrolled intersections and driveways on urban roadways. Benefits included cost savings in delay, fuel consumption, and crashes. Costs considered construction and maintenance of the turn lane. Table G-6 lists the guidelines for urban two-lane roadways.

Hasan and Stokes (*17*) also developed guidelines for right-turn treatments at unsignalized intersections and driveways on rural highways. Their guidelines considered two types of treatments: full-width lane and taper. A benefit-cost evaluation along with operational effects and safety effects were considered during the development. The safety effects evaluation used the relationship between speed differential and crash to estimate the reduction in right-turn, same-direction, rear-end crashes that would be expected to result from the provision of a right-turn treatment. Table G-7 lists the guidelines developed.

Table G-6. Right-Turn Lane Guidelines for Urban Two-Lane Roadways (*16*).

Roadway DDHV (vph)	**Minimum Right-Turn DHV (vph)**															
	Within Existing ROW				**ROW Cost = $0.093/m²**				**ROW Cost = $0.465/m²**				**ROW Cost = $0.93/m²**			
	Roadway Speed (km/h)				**Roadway Speed (km/h)**				**Roadway Speed (km/h)**				**Roadway Speed (km/h)**			
	40	**56**	**72**	**89**	**40**	**56**	**72**	**89**	**40**	**56**	**72**	**89**	**40**	**56**	**72**	**89**
100	-	-	65	30	-	-	70	40	-	-	-	-	-	-	-	-
125	65	60	40	25	70	65	50	25	-	-	75	45	-	-	-	-
150	60	50	35	20	65	55	40	20	75	75	60	35	95	95	90	50
200	50	45	30	15	55	45	30	15	65	65	40	25	80	80	60	30
400	40	35	20	10	40	35	20	10	40	40	30	20	55	55	40	20
600	35	30	15	10	35	30	15	10	35	35	25	15	45	45	35	15
800	30	25	15	10	30	25	15	10	30	30	20	10	35	35	30	15
1000	25	20	15	10	30	25	15	10	30	30	20	10	35	35	30	15
1200	25	20	15	10	30	25	15	10	30	30	20	10	35	35	30	15

* 1 km/h = 0.6 mph

Table G-7. Right-Turn Treatment Guidelines for Two-Lane Highways (*17*).

Roadway DDHV (vph)	Minimum Right-Turn DHV (vph) [a]											
	Lane						Taper					
	Roadway Speed (km/h)						Roadway Speed (km/h)					
	64	72	81	89	97	105	64	72	81	89	97	150
200			73	35	20	15		83	30	14	8	7
300		120	41	24	15	12		40	19	9	7	6
400	200	52	30	19	12	11	85	27	14	8	6	5
600	50	26	20	14	10	9	27	13	9	6	5	4
800	25	16	15	11	9	8	12	8	7	5	4	3
1000	14	12	11	9	8	7	8	5	5	4	3	3
1200	10	9	98	8	7	7	6	4	4	4	3	3

[a] Minimum right-turn design hour volume (vph) required to warrant right-turn treatments based on an assumed turning speed of 24 km/h.
1 km/h = 0.6 mph

CHANNELIZATION

Potential conflicts among vehicles and between vehicles and pedestrians may be reduced through channelization of traffic movements. The traffic may be channeled into specific and clearly defined vehicle paths. Operational objectives of channelization are as follows (*18*):

- direct traffic movements,
- assure orderly movement,
- increase capacity,
- improve safety,
- maximize effective traffic control and communication with the driver, and
- reduce conflicts.

Because traffic volumes, pedestrian patterns, and physical conditions vary, individual channelization treatments are generally needed for each intersection. Good design should adhere to the following principles (*18*):

- The proper traffic channels should appear natural and convenient to drivers and pedestrians. There should be no choice of vehicle paths leading to the same destination. The number of islands should be held to a practical minimum to avoid confusion.
- Islands should be large enough to be effective. Islands that are too small are ineffective as a method of guidance and often present problems in maintenance. The area of an island should be at least 75 ft^2 (7 m^2). Accordingly, triangular islands should not be less than about 12 ft (3.7 m) on a side, after the rounding of corners. Elongated or divisional islands should be at least 4 ft (1.2 m) wide and 12 to 20 ft (3.7 to 6.1 m) long.

- Channelization should be visible. It should not be introduced where sight distance is limited. When an island must be located near a high point in the roadway profile or near the beginning of a horizontal curve, the approach end of the island should be extended so that it will be clearly visible to approaching drivers.
- The major traffic flows should be favored.
- Conflicts should be separated so that drivers and pedestrians may deal with only one conflict and make only one decision at a time.
- Islands should be designed for the design speed of the road. The approach end treatment and delineation should be carefully designed to be consistent with the speed characteristics of the roadway design.

Additional guidance on channelization is provided in several reference materials, such as the *Green Book* (*5*), Stover and Koepke (*18*), and NCHRP Report 279 (*7*).

The effectiveness of various safety improvement projects was evaluated in the early 1970s by Dale (*19*) . He found that channelization of intersections produced an average 32.4 percent reduction in all types of crashes. Crashes involving personal injuries decreased by over 50 percent. An analysis done in 1978 by Strate (*20*) of the impact of 34 types of safety improvement projects indicated that intersection channelization projects had produced an average benefit/cost ratio of 2.31.

RUMBLE STRIPS ON APPROACHES TO INTERSECTIONS

While the *TMUTCD* (*21*) 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 devices and as approach end treatments for curb islands.

> 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.

It also provides the following options and guidance:

- 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 may 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.

ADVANCE WARNING

Studies have examined the effect of different signs and beacons on crashes or speed. A regulatory speed-zone configuration and 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 (*22*). A study of rural high-speed intersections found that providing the driver with adequate warning of the intersection is of primary importance for this type of intersection (*23*).

NCHRP Report 440 (*9*) included an example of where a flasher was used on an advance warning sign along with other treatments. The intersection of two state highways has experienced several severe side and rear-end collisions over the past 25 years. Initially, the intersection was a two-way stop on the minor cross street. Historically, daily travel volumes on the major highway have been double the volumes of the minor roadway. The intersection is in a rural area with limited development surrounding the intersection.

Several approaches have been implemented at this location to improve safety with limited results. In November 1980, overhead flashing signals were installed 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" advanced warning signs on the minor approach. Recent severe crashes 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. Advance red flashing beacons with stop ahead signs were installed on all approaches (see Figure G-4). At the intersection, flashers were added to the stop signs (see Figure G-5). The project was completed in March of 1998. State officials state that the next step toward improving this location would be to install signal heads on all approaches. Currently, traffic volumes do not meet MUTCD warrants for a traffic signal.

Preliminary results suggest that the countermeasure has been 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.

Figure G-4. Beacons on Stop Ahead Sign (*9*).

Figure G-5. Beacons on Stop Sign (*9*).

SUPPLEMENTAL SIGNS ON STOP SIGNS

The traffic control for low-volume rural intersections is generally no-control, yield, or stop signs. A 1978 NCHRP study (*24*) made the following comments on the general safety aspects of sign controls at intersections:

- Yield signs effectively reduce crashes at low-volume, isolated urban intersections.
- Four-way stop controls significantly reduce crashes at intersections where entering traffic volumes on all approaches are relatively equal.
- Four-way stop controls result in increased crashes where traffic volumes on approaches are not relatively equal.

Signs warning motorists that traffic on the cross street does not stop can be found at some intersections that are not all-way stop controlled. These "cross traffic" signs have been installed to provide a special warning where some motorists on the minor approach may incorrectly assume that the major crossing street also has stop signs. A review of crash data offered mixed results about the signs' effectiveness: at some locations, the signs appeared to reduce crash frequencies; at others, crashes continued despite their presence (*25*). Care should be taken to control the use of the sign because expanded use could cause drivers to expect them at all two-way, stop-controlled situations. More information on the long-term impact of the signs is needed. Another study determined that if supplemental signs are used, most drivers understand and prefer the design shown in Figure G-6.

Figure G-6. Preferred Supplemental Sign at Two-Way, Stop-Controlled Intersections (*26*).

INTERSECTION FLASHING BEACON

Intersection control beacons have flashing yellow or red indications on each face. They are installed and used only at an intersection to control two or more directions of travel. 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.

Results of a 1970 North Carolina State University study (*27*) of crashes before and after installation of flashers at stop sign controlled rural intersections are shown in Table G-8. The authors state that there was a statistically significant decrease in crash rates on the aggregate sites, on three and four sections. Most noticeable was the decrease in single-vehicle crashes.

Table G-8. Change in Crash Experience with Addition of Flashers at Stop Sign Controlled Rural Intersections (*27*).

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

Results of a similar study in California (*8*) of changes in crash patterns as a result of installation of flashing beacons at stop sign controlled intersections was summarized as:

- Total crashes decreased 43 percent.
- Single-vehicle crashes decreased 67 percent.
- Left-turn crashes decreased 39 percent.

- Rear-end crashes decreased 17 percent.
- Angle crashes decreased 45 percent.
- Other two-vehicle crashes decreased 47 percent.

The severity of crashes was also reduced:

- Property damage crashes decreased 34 percent.
- Injury crashes decreased 51 percent.
- Fatal crashes decreased 80 percent.

There was a marked decrease in both daytime and nighttime crashes; those in the day decreased 43 percent, those at night decreased 46 percent.

Table G-9 shows a comparison of safety impacts for different types of flasher control. 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. The decrease in severity of crashes and in the number occurring in daytime and nighttime hours was quite similar to the averages previously described for all crashes.

Table G-9. Change in Crash Rates at Intersections with Addition of Flashing Beacons (*8*).

Crash Type	Percent Changes		
	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 G-10 indicates that the California study did not find a significant difference in effect between flashers that were installed at channelized intersections and those at non-channelized intersections. 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 G-11.

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 G-10. Change in Crash Rates with Red-Yellow Flashing Beacons Added At Channelized and Non-Channelized Intersections (*8*).

Channelization Present	Percent Change	
	3-Leg	4-Leg
Channelized	- 51	- 25
Non-Channelized	- 54	- 38

A study in Ohio examined 82 intersections, each of which was controlled by a flashing beacon (*28*). 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: 1) standard stop sign on the side of the road with one or two flashing beacons attached to the support post; 2) a single unit placed overhead in the center of the minor approach roadway and displaying two beacons flashing alternately; and 3) 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—4-leg intersections with 2-lane main and minor approaches.

Table G-11. Change in Crash Rates When Four-Way Stop Control with Flashing Beacons Are Added to Intersections with Various Types of Traffic Control (*8*).

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

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 (*29*). 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. Guidelines for installation of intersection control beacons are included in the report.

ILLUMINATION

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. Specific values on crash experiences related to lighting are not available. 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 should consult both the *Roadway Lighting Handbook* (*30*) and the *Addendum to Chapter Six of the Roadway Lighting Handbook — Designing the Lighting System Using Pavement Luminance* (*31*) for more information on the design of a lighting system.

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. If the N is greater than D/3, the likely average benefit should be taken as N-D/3 crash per year. 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 (*32*).

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" (*33*). 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 (*34*). 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.

PAVEMENT MARKINGS

Pavement markings are used to supplement the regulations or warnings of other devices such as traffic signs or signals (*21*). 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 *MUTCD* (*21*) provides information on the use and installation of pavement markings along roadways and at intersections.

At intersections, pavement markings can be used to help guide vehicles through the intersection or through the turns. White dotted lines are typically used when guiding vehicles through a turn within the shared intersection area. Solid lines are used along the approaches of the intersection.

In some cases, wider lines or raised pavement markings are used. A stop line is used to stop vehicles in advance of crosswalks or areas where pedestrians are crossing or to indicate where a vehicle is to stop at a stop sign or traffic signal. Crosswalks are used as a guide to pedestrians and as a warning to motorists of a pedestrian crossing point. Words and symbol messages on the pavement are also used to guide, warn, or regulate traffic.

SIGHT DISTANCE

Clear sight distance areas should be established, where possible, to ensure that obstructions do not infringe on the sight lines needed by motorists, pedestrians, or bicyclists approaching potential conflict points. The AASHTO *Green Book* (*5*) includes detailed descriptions of how to determine sight distance along the approaches at an intersection and across their intersecting corners for a distance sufficient to allow motorists, approaching simultaneously, to see each other in time to accelerate, slow down, or stop before a collision occurs. In addition, the *Green Book* discusses the process to determine the necessary sight distance for a driver to make a safe departure through the intersection area from a stop position.

Table G-12 lists suggested countermeasures for intersections with sight distance concerns.

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 (*35*).

The IHSDM crash prediction algorithm for rural two-lane highways incorporates the judgment by an expert panel on sight distance obstructions. At a stop control on minor road intersection, when a sight distance obstruction results in a difference of 12.4 mph (20 km/h) or more between the calculated speed for the available sight distance and design speed, the crash frequency would increase by approximately 5 percent (*37*).

Table G-12. Suggested Countermeasures for Intersections (*36*).

Rural Uncontrolled Intersections • Enact maximum statewide (or county-wide) speed limit of 45 to 50 mph (72.5 to 80.5 km/h) for unsigned roads. • Formulate simple agreements with property owners to provide obstruction-free corner triangles as large as possible. • Cut back vegetation and/or embankments to achieve the *Green Book* sight distance values. • Remove walls, fences, signs, or other obstructions on right-of-way. • Use 2-ft (0.6 m) object height where possible for nighttime view of headlights. • Use speed zoning on approach to intersection. • Place two-way stop signs where *Green Book* sight distance values cannot be obtained in all four quadrants.
Stop-Controlled Intersections • Cut back vegetation and/or embankments as far as possible. • Restrict parking. • Paint stop line closer to the intersection when that position offers a clearer sight line, and install sign stating "Pull Up To See." • Install traffic signals when warranted. • Remove walls, fences, advertising signs, or other obstructions on right-of-way. • Reduce through roadway approach speed limits. • Install four-way stop signs when adequate sight distance cannot be achieved. • Use 2-ft (0.6 m) object height where possible for nighttime view of headlights.

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APPENDIX H: WILDLIFE CRASHES

Transportation routes can have an effect on animals throughout North America. Although the literature varies with regard to the amount of displacement and other impacts, there is irrefutable evidence that roads and their associated disturbances reduce habitat effectiveness. This results in reduced fitness and in increased risk of mortality (*1*).

Crashes between large animals, especially deer, and vehicles are a significant safety problem for a number of rural two-lane highways. According to recent estimates, the number of white tail deer in the lower 48 states (approximately 25 million) has almost doubled in the past decade and is expected to continue increasing in the future (*2*). The increase in numbers of deer and their behavior around highways may explain why deer are involved in so many crashes on rural 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. Deer-vehicle crashes in recent years are estimated to range from 12,000 to 16,000 per year in Minnesota. The average vehicle damage is estimated to be $2000 per crash, and the recreational cost of a deer is estimated to be $500. Therefore, the roadkill of white-tailed deer in Minnesota is about a $35 million problem each year (*3*).

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 (*4*). These trends are expected to continue in the immediate future, increasing the potential for vehicle-animal crashes. The following were identified as part of the study:

- The information available indicates that deer are the animal most frequently involved in crashes. In Michigan, almost all reported vehicle-animal crashes were deer related (97.6 percent) or deer associated (2.2 percent). Data from Minnesota indicate that deer were involved in more than 90 percent of all reported animal crashes.

- In addition to increasing in frequency, vehicle-animal crashes have increased as a percentage of all reported crashes, from 4.7 percent in 1985 to 8.2 percent in 1991. These figures indicate that vehicle-animal crashes are increasing at a rate that substantially exceeds that of other types of crashes. This increase could be a result of continued development and changing land use patterns, increases in deer population, and increases in traffic volume through areas populated by deer.

- Vehicle-animal crashes also occurred more frequently at night. Of all reported animal crashes, 69 percent to 85 percent occurred at night. The average annual animal crash frequencies were found to be two to five times higher at night than during the day. 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.

APPENDIX H: WILDLIFE CRASHES

Several studies on various types of wildlife crashes are summarized on the following pages.

DEER

Countermeasures used to decrease deer 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.

Signing

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 *MUTCD* states that "advance crossing signs should be used to alert vehicle operators to unexpected entries into the roadway by pedestrians, trucks, bicyclists, animals, and other potential conflicts" (*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.

Roadside Vegetation

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 (*6*). These feeding areas intercepted foraging deer and kept them away from the highways, making the roads safer for passing motorists. A high big-game fence was installed 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 (*7*).

Reflective Devices

Reflective devices have been designed to redirect the light from vehicle headlights to create "optical fences" to keep deer from crossing or entering the roadway. The reflectors are installed on both sides of the road and reflect the headlights as red lights into the adjoining terrain. The theory is that white-tailed deer are afraid of the illuminated red reflectors to the point that they either stop or run away when the reflectors are illuminated.

Studies have attempted to determine whether the red 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 to the red reflectors as anticipated (*8*, *9*).

In 1980, the Minnesota Department of Transportation (Mn/DOT) installed the Swareflex brand red reflector along a one-mile stretch of I-94 in central Minnesota. Another brand of white reflector was installed on a one-mile stretch of TH 169 in the Minnesota River valley in southern Minnesota. The red reflector reduced deer-vehicle crash rates over 80 percent while the white reflector was unsuccessful. Minnesota has since installed reflectors at 38 locations throughout the state. Later installations indicated that reflector installations apparently work in rural Minnesota and failed in suburban areas. The theory for the success of reflector installations is that headlights of approaching vehicles shine into reflectors located parallel to the roadway and the prisms reflect a red glow visible to deer on the roadside. This red glow, perhaps mimicking the eyes of predators, causes deer to remain motionless or escape away from the roadway while vehicles are present. The necessity for headlights means they will function as intended only during nighttime and other low light conditions. Deer are most active and deer vehicle crashes occur predominantly during night or low light conditions. 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 (*3*).

Fences and Underpasses

Use of fencing and underpasses has resulted in fewer deer crossing the roadways and fewer crashes (*7*, *10*). 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 60 and 93 percent from the expected number for the two segments (*10*).

Highway Crosswalk System

A new mitigative technique was studied in Summit and Wasatch counties in northeastern Utah. Analysis of designated kill zones compared to non-kill zones on each highway helped identify distinguishing features that aided placement of the crossing structures. The percent of vegetative cover was higher for designated kill zones (40 percent) compared to non-kill zones (29 percent) (*11*).

The crosswalk system restricted deer crossings to specific, well-marked areas along the highways where motorists could anticipate them. Right-of-ways were fenced off with deer-proof fencing to direct the animals to the designated crossing areas. At these locations, deer jumped a 3.3-ft (1.0 m) high fence to enter the crosswalk funnel. Once in the funnel, the animal could choose to forage on desired vegetation or continue to approach the road. The fence could not extend closer than 30 ft (9.1 m) from the highway surface, so fields of rounded river cobbles were used to demarcate a path for the deer to follow as it continued to approach the road. Painted cattle-guard lines on the road surface were used to delineate crosswalk boundaries for oncoming motorists and may have served as a visual cue to guide deer directly across the highway. Once across the road, the deer encountered another dirt path bordered by cobbles, and a narrow fence opening allowing entry to the crosswalk funnel and distant habitat. This system is illustrated in Figure H-1.

Vegetation in and along cobble paths was eliminated to discourage deer from remaining near the highway. A series of three warning signs was installed at each crosswalk to advise motorists that they were entering a crossing zone. Four one-way grates were installed in the vicinity of each

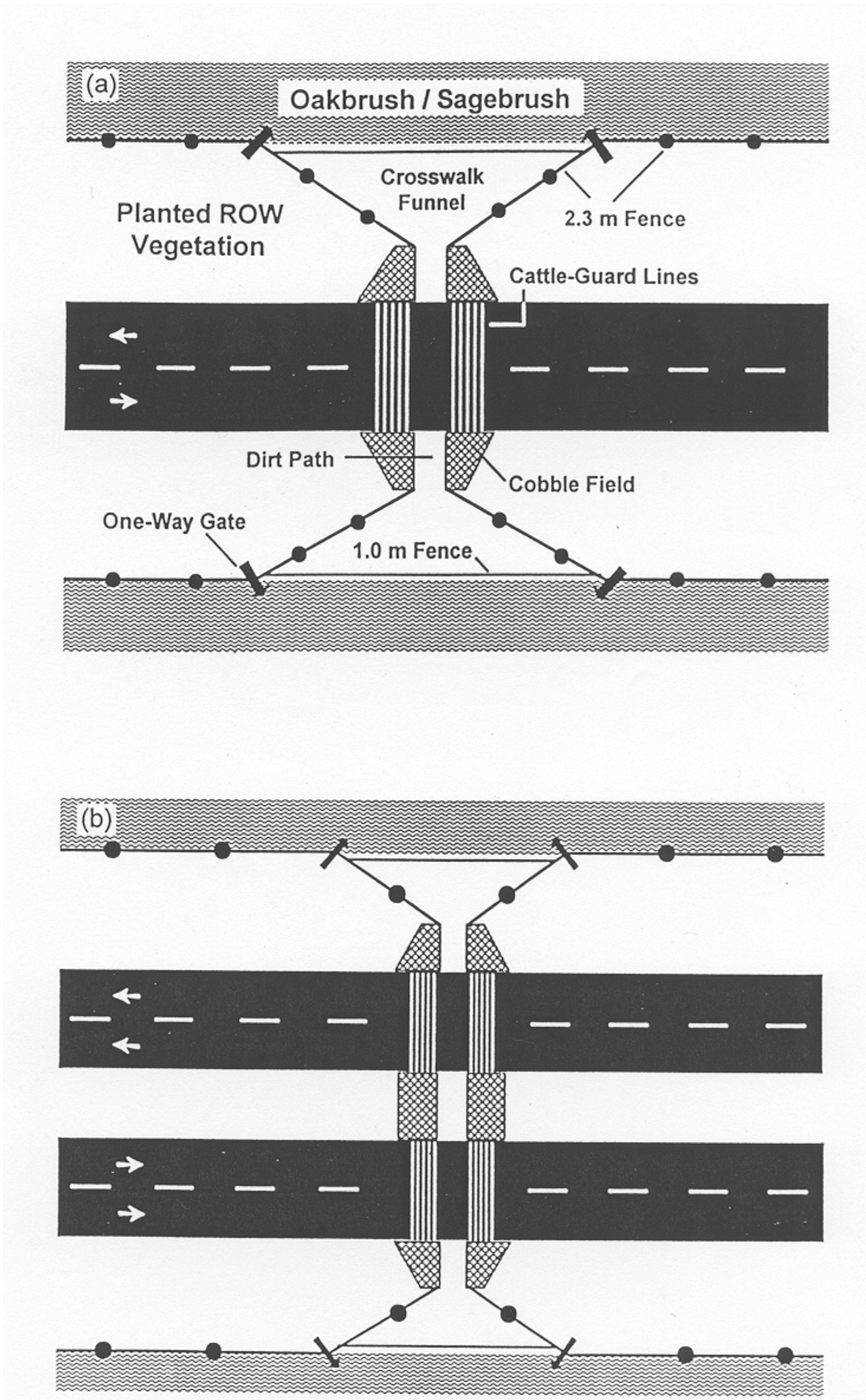

Figure H-1. Major Crosswalk Features on (a) Two-Lane Highways and (b) Four-Lane Highways (*11*).

crosswalk to enable deer that became trapped along the highway corridor to escape to the right-of-way.

This study represents the initial implementation and testing of the crosswalk system. The crosswalks were used because they could be easily installed along the existing roadways at one-sixth the cost required to excavate tunnels and install underpasses. Observations of deer successfully crossing within crosswalk boundaries, the apparent maintenance of migratory behavior, and reduced deer use of the highway right-of-way indicate the system warrants further testing. This study also identified problems in the original design so that modification can be made (*11*).

LARGE MAMMALS

The Bow River Valley is rich in natural, wildland resources, particularly wildlife. Banff National Park has 54 species of mammals and 280 species of birds. The TransCanada Highway (TCH) has directly impacted many of these species of wildlife or affected their habitats. Original construction in the 1950s had realigned the river in numerous locations. When planning to upgrade the roadway, it was clear that environmental protection would be a major objective and a scientific challenge (*12*).

Elk, mule and white-tailed deer, moose, black bears, coyotes, bighorn sheep, and smaller mammals, such as pine squirrels and hare, were regularly killed on the highway. Occasionally, grizzly bear, wolf, wolverine, lynx, marten, porcupine, hawk, owl, and others were struck (*12*). Banff National Park and Alberta Provincial records (Alberta, Canada) have documented the number of carnivores killed in vehicle collision in the past 10 years (see Table H-1). This must be considered a minimum as the animals that were hit but never found have not been recorded.

It was decided to fence both sides of the new roadway with an 8-ft (2.4 m) high page wire fence. A system of 10 wildlife underpasses was also installed in an effort to mitigate wildlife crashes. Texas gates and stiles were used to allow unimpeded vehicular and pedestrian passage through the fences. One-way and conventional gates were installed for wildlife management actions. Fish habitat was recreated where major fish-bearing streams were impacted. Underpasses varied from conventional, bridge-like concrete structures with 42.8-ft (13 m) span openings and 13.2-ft (4 m) headway to 13.2-ft (4 m) circular culverts and 13.2 ft (4 m) by 23.0 ft (7 m) elliptical multiplate culverts. Underpasses varied depending on the centerline to centerline separation of the roadway. By 1990, 19.3 mi (31 km) of twinned highway and 10 underpasses had been constructed.

The research revealed the fences to be highly effective in reducing wildlife collisions—over 94 percent for elk. Other large species were similar. Detailed research of deer has not been pursued although tracking beds show that deer use the underpasses. Most other highly transient species, such as wolf, grizzly and black bear, bighorn sheep, coyote, lynx, and some small mammals, have been recorded using the underpasses (*12*). However, problems have been identified and several unexpected wildlife impact occurrences were recorded.

Table H-1. Highway and Railway Mortality of Large Carnivores in the Bow River Valley, Alberta, Canada (*12*).

Species	Inside Banff National Park		Outside Banff National Park		Total
	Highway	Rail	Highway	Rail	
Coyote	117	7	39	1	164
Black bear	12	5	8	2	27
Cougar	1	0	2	0	3
Grizzly bear	1	0	0	0	1
Wolverine	2	0	0	0	2
Lynx	0	0	4	0	4

TORTOISES AND SMALL VERTEBRATES

Roads and highways impact tortoise populations through restriction of movement in addition to direct mortality and facilitating illegal collections. Because there are many roads and highways through the habitat of the desert tortoise, the potential for road kills to affect tortoise populations is high. Consequently, reducing road kills could help to facilitate recovery of tortoise populations. Barrier fences are a potential mitigation measure, but they also increase population fragmentation. Culverts beneath the roadway may reduce fragmentation by facilitating movements of tortoises between both sides of the road (*13*).

A scientific research project was designed to learn the effectiveness of a highway barrier fence built to aid in the recovery of desert tortoise population along California State Highway 58 (Hwy 58) in the western Mojave Desert of California. In 1990, the California Department of Transportation (CalTrans) erected tortoise-barrier fencing along a section of Hwy 58 that was scheduled for widening from two lanes to four lanes. Several agencies joined the cooperative monitoring project to learn the effectiveness of protective fencing and culverts. The 14.9 mi (24 km) long fence consists of 2-ft (60 cm) wide, 0.5-ft (1.3 cm) mesh, galvanized steel, hardware cloth that is buried to 5.9 inches (15 cm) beneath ground level and extends 17.7 inches (45 cm) above the ground. The fence is supported by a six-strand wire fence; the top three strands are barbed to inhibit access by humans and livestock, and the three bottom strands are unbarbed to allow easy installation of the hardware cloth and to allow medium-sized mammals to climb over without being injured. The bottom two strands are placed beneath the top of the hardware cloth to provide structural support to the cloth. The wires are attached to the cloth by steel rings. The fence is held up by 6.6-ft (2 m) t-bars spaced approximately 9.9 ft (3 m) apart. Gates, which are required to allow access to private property along the highway edge, were also designed as barriers to tortoises. The same hardware cloth that is used on the fence is separately attached to the lower part of the gate. The gates are hung close to the ground and flush to 7.9 inches (20 cm) by 7.9 inches (20 cm) wood beams buried between gate posts to prevent tortoises from escaping under the gates.

Twenty-four culverts that span the entire width of the highway are in place and are all designed for rainwater runoff. In August 1992, the fence on Hwy 58 was attached in funnel fashion to storm-drain culverts to facilitate movements by tortoises under the highway. The culverts are made of 3 ft (0.9 m) to 4.9 ft (1.5 m) diameter corrugated steel pipe, 4.6 ft (1.4 m) diameter reinforced concrete pipe, or 9.9 ft (3 m) to 11.8 ft (3.6 m) by 5.9 ft (1.8 m) to 9.9 ft (3 m) reinforced concrete boxes. The culverts are 109 ft (33 m) to 217 ft (66 m) long.

Researchers conducted surveys in July of 1992, 1993, and 1994 and recorded the identity and location of all animal carcasses. A total of 1080 carcasses were found, including 36 tortoise carcasses. Researchers searched for the carcasses along a 14.9-mi (24 km) section of fenced highway and along a 14.9-mi (24 km) section of unfenced highway. They found 88 percent fewer vertebrate carcasses and 93 percent fewer tortoise carcasses along the fenced section of highway. These differences were highly significant and indicate that the fence was very successful at reducing road mortality. However, in 1995, several tortoises were killed along the fenced section of Hwy 58, all within 0.3-mi (0.5 km) gaps in the fence. Most of the gaps were due to poor maintenance, indicating that proper maintenance of the fence is critical to its success.

The results indicate that, when new or properly maintained, the barrier fence was effective in greatly reducing highway mortality in several species of vertebrates, including the threatened tortoise. However, tortoises can escape from relatively small gaps in improperly installed or maintained fences and gates. Tortoises and other vertebrates also used culverts, but it has not yet been determined whether their use will reduce the fragmenting effects of the fence and highway. Culvert use is expected to increase with time as more animals settle near and discover the culverts (*13*).

BROWN PELICANS

The Texas Department of Transportation (TxDOT) is continuing efforts to eliminate the accidental deaths and injuries of endangered brown pelicans on the Queen Isabella Causeway. The Queen Isabella Causeway is a 2.4-mi (3.9 km) long, four-lane bridge connecting Port Isabel and South Padre Island. The bridge center span rises 84 ft (25.6 m) above the Gulf Intercostal Waterway (*14*).

The eastern brown pelican is a large bird with an average weight of 7.5 lb (2.8 kg), a body length of 4 ft (1.2 m), and a wingspan of 6.5 ft (2 m). It flies 14 to 35 mph (12 to 56 km/h), often with slow wing beats close to the water. The brown pelican is a coastal resident that seldom strays inland. These large birds land on the Queen Isabella Causeway and are sometimes struck by vehicles.

The first reported death of a brown pelican on the Causeway was in September 1984. Since then, a number of brown pelican deaths have been documented between September and early March each year. The increasing traffic mortality of the endangered birds prompted a 1988-1990 study by the Texas Transportation Institute. This study, coupled with wind tunnel studies of the airflow around models of the bridge, led to the conclusion that the mortalities result from a combination of several factors:

- an increase in pelican population,
- flight patterns of the birds as they fly to roosting sites in the evening,
- the occasional presence of strong northerly winds and inclement weather, and
- air flow patterns above the bridge deck.

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 especially indicates a connection between pelican deaths and the passage of cold fronts accompanied by strong wind (northers). 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.

As a result of meetings with many interested agencies and recommendations from the 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.
- 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 pelican 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.

In addition, 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 provided 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 installation of weather monitoring devices to detect northers (*14*).

BATS

Although not directly related to wildlife crashes, TxDOT has initiated a study of bats and bridges. The knowledge developed in the Bats and Bridges Study is helping to define how to include bats in a new bridge design where appropriate and to exclude them where not desired (*14*).

OCELOTS

The ocelot is a medium-sized, spotted and blotched cat with a moderately long tail and is a federally listed endangered species. The cats once ranged over the southern part of Texas with occasional records from north and central Texas, but they are now restricted to several isolated patches of suitable habitat in three or four counties of the Rio Grande Plains.

The major cause of mortality for the ocelot population has been ocelot-automobile collisions. In 1993, TxDOT proposed improvements to State Highway 100 in Cameron County, Texas. Due to reported ocelot sightings (transportation-related mortalities) in the area, TxDOT worked in cooperation with wildlife agencies regarding the concern for the ocelot population.

A 48-in (122 cm) pipe culvert in a drainage ditch containing suitable habitat for the ocelot was installed adjacent to an 8 ft (2.4 m) by 5 ft (1.5 m) box culvert and was placed above the usual plane of high water. A 1 ft (0.3 m) wide concrete cat ramp at each end of the culvert was built from the entrance to the edge of the ditch below the level of the berm. Brush was allowed to revegetate the area immediately adjacent to the rip-rap, and a no mow area was established on either side of the culvert. Finally, a hog-wire fence was constructed after highway construction was completed.

TxDOT has installed several ocelot crossings throughout the southern portion of the state. Research is being proposed to ascertain the efficiency of the structures (*14*).

FLORIDA PANTHERS AND OTHER WILDLIFE IN SOUTHWEST FLORIDA

A contiguous system of wild lands is necessary to accommodate the spatial needs of the Florida panther population. Adult male and female panthers maintain home ranges of >193 sq mi (500 sq km) and >73 sq mi (190 sq km), respectively, with limited overlap among males. These home ranges often include many miles of improved roads that are regularly traversed. Road-kill mortality can be expected among panthers as a result of the interspersion of roads with panther habitat (*15*).

Efforts to reduce this unnatural source of mortality have included the creation of nighttime speed reduction zones, installation of special roadside headlight reflections, and adding rumble strips to the highway surface. However, a more ambitious project was completed when State Road 84 was converted to Interstate 75.

Locations of previous road-kills and knowledge of where radio-instrumented panthers crossed this busy highway were used to incorporate 24 wildlife underpasses into the highway conversion design. These strategically placed structures offer safe passage to wildlife that is beneath the flow of traffic. Use of these underpasses was encouraged by erecting an 11.2-ft (3.4 m) chain-link fence topped with three strands of outrigged barbed wire along the 40.4-mi (65 km) stretch of interstate that runs through panther habitat. A second wildlife crossing design was developed for State Road (SR) 29, a two-lane highway running through panther habitat. The crossings on SR 29 consisted of a pre-formed box culvert 7.9 ft (2.4 m) high, 24 ft (7.3 m) wide, and 48 ft (14.6 m) long. The culverts rest at ground level, and the roadway gradually rises over the culverts. The crossing also includes a concrete span that forms a bridge across the adjacent canal. The surface of the span contains a layer of soil to support growth of natural vegetation. This crossing was installed at two critical areas. The SR 29 corridor with the installed crossings was fenced similarly to I-75.

The objectives were to evaluate the effectiveness of the underpass design installed on SR 29 and to compare the use to the I-75 wildlife crossings. Both designs of wildlife crossings have been used by Florida panthers and a host of other animal species. The I-75 wildlife crossings with their openness and creation of early successional habitat may have encouraged use by white-tailed deer. The more shaded, cooler, and damper SR 29 structures may have created ideal habitat for raccoon prey items, accounting for the heavy use by these mammals. It appears that either wildlife crossing design will be successful when placed at sites where animals habitually cross (*15*).

REVIEW OF VEHICLE-ANIMAL CRASHES

The recent review of vehicle-animal crashes developed the following recommendations for additional consideration (*4*):

- Policies for installing deer warning signs should be reviewed to limit their use to locations with significant deer crash problems or areas with high deer activity. In this way, the signs may become more meaningful for alerting drivers to potentially dangerous situations.
- Warning reflectors should be further evaluated as a low-cost countermeasure.
- Other, more sophisticated roadway- or vehicle-based detection devices should be considered in the development and operational testing of rural intelligent transportation system applications.
- Driver education classes in areas with high vehicle-animal crashes should include information on the patterns of animal crashes. If drivers are conditioned to expect a higher chance of encountering deer during November or early morning and early nighttime, they may be better prepared to react to such a sudden encounter.

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Several sources of information are available on work zones including the National Work Zone Safety Information Clearinghouse (*1*). Opened in February 1998, the clearinghouse is a cooperative venture between the Federal Highway Administration and ARTBA to improve safety at roadway construction sites. The clearinghouse is operated and maintained by the Texas Transportation Institute and includes an interactive Internet website, on-site research personnel, and customer service representatives. Besides FHWA, ARTBA, and TTI, the clearinghouse is being sponsored by the American Association of State Highway and Transportation Officials, the Laborers' International Union of North America, CNA Commercial Insurance, the International Municipal Signal Association, the National Association of County Engineers, and Lanford Bros. Company. Marketing partners include the National Utility Contractors Association and the Institute of Traffic Engineers. The URL is http://wzsafety.tamu.edu/ and the e-mail is workzone@tamu.edu.

While the clearinghouse receives a number of phone and fax requests for information, it is the website that services many requests – now receiving over 5000 hits a month. The site includes five searchable databases on key contact personnel, safety practices, available technologies, research results, and safety training courses and programs. Besides links to other related sites, the site now offers many materials and even some full reports online.

A TxDOT study produced a catalog of effective treatments to improve driver and worker safety at short-term work zones on rural highways (*2*). The catalog provides a brief description of each treatment, along with a summary of the treatment's effectiveness, and recommendations for its use at short-term work zones. Devices that were found to be effective included:

- fluorescent yellow-green worker vests and hard hat covers,
- portable variable message signs,
- speed display trailers,
- fluorescent orange roll-up signs,
- radar drones, and
- retroreflective magnetic strips for worker vehicles.

APPENDIX I: WORK ZONES

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CRASH FREQUENCIES AND DISTRIBUTIONS FOR ON-SYSTEM, RURAL TWO-LANE HIGHWAYS BY AREA TYPE AND VOLUME

Data Source: Traffic Accident Database, Texas Department of Public Safety, 1997 to 1999, Low-Volume (ADT≤ 2000), Rural Two-Lane Highways

Table J-1. Crashes by Accident Severity.

Dev, ADT	ACCIDENT SEVERITY			
Frequency Percent Row Percent Col Percent	**Non-incapacitating Injury**	**Incapacitating Injury**	**Fatal**	**TOTAL**
RURAL, ADT<=2K	**8930**	**4348**	**1344**	**14,622**
	18.55	9.03	2.79	30.38
	61.07	29.74	9.19	
	28.49	32.86	37.78	
RURAL, ADT=2-6K	**8842**	**4128**	**1229**	**14,199**
	18.37	8.58	2.55	29.50
	62.27	29.07	8.66	
	28.21	31.20	34.55	
RURAL, ADT>6K	4413	1834	521	**6768**
	9.17	3.81	1.08	14.06
	65.20	27.10	7.70	
	14.08	13.86	14.65	
URBAN, ADT<=2K	**393**	**164**	**45**	**602**
	0.82	0.34	0.09	1.25
	65.28	27.24	7.48	
	1.25	1.24	1.27	
URBAN, ADT=2-6K	**2328**	**834**	**138**	**3300**
	4.84	1.73	0.29	6.86
	70.55	25.27	4.18	
	7.43	6.30	3.88	
URBAN, ADT>6K	**6436**	**1922**	**280**	**8638**
	13.37	3.99	0.58	17.95
	74.51	22.25	3.24	
	20.53	14.53	7.87	
TOTAL	**31,342**	**13,230**	**3557**	**48,129**
	65.12	**27.49**	**7.39**	**100**

Table J-2. Crashes by Intersection Related.

Dev, ADT	INTERSECTION RELATED				
Frequency Percent Row Percent Col Percent	Intersection	Intersection Related	Driveway Access	Non Intersection	TOTAL
RURAL, ADT<=2K	**2248**	**1346**	**1269**	**9759**	**14,622**
	4.67	2.80	2.64	20.28	30.38
	15.37	9.21	8.68	66.74	
	19.47	22.85	20.98	39.60	
RURAL, ADT=2-6K	**2942**	**1479**	**1896**	**7882**	**14,199**
	6.11	3.07	3.94	16.38	29.50
	20.72	10.42	13.35	55.51	
	25.48	25.11	31.34	31.99	
RURAL, ADT>6K	**1612**	**917**	**1188**	**3051**	**6768**
	3.35	1.91	2.47	6.34	14.06
	23.82	13.55	17.55	45.08	
	13.96	15.57	19.64	12.38	
URBAN, ADT<=2K	**230**	**84**	**58**	**230**	**602**
	0.48	0.17	0.12	0.48	1.25
	38.21	13.95	9.63	38.21	
	1.99	1.43	0.96	0.93	
URBAN, ADT=2-6K	**1256**	**548**	**378**	**1118**	**3300**
	2.61	1.14	0.79	2.32	6.86
	38.06	16.61	11.45	33.88	
	10.88	9.30	6.25	4.54	
URBAN, ADT>6K	**3259**	**1516**	**1261**	**2602**	**8638**
	6.77	3.15	2.62	5.41	17.95
	37.73	17.55	14.60	30.12	
	28.22	25.74	20.84	10.56	
TOTAL	**11,547**	**5890**	**6050**	**24,642**	**48,129**
	23.99	**12.24**	**12.57**	**51.20**	**100**

Table J-3. Crashes by First Harmful Event.

Dev, ADT	FIRST HARMFUL EVENT					
Frequency Percent Row Percent Col Percent	Other Non-Collision	Overturned	Pedestrian	Other Motor Vehicle in Transit	RR Train	Parked Car
RURAL, ADT<=2K	**122**	**4209**	**145**	**4548**	**35**	**72**
	0.25	8.75	0.30	9.45	0.07	0.15
	0.83	28.79	0.99	31.10	0.24	0.49
	36.53	52.92	17.79	17.68	46.05	21.24
RURAL, ADT=2-6K	**104**	**2352**	**211**	**7237**	**24**	**111**
	0.22	4.89	0.44	15.04	0.05	0.23
	0.73	16.56	1.49	50.97	0.17	0.78
	31.14	29.57	25.89	28.13	31.58	32.74
RURAL, ADT>6K	**31**	**615**	**134**	**4586**	**2**	**81**
	0.06	1.28	0.28	9.53	0.00	0.17
	0.46	9.09	1.98	67.76	0.03	1.20
	9.28	7.73	16.44	17.83	2.63	23.89
URBAN, ADT<=2K	**6**	**83**	**7**	**351**	**2**	**1**
	0.01	0.17	0.01	0.73	0.00	0.00
	1.00	13.79	1.16	58.31	0.33	0.17
	1.80	1.04	0.86	1.36	2.63	0.29
URBAN, ADT=2-6K	**23**	**294**	**63**	**2199**	**4**	**31**
	0.05	0.61	0.13	4.57	0.01	0.06
	0.70	8.91	1.91	66.64	0.12	0.94
	6.89	3.70	7.73	8.55	5.26	9.14
URBAN, ADT>6K	**48**	**401**	**255**	**6805**	**9**	**43**
	0.10	0.83	0.53	14.14	0.02	0.09
	0.56	4.64	2.95	78.78	0.10	0.50
	14.37	5.04	31.29	26.45	11.84	12.68
TOTAL	**334**	**7954**	**815**	**25,726**	**76**	**339**
	0.69	**16.53**	**1.69**	**53.45**	**0.16**	**0.70**

Table J-3. Crashes by First Harmful Event (continued).

Dev, ADT	FIRST HARMFUL EVENT				
Frequency Percent Row Percent Col Percent	Pedalcyclist	Animal	Fixed Object	Other Object	TOTAL
RURAL, ADT<=2K	**71**	**637**	**4739**	**44**	**14,622**
	0.15	1.32	9.85	0.09	30.38
	0.49	4.36	32.41	0.30	
	18.49	51.21	42.55	36.97	
RURAL, ADT=2-6K	**77**	**401**	**3645**	**37**	**14,199**
	0.16	0.83	7.57	0.08	29.50
	0.54	2.82	25.67	0.26	
	20.05	32.23	32.73	31.09	
RURAL, ADT>6K	**53**	**101**	**1152**	**13**	**6768**
	0.11	0.21	2.39	0.03	14.06
	0.78	1.49	17.02	0.19	
	13.80	8.12	10.34	10.92	
URBAN, ADT<=2K	**8**	**6**	**138**	**0**	**602**
	0.02	0.01	0.29	0.00	1.25
	1.33	1.00	22.92	0.00	
	2.08	0.48	1.24	0.00	
URBAN, ADT=2-6K	**53**	**52**	**574**	**7**	**3300**
	0.11	0.11	1.19	0.01	6.86
	1.61	1.58	17.39	0.21	
	13.80	4.18	5.15	5.88	
URBAN, ADT>6K	**122**	**47**	**890**	**18**	**8638**
	0.25	0.10	1.85	0.04	17.95
	1.41	0.54	10.30	0.21	
	31.77	3.78	7.99	15.13	
TOTAL	**384**	**1244**	**11,138**	**119**	**48,129**
	0.80	**2.58**	**23.14**	**0.25**	**100.00**

Table J-4. Crashes by Object Struck.

Dev, ADT	OBJECT STRUCK						
Frequency Percent Row Percent Col Percent	No Code Applicable	Vehicle Over-turned	Hole in Road	Vehicle Jack-knifed	Person Fell or Jumped from Vehicle	Vehicle Hit Train on Parallel Tracks	Train Moving Forward
RURAL, ADT<=2K	**7261**	**230**	**8**	**33**	**68**	**1**	**34**
	15.09	0.48	0.02	0.07	0.14	0.00	0.07
	49.66	1.57	0.05	0.23	0.47	0.01	0.23
	23.99	27.28	61.54	27.50	41.98	25.00	45.95
RURAL, ADT=2-6K	**8439**	**278**	**4**	**48**	**42**	**3**	**22**
	17.53	0.58	0.01	0.10	0.09	0.01	0.05
	59.43	1.96	0.03	0.34	0.30	0.02	0.15
	27.88	32.98	30.77	40.00	25.93	75.00	29.73
RURAL, ADT>6K	**4843**	**145**	**0**	**21**	**14**	**0**	**3**
	10.06	0.30	0.00	0.04	0.03	0.00	0.01
	71.56	2.14	0.00	0.31	0.21	0.00	0.04
	16.00	17.20	0.00	17.50	8.64	0.00	4.05
URBAN, ADT<=2K	**379**	**12**	**1**	**2**	**4**	**0**	**2**
	0.79	0.02	0.00	0.00	0.01	0.00	0.00
	62.96	1.99	0.17	0.33	0.66	0.00	0.33
	1.25	1.42	7.69	1.67	2.47	0.00	2.70
URBAN, ADT=2-6K	**2361**	**52**	**0**	**4**	**13**	**0**	**4**
	4.91	0.11	0.00	0.01	0.03	0.00	0.01
	71.55	1.58	0.00	0.12	0.39	0.00	0.12
	7.80	6.17	0.00	3.33	8.02	0.00	5.41
URBAN, ADT>6K	**6986**	**126**	**0**	**12**	**21**	**0**	**9**
	14.52	0.26	0.00	0.02	0.04	0.00	0.02
	80.88	1.46	0.00	0.14	0.24	0.00	0.10
	23.08	14.95	0.00	10.00	12.96	0.00	12.16
TOTAL	**30,269**	**843**	**13**	**120**	**162**	**4**	**74**
	62.89	**1.75**	**0.03**	**0.25**	**0.34**	**0.01**	**0.15**

Table J-4. Crashes by Object Struck (continued).

Dev, ADT	OBJECT STRUCK						
Frequency Percent Row Percent Col Percent	Train Backing	Train Standing Still	Train/ Action Unknown	Highway Sign	Curb	Culvert/ Headwall	Guardrail
RURAL, ADT<=2K	**0**	**1**	**0**	**546**	**14**	**727**	**173**
	0.00	0.00	0.00	1.13	0.03	1.51	0.36
	0.00	0.01	0.00	3.73	0.10	4.97	1.18
	0.00	33.33	0.00	37.22	15.73	43.20	26.57
RURAL, ADT=2-6K	**2**	**2**	**0**	**472**	**14**	**583**	**241**
	0.00	0.00	0.00	0.98	0.03	1.21	0.50
	0.01	0.01	0.00	3.32	0.10	4.11	1.70
	100.00	66.67	0.00	32.17	15.73	34.64	37.02
RURAL, ADT>6K	**0**	**0**	**1**	**172**	**8**	**198**	**114**
	0.00	0.00	0.00	0.36	0.02	0.41	0.24
	0.00	0.00	0.01	2.54	0.12	2.93	1.68
	0.00	0.00	100.00	11.72	8.99	11.76	17.51
URBAN, ADT<=2K	**0**	**0**	**0**	**28**	**1**	**14**	**6**
	0.00	0.00	0.00	0.06	0.00	0.03	0.01
	0.00	0.00	0.00	4.65	0.17	2.33	1.00
	0.00	0.00	0.00	1.91	1.12	0.83	0.92
URBAN, ADT=2-6K	**0**	**0**	**0**	**91**	**6**	**73**	**39**
	0.00	0.00	0.00	0.19	0.01	0.15	0.08
	0.00	0.00	0.00	2.76	0.18	2.21	1.18
	0.00	0.00	0.00	6.20	6.74	4.34	5.99
URBAN, ADT>6K	**0**	**0**	**0**	**158**	**46**	**88**	**78**
	0.00	0.00	0.00	0.33	0.10	0.18	0.16
	0.00	0.00	0.00	1.83	0.53	1.02	0.90
	0.00	0.00	0.00	10.77	51.69	5.23	11.98
TOTAL	**2**	**3**	**1**	**1467**	**89**	**1683**	**651**
	0.00	**0.01**	**0.00**	**3.05**	**0.18**	**3.50**	**1.35**

Table J-4. Crashes by Object Struck (continued).

Dev, ADT	OBJECT STRUCK						
Frequency Percent Row Percent Col Percent	RR Signal Pole	RR Crossing Gates	Signal Pole/Post	Signal Light/Wires	Work Zone Barricade	Luminaire Pole	Utility Pole
RURAL, ADT<=2K	**8**	**3**	**13**	**0**	**3**	**16**	**300**
	0.02	0.01	0.03	0.00	0.01	0.03	0.62
	0.05	0.02	0.09	0.00	0.02	0.11	2.05
	33.33	37.50	12.62		8.33	13.01	28.22
RURAL, ADT=2-6K	**8**	**1**	**14**	**0**	**10**	**19**	**308**
	0.02	0.00	0.03	0.00	0.02	0.04	0.64
	0.06	0.01	0.10	0.00	0.07	0.13	2.17
	33.33	12.50	13.59		27.78	15.45	28.97
RURAL, ADT>6K	**2**	**2**	**5**	**0**	**10**	**17**	**146**
	0.00	0.00	0.01	0.00	0.02	0.04	0.30
	0.03	0.03	0.07	0.00	0.15	0.25	2.16
	8.33	25.00	4.85		27.78	13.82	13.73
URBAN, ADT<=2K	**0**	**0**	**1**	**0**	**0**	**2**	**24**
	0.00	0.00	0.00	0.00	0.00	0.00	0.05
	0.00	0.00	0.17	0.00	0.00	0.33	3.99
	0.00	0.00	0.97		0.00	1.63	2.26
URBAN, ADT=2-6K	**4**	**1**	**14**	**0**	**3**	**17**	**85**
	0.01	0.00	0.03	0.00	0.01	0.04	0.18
	0.12	0.03	0.42	0.00	0.09	0.52	2.58
	16.67	12.50	13.59		8.33	13.82	8.00
URBAN, ADT>6K	**2**	**1**	**56**	**0**	**10**	**52**	**200**
	0.00	0.00	0.12	0.00	0.02	0.11	0.42
	0.02	0.01	0.65	0.00	0.12	0.60	2.32
	8.33	12.50	54.37		27.78	42.28	18.81
TOTAL	**24**	**8**	**103**	**0**	**36**	**123**	**1063**
	0.05	**0.02**	**0.21**	**0.00**	**0.07**	**0.26**	**2.21**

Table J-4. Crashes by Object Struck (continued).

Dev, ADT	OBJECT STRUCK						
Frequency Percent Row Percent Col Percent	Mailbox	Tree/Shrub	Fence	House/ Building	Commercial Sign	Other Fixed Object	Maintenance Barricade or Materials
RURAL, ADT<=2K	**165**	**1411**	**1972**	**44**	**7**	**338**	**2**
	0.34	2.93	4.10	0.09	0.01	0.70	0.00
	1.13	9.65	13.49	0.30	0.05	2.31	0.01
	37.41	46.31	51.37	30.99	14.89	38.11	28.57
RURAL, ADT=2-6K	**154**	**1041**	**1218**	**44**	**8**	**261**	**1**
	0.32	2.16	2.53	0.09	0.02	0.54	0.00
	1.08	7.33	8.58	0.31	0.06	1.84	0.01
	34.92	34.16	31.73	30.99	17.02	29.43	14.29
RURAL, ADT>6K	**70**	**255**	**283**	**14**	**8**	**114**	**3**
	0.15	0.53	0.59	0.03	0.02	0.24	0.01
	1.03	3.77	4.18	0.21	0.12	1.68	0.04
	15.87	8.37	7.37	9.86	17.02	12.85	42.86
URBAN, ADT<=2K	**4**	**34**	**47**	**3**	**0**	**5**	**0**
	0.01	0.07	0.10	0.01	0.00	0.01	0.00
	0.66	5.65	7.81	0.50	0.00	0.83	0.00
	0.91	1.12	1.22	2.11	0.00	0.56	0.00
URBAN, ADT=2-6K	**19**	**150**	**140**	**14**	**9**	**58**	**0**
	0.04	0.31	0.29	0.03	0.02	0.12	0.00
	0.58	4.55	4.24	0.42	0.27	1.76	0.00
	4.31	4.92	3.65	9.86	19.15	6.54	0.00
URBAN, ADT>6K	**29**	**156**	**179**	**23**	**15**	**111**	**1**
	0.06	0.32	0.37	0.05	0.03	0.23	0.00
	0.34	1.81	2.07	0.27	0.17	1.29	0.01
	6.58	5.12	4.66	16.20	31.91	12.51	14.29
TOTAL	**441**	**3047**	**3839**	**142**	**47**	**887**	**7**
	0.92	**6.33**	**7.98**	**0.30**	**0.10**	**1.84**	**0.01**

Table J-4. Crashes by Object Struck (continued).

Dev, ADT	OBJECT STRUCK						
Frequency Percent Row Percent Col Percent	Median Barrier	End of Bridge	Side of Bridge	Pier at Underpass	Top of Underpass	Bridge Crossing Gate	Attenuation Device
RURAL, ADT<=2K	**7**	**62**	**163**	**5**	**0**	**0**	**0**
	0.01	0.13	0.34	0.01	0.00	0.00	0.00
	0.05	0.42	1.11	0.03	0.00	0.00	0.00
	14.29	40.26	33.00	22.73	0.00		0.00
RURAL, ADT=2-6K	**5**	**64**	**209**	**4**	**0**	**0**	**1**
	0.01	0.13	0.43	0.01	0.00	0.00	0.00
	0.04	0.45	1.47	0.03	0.00	0.00	0.01
	10.20	41.56	42.31	18.18	0.00		12.50
RURAL, ADT>6K	**7**	**17**	**55**	**3**	**0**	**0**	**4**
	0.01	0.04	0.11	0.01	0.00	0.00	0.01
	0.10	0.25	0.81	0.04	0.00	0.00	0.06
	14.29	11.04	11.13	13.64	0.00		50.00
URBAN, ADT<=2K	**1**	**1**	**7**	**0**	**0**	**0**	**0**
	0.00	0.00	0.01	0.00	0.00	0.00	0.00
	0.17	0.17	1.16	0.00	0.00	0.00	0.00
	2.04	0.65	1.42	0.00	0.00		0.00
URBAN, ADT=2-6K	**2**	**5**	**19**	**5**	**0**	**0**	**0**
	0.00	0.01	0.04	0.01	0.00	0.00	0.00
	0.06	0.15	0.58	0.15	0.00	0.00	0.00
	4.08	3.25	3.85	22.73	0.00		0.00
URBAN, ADT>6K	**27**	**5**	**41**	**5**	**1**	**0**	**3**
	0.06	0.01	0.09	0.01	0.00	0.00	0.01
	0.31	0.06	0.47	0.06	0.01	0.00	0.03
	55.10	3.25	8.30	22.73	100.00		37.50
TOTAL	**49**	**154**	**494**	**22**	**1**	**0**	**8**
	0.10	**0.32**	**1.03**	**0.05**	**0.00**	**0.00**	**0.02**

Table J-4. Crashes by Object Struck (continued).

Dev, ADT	OBJECT STRUCK						
Frequency Percent Row Percent Col Percent	Rocks from Trucks	Debris on Road	Object from Another Vehicle	Previously Wrecked Vehicle	Other Machinery	Other Object	Concrete Traffic Barrier
RURAL, ADT<=2K	**0**	**12**	**6**	**19**	**5**	**37**	**3**
	0.00	0.02	0.01	0.04	0.01	0.08	0.01
	0.00	0.08	0.04	0.13	0.03	0.25	0.02
		52.17	37.50	24.05	27.78	37.76	15.00
RURAL, ADT=2-6K	**0**	**8**	**5**	**30**	**5**	**28**	**3**
	0.00	0.02	0.01	0.06	0.01	0.06	0.01
	0.00	0.06	0.04	0.21	0.04	0.20	0.02
		34.78	31.25	37.97	27.78	28.57	15.00
RURAL, ADT>6K	**0**	**2**	**3**	**12**	**1**	**15**	**4**
	0.00	0.00	0.01	0.02	0.00	0.03	0.01
	0.00	0.03	0.04	0.18	0.01	0.22	0.06
		8.70	18.75	15.19	5.56	15.31	20.00
URBAN, ADT<=2K	**0**	**0**	**0**	**1**	**0**	**0**	**0**
	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.17	0.00	0.00	0.00
		0.00	0.00	1.27	0.00	0.00	0.00
URBAN, ADT=2-6K	**0**	**1**	**0**	**3**	**0**	**7**	**1**
	0.00	0.00	0.00	0.01	0.00	0.01	0.00
	0.00	0.03	0.00	0.09	0.00	0.21	0.03
		4.35	0.00	3.80	0.00	7.14	5.00
URBAN, ADT>6K	**0**	**0**	**2**	**14**	**7**	**11**	**9**
	0.00	0.00	0.00	0.03	0.01	0.02	0.02
	0.00	0.00	0.02	0.16	0.08	0.13	0.10
		0.00	12.50	17.72	38.89	11.22	45.00
TOTAL	**0**	**23**	**16**	**79**	**18**	**98**	**20**
	0.00	**0.05**	**0.03**	**0.16**	**0.04**	**0.20**	**0.04**

Table J-4. Crashes by Object Struck (continued).

Dev, ADT	OBJECT STRUCK							
Frequency Percent Row Percent Col Percent	Delineator Post	Retaining Wall	HOV Lane Gate	Guard Post	Fire Hydrant	Ditch (Earth)	Embank-ment	TOTAL
RURAL, ADT<=2K	**189**	**7**	**0**	**2**	**3**	**359**	**365**	**14,622**
	0.39	0.01	0.00	0.00	0.01	0.75	0.76	30.38
	1.29	0.05	0.00	0.01	0.02	2.46	2.50	
	60.19	36.84		33.33	9.68	40.56	49.06	
RURAL, ADT=2-6K	**80**	**3**	**0**	**1**	**5**	**265**	**246**	**14,199**
	0.17	0.01	0.00	0.00	0.01	0.55	0.51	29.50
	0.56	0.02	0.00	0.01	0.04	1.87	1.73	
	25.48	15.79		16.67	16.13	29.94	33.06	
RURAL, ADT>6K	**20**	**2**	**0**	**2**	**5**	**102**	**66**	**6768**
	0.04	0.00	0.00	0.00	0.01	0.21	0.14	14.06
	0.30	0.03	0.00	0.03	0.07	1.51	0.98	
	6.37	10.53		33.33	16.13	11.53	8.87	
URBAN, ADT<=2K	**5**	**0**	**0**	**0**	**1**	**8**	**9**	**602**
	0.01	0.00	0.00	0.00	0.00	0.02	0.02	1.25
	0.83	0.00	0.00	0.00	0.17	1.33	1.50	
	1.59	0.00		0.00	3.23	0.90	1.21	
URBAN, ADT=2-6K	**4**	**1**	**0**	**1**	**7**	**60**	**27**	**3300**
	0.01	0.00	0.00	0.00	0.01	0.12	0.06	6.86
	0.12	0.03	0.00	0.03	0.21	1.82	0.82	
	1.27	5.26		16.67	22.58	6.78	3.63	
URBAN, ADT>6K	**16**	**6**	**0**	**0**	**10**	**91**	**31**	**8638**
	0.03	0.01	0.00	0.00	0.02	0.19	0.06	17.95
	0.19	0.07	0.00	0.00	0.12	1.05	0.36	
	5.10	31.58		0.00	32.26	10.28	4.17	
TOTAL	**314**	**19**	**0**	**6**	**31**	**885**	**744**	**48,129**
	0.65	**0.04**	**0.00**	**0.01**	**0.06**	**1.84**	**1.55**	**100.00**

Table J-5. Crashes by Alignment.

Dev, ADT	ALIGNMENT							
Frequency Percent Row Percent Col Percent	Unknown	Straight, Level	Straight, Grade	Straight, Hillcrest	Curve, Level	Curve, Grade	Curve, Hillcrest	TOTAL
RURAL, ADT<=2K	**0**	**9615**	**50**	**167**	**4726**	**22**	**42**	**14,622**
	0.00	19.98	0.10	0.35	9.82	0.05	0.09	30.38
	0.00	65.76	0.34	1.14	32.32	0.15	0.29	
		24.83	40.32	41.85	53.96	48.89	51.22	
RURAL, ADT=2-6K	**0**	**11,429**	**38**	**146**	**2546**	**15**	**25**	**14,199**
	0.00	23.75	0.08	0.30	5.29	0.03	0.05	29.50
	0.00	80.49	0.27	1.03	17.93	0.11	0.18	
		29.52	30.65	36.59	29.07	33.33	30.49	
RURAL, ADT>6K	**0**	**6090**	**17**	**45**	**607**	**4**	**5**	**6768**
	0.00	12.65	0.04	0.09	1.26	0.01	0.01	14.06
	0.00	89.98	0.25	0.66	8.97	0.06	0.07	
		15.73	13.71	11.28	6.93	8.89	6.10	
URBAN, ADT<=2K	**0**	**504**	**1**	**3**	**91**	**1**	**2**	**602**
	0.00	1.05	0.00	0.01	0.19	0.00	0.00	1.25
	0.00	83.72	0.17	0.50	15.12	0.17	0.33	
		1.30	0.81	0.75	1.04	2.22	2.44	
URBAN, ADT=2-6K	**0**	**2908**	**4**	**15**	**367**	**0**	**6**	**3300**
	0.00	6.04	0.01	0.03	0.76	0.00	0.01	6.86
	0.00	88.12	0.12	0.45	11.12	0.00	0.18	
		7.51	3.23	3.76	4.19	0.00	7.32	
URBAN, ADT>6K	**0**	**8174**	**14**	**23**	**422**	**3**	**2**	**8638**
	0.00	16.98	0.03	0.05	0.88	0.01	0.00	17.95
	0.00	94.63	0.16	0.27	4.89	0.03	0.02	
		21.11	11.29	5.76	4.82	6.67	2.44	
TOTAL	**0**	**38,720**	**124**	**399**	**8759**	**45**	**82**	**48,129**
	0.00	**80.45**	**0.26**	**0.83**	**18.20**	**0.09**	**0.17**	**100.00**

Table J-6. Crashes by Degree of Curve.

Dev, ADT	DEGREE OF CURVE						
Frequency Percent Row Percent Col Percent	Unknown	No Curve	0.1 to 1.9	2.0 to 3.9	4.0 to 5.9	6.0 to 7.9	8.0 to 9.9
RURAL, ADT<=2K	**601**	**8853**	**695**	**1384**	**1195**	**566**	**284**
	1.25	18.39	1.44	2.88	2.48	1.18	0.59
	4.11	60.55	4.75	9.47	8.17	3.87	1.94
	38.87	25.54	26.28	37.89	50.66	56.54	59.29
RURAL, ADT=2-6K	**451**	**10,268**	**919**	**1153**	**640**	**233**	**112**
	0.94	21.33	1.91	2.40	1.33	0.48	0.23
	3.18	72.31	6.47	8.12	4.51	1.64	0.79
	29.17	29.62	34.74	31.56	27.13	23.28	23.38
RURAL, ADT>6K	**147**	**5429**	**422**	**401**	**193**	**74**	**17**
	0.31	11.28	0.88	0.83	0.40	0.15	0.04
	2.17	80.22	6.24	5.92	2.85	1.09	0.25
	9.51	15.66	15.95	10.98	8.18	7.39	3.55
URBAN, ADT<=2K	**18**	**451**	**21**	**44**	**35**	**9**	**5**
	0.04	0.94	0.04	0.09	0.07	0.02	0.01
	2.99	74.92	3.49	7.31	5.81	1.50	0.83
	1.16	1.30	0.79	1.20	1.48	0.90	1.04
URBAN, ADT=2-6K	**119**	**2523**	**167**	**194**	**120**	**52**	**36**
	0.25	5.24	0.35	0.40	0.25	0.11	0.07
	3.61	76.45	5.06	5.88	3.64	1.58	1.09
	7.70	7.28	6.31	5.31	5.09	5.19	7.52
URBAN, ADT>6K	**210**	**7143**	**421**	**477**	**176**	**67**	**25**
	0.44	14.84	0.87	0.99	0.37	0.14	0.05
	2.43	82.69	4.87	5.52	2.04	0.78	0.29
	13.58	20.60	15.92	13.06	7.46	6.69	5.22
TOTAL	**1546**	**34,667**	**2645**	**3653**	**2359**	**1001**	**479**
	3.21	**72.03**	**5.50**	**7.59**	**4.90**	**2.08**	**1.00**

Table J-6. Crashes by Degree of Curve (continued).

Dev, ADT	DEGREE OF CURVE							
Frequency Percent Row Percent Col Percent	10.0 to 11.9	12.0 to 13.9	14.0 to 15.9	16.0 to 17.9	18.0 and Over	TOTAL	0 to 3.9	4 to 18+
RURAL, ADT<=2K	**456**	**107**	**110**	**31**	**340**	**14,622**	**2079**	**3089**
	0.95	0.22	0.23	0.06	0.71	30.38		
	3.12	0.73	0.75	0.21	2.33		14.22	21.13
	57.36	74.31	54.19	60.78	58.02			
RURAL, ADT=2-6K	**210**	**20**	**52**	**12**	**129**	**14,199**	**2072**	**1408**
	0.44	0.04	0.11	0.02	0.27	29.50		
	1.48	0.14	0.37	0.08	0.91		14.59	9.92
	26.42	13.89	25.62	23.53	22.01			
RURAL, ADT>6K	**36**	**6**	**12**	**1**	**30**	**6768**	**823**	**369**
	0.07	0.01	0.02	0.00	0.06	14.06		
	0.53	0.09	0.18	0.01	0.44		12.16	5.45
	4.53	4.17	5.91	1.96	5.12			
URBAN, ADT<=2K	**14**	**1**	**1**	**0**	**3**	**602**	**65**	**68**
	0.03	0.00	0.00	0.00	0.01	1.25		
	2.33	0.17	0.17	0.00	0.50		10.80	11.30
	1.76	0.69	0.49	0.00	0.51			
URBAN, ADT=2-6K	**32**	**6**	**9**	**4**	**38**	**3300**	**361**	**297**
	0.07	0.01	0.02	0.01	0.08	6.86		
	0.97	0.18	0.27	0.12	1.15		10.94	9.00
	4.03	4.17	4.43	7.84	6.48			
URBAN, ADT>6K	**47**	**4**	**19**	**3**	**46**	**8638**	**898**	**387**
	0.10	0.01	0.04	0.01	0.10	17.95		
	0.54	0.05	0.22	0.03	0.53		10.40	4.48
	5.91	2.78	9.36	5.88	7.85			
TOTAL	**795**	**144**	**203**	**51**	**586**	**48,129**	**6298**	**5618**
	1.65	**0.30**	**0.42**	**0.11**	**1.22**	**100.00**		

Table J-7. Crashes by Weather.

Dev, ADT	WEATHER			
Frequency Percent Row Percent Col Percent	**Clear (Cloudy)**	**Raining**	**Snowing**	**Fog**
RURAL, ADT<=2K	**13,054**	**1057**	**57**	**395**
	27.12	2.20	0.12	0.82
	89.28	7.23	0.39	2.70
	30.54	25.74	44.88	39.50
RURAL, ADT=2-6K	**12,404**	**1347**	**44**	**351**
	25.77	2.80	0.09	0.73
	87.36	9.49	0.31	2.47
	29.02	32.81	34.65	35.10
RURAL, ADT>6K	**5997**	**637**	**8**	**109**
	12.46	1.32	0.02	0.23
	88.61	9.41	0.12	1.61
	14.03	15.51	6.30	10.90
URBAN, ADT<=2K	**541**	**47**	**0**	**14**
	1.12	0.10	0.00	0.03
	89.87	7.81	0.00	2.33
	1.27	1.14	0.00	1.40
URBAN, ADT=2-6K	**2960**	**273**	**7**	**52**
	6.15	0.57	0.01	0.11
	89.70	8.27	0.21	1.58
	6.93	6.65	5.51	5.20
URBAN, ADT>6K	**7787**	**745**	**11**	**79**
	16.18	1.55	0.02	0.16
	90.15	8.62	0.13	0.91
	18.22	18.14	8.66	7.90
TOTAL	**42,743**	**4106**	**127**	**1000**
	88.81	**8.53**	**0.26**	**2.08**

Table J-7. Crashes by Weather (continued).

Dev, ADT	WEATHER				
Frequency Percent Row Percent Col Percent	Blowing Dust	Smoke	Other	Sleeting	TOTAL
RURAL, ADT<=2K	**5**	**5**	**11**	**38**	**14,622**
	0.01	0.01	0.02	0.08	30.38
	0.03	0.03	0.08	0.26	
	55.56	38.46	50.00	34.86	
RURAL, ADT=2-6K	**0**	**5**	**6**	**42**	**14,199**
	0.00	0.01	0.01	0.09	29.50
	0.00	0.04	0.04	0.30	
	0.00	38.46	27.27	38.53	
RURAL, ADT>6K	**2**	**2**	**2**	**11**	**6768**
	0.00	0.00	0.00	0.02	14.06
	0.03	0.03	0.03	0.16	
	22.22	15.38	9.09	10.09	
URBAN, ADT<=2K	**0**	**0**	**0**	**0**	**602**
	0.00	0.00	0.00	0.00	1.25
	0.00	0.00	0.00	0.00	
	0.00	0.00	0.00	0.00	
URBAN, ADT=2-6K	**1**	**1**	**0**	**6**	**3300**
	0.00	0.00	0.00	0.01	6.86
	0.03	0.03	0.00	0.18	
	11.11	7.69	0.00	5.50	
URBAN, ADT>6K	**1**	**0**	**3**	**12**	**8638**
	0.00	0.00	0.01	0.02	17.95
	0.01	0.00	0.03	0.14	
	11.11	0.00	13.64	11.01	
TOTAL	**9**	**13**	**22**	**109**	**48,129**
	0.02	**0.03**	**0.05**	**0.23**	**100.00**

Table J-8. Crashes by Surface Condition.

Dev, ADT	SURFACE CONDITION					
Frequency Percent Row Percent Col Percent	Dry	Wet	Muddy	Snowy	Icy	TOTAL
RURAL, ADT<=2K	**12,539**	**1909**	**7**	**167**	**0**	**14,622**
	26.05	3.97	0.01	0.35	0.00	30.38
	85.75	13.06	0.05	1.14	0.00	
	30.61	28.48	38.89	37.53		
RURAL, ADT=2-6K	**11,886**	**2129**	**2**	**182**	**0**	**14,199**
	24.70	4.42	0.00	0.38	0.00	29.50
	83.71	14.99	0.01	1.28	0.00	
	29.02	31.76	11.11	40.90		
RURAL, ADT>6K	**5775**	**949**	**2**	**42**	**0**	**6768**
	12.00	1.97	0.00	0.09	0.00	14.06
	85.33	14.02	0.03	0.62	0.00	
	14.10	14.16	11.11	9.44		
URBAN, ADT<=2K	**513**	**88**	**0**	**1**	**0**	**602**
	1.07	0.18	0.00	0.00	0.00	1.25
	85.22	14.62	0.00	0.17	0.00	
	1.25	1.31	0.00	0.22		
URBAN, ADT=2-6K	**2846**	**437**	**1**	**16**	**0**	**3300**
	5.91	0.91	0.00	0.03	0.00	6.86
	86.24	13.24	0.03	0.48	0.00	
	6.95	6.52	5.56	3.60		
URBAN, ADT>6K	**7403**	**1192**	**6**	**37**	**0**	**8638**
	15.38	2.48	0.01	0.08	0.00	17.95
	85.70	13.80	0.07	0.43	0.00	
	18.07	17.78	33.33	8.31		
TOTAL	**40,962**	**6704**	**18**	**445**	**0**	**48,129**
	85.11	**13.93**	**0.04**	**0.92**	**0.00**	**100.00**

Table J-9. Crashes by Light Condition.

Dev, ADT	LIGHT CONDITION					
Frequency Percent Row Percent Col Percent	Daylight	Dawn	Dark Not Lighted	Dark Lighted	Dusk	TOTAL
RURAL, ADT<=2K	**8338**	**269**	**5344**	**389**	**282**	**14,622**
	17.32	0.56	11.10	0.81	0.59	30.38
	57.02	1.84	36.55	2.66	1.93	
	28.03	31.54	39.65	12.36	30.99	
RURAL, ADT=2-6K	**8738**	**277**	**4336**	**609**	**239**	**14,199**
	18.16	0.58	9.01	1.27	0.50	29.50
	61.54	1.95	30.54	4.29	1.68	
	29.38	32.47	32.17	19.35	26.26	
RURAL, ADT>6K	**4260**	**120**	**1776**	**464**	**148**	**6768**
	8.85	0.25	3.69	0.96	0.31	14.06
	62.94	1.77	26.24	6.86	2.19	
	14.32	14.07	13.18	14.74	16.26	
URBAN, ADT<=2K	**377**	**7**	**164**	**49**	**5**	**602**
	0.78	0.01	0.34	0.10	0.01	1.25
	62.62	1.16	27.24	8.14	0.83	
	1.27	0.82	1.22	1.56	0.55	
URBAN, ADT=2-6K	**2146**	**51**	**647**	**386**	**70**	**3300**
	4.46	0.11	1.34	0.80	0.15	6.86
	65.03	1.55	19.61	11.70	2.12	
	7.22	5.98	4.80	12.27	7.69	
URBAN, ADT>6K	**5883**	**129**	**1210**	**1250**	**166**	**8638**
	12.22	0.27	2.51	2.60	0.34	17.95
	68.11	1.49	14.01	14.47	1.92	
	19.78	15.12	8.98	39.72	18.24	
TOTAL	**29,742**	**853**	**13,477**	**3147**	**910**	**48,129**
	61.80	**1.77**	**28.00**	**6.54**	**1.89**	**100.00**

Table J-10. Crashes by Month.

Dev, ADT	MONTH						
Frequency Percent Row Percent Col Percent	January	February	March	April	May	June	July
RURAL, ADT<=2K	**1058**	**984**	**1163**	**1197**	**1333**	**1192**	**1377**
	2.20	2.04	2.42	2.49	2.77	2.48	2.86
	7.24	6.73	7.95	8.19	9.12	8.15	9.42
	30.43	29.13	29.53	30.20	30.10	29.75	33.11
RURAL, ADT=2-6K	**1006**	**979**	**1157**	**1143**	**1308**	**1247**	**1207**
	2.09	2.03	2.40	2.37	2.72	2.59	2.51
	7.09	6.89	8.15	8.05	9.21	8.78	8.50
	28.93	28.98	29.38	28.84	29.53	31.12	29.02
RURAL, ADT>6K	**489**	**487**	**514**	**555**	**646**	**542**	**571**
	1.02	1.01	1.07	1.15	1.34	1.13	1.19
	7.23	7.20	7.59	8.20	9.54	8.01	8.44
	14.06	14.42	13.05	14.00	14.59	13.53	13.73
URBAN, ADT<=2K	**44**	**40**	**52**	**60**	**48**	**46**	**52**
	0.09	0.08	0.11	0.12	0.10	0.10	0.11
	7.31	6.64	8.64	9.97	7.97	7.64	8.64
	1.27	1.18	1.32	1.51	1.08	1.15	1.25
URBAN, ADT=2-6K	**258**	**222**	**306**	**286**	**292**	**275**	**262**
	0.54	0.46	0.64	0.59	0.61	0.57	0.54
	7.82	6.73	9.27	8.67	8.85	8.33	7.94
	7.42	6.57	7.77	7.22	6.59	6.86	6.30
URBAN, ADT>6K	**622**	**666**	**746**	**722**	**802**	**705**	**690**
	1.29	1.38	1.55	1.50	1.67	1.46	1.43
	7.20	7.71	8.64	8.36	9.28	8.16	7.99
	17.89	19.72	18.94	18.22	18.11	17.59	16.59
TOTAL	**3477**	**3378**	**3938**	**3963**	**4429**	**4007**	**4159**
	7.22	**7.02**	**8.18**	**8.23**	**9.20**	**8.33**	**8.64**

Table J-10. Crashes by Month (continued).

Dev, ADT	MONTH					
Frequency Percent Row Percent Col Percent	August	September	October	November	December	TOTAL
RURAL, ADT<=2K	**1219**	**1198**	**1331**	**1287**	**1283**	**14,622**
	2.53	2.49	2.77	2.67	2.67	30.38
	8.34	8.19	9.10	8.80	8.77	
	30.04	30.38	30.30	31.05	30.27	
RURAL, ADT=2-6K	**1180**	**1155**	**1283**	**1225**	**1309**	**14,199**
	2.45	2.40	2.67	2.55	2.72	29.50
	8.31	8.13	9.04	8.63	9.22	
	29.08	29.29	29.21	29.55	30.88	
RURAL, ADT>6K	**600**	**606**	**620**	**580**	**558**	**6768**
	1.25	1.26	1.29	1.21	1.16	14.06
	8.87	8.95	9.16	8.57	8.24	
	14.79	15.37	14.11	13.99	13.16	
URBAN, ADT<=2K	**34**	**52**	**63**	**56**	**55**	**602**
	0.07	0.11	0.13	0.12	0.11	1.25
	5.65	8.64	10.47	9.30	9.14	
	0.84	1.32	1.43	1.35	1.30	
URBAN, ADT=2-6K	**283**	**269**	**298**	**280**	**269**	**3300**
	0.59	0.56	0.62	0.58	0.56	6.86
	8.58	8.15	9.03	8.48	8.15	
	6.97	6.82	6.78	6.76	6.35	
URBAN, ADT>6K	**742**	**663**	**798**	**717**	**765**	**8638**
	1.54	1.38	1.66	1.49	1.59	17.95
	8.59	7.68	9.24	8.30	8.86	
	18.28	16.81	18.17	17.30	18.05	
TOTAL	**4058**	**3943**	**4393**	**4145**	**4239**	**48,129**
	8.43	**8.19**	**9.13**	**8.61**	**8.81**	**100.00**

Table J-11. Crashes by Day of Week.

Dev, ADT	DAY OF WEEK							
Frequency Percent Row Percent Col Percent	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	TOTAL
RURAL, ADT<=2K	**2449**	**1812**	**1653**	**1789**	**1848**	**2320**	**2751**	**14,622**
	5.09	3.76	3.43	3.72	3.84	4.82	5.72	30.38
	16.75	12.39	11.30	12.23	12.64	15.87	18.81	
	35.55	28.89	28.02	28.83	28.31	28.96	33.04	
RURAL, ADT=2-6K	**2111**	**1866**	**1663**	**1805**	**1920**	**2339**	**2495**	**14,199**
	4.39	3.88	3.46	3.75	3.99	4.86	5.18	29.50
	14.87	13.14	11.71	12.71	13.52	16.47	17.57	
	30.65	29.76	28.19	29.08	29.42	29.20	29.96	
RURAL, ADT>6K	**893**	**849**	**860**	**914**	**912**	**1162**	**1178**	**6768**
	1.86	1.76	1.79	1.90	1.89	2.41	2.45	14.06
	13.19	12.54	12.71	13.50	13.48	17.17	17.41	
	12.96	13.54	14.58	14.73	13.97	14.51	14.15	
URBAN, ADT<=2K	**80**	**80**	**85**	**84**	**86**	**99**	**88**	**602**
	0.17	0.17	0.18	0.17	0.18	0.21	0.18	1.25
	13.29	13.29	14.12	13.95	14.29	16.45	14.62	
	1.16	1.28	1.44	1.35	1.32	1.24	1.06	
URBAN, ADT=2-6K	**392**	**471**	**425**	**447**	**510**	**571**	**484**	**3300**
	0.81	0.98	0.88	0.93	1.06	1.19	1.01	6.86
	11.88	14.27	12.88	13.55	15.45	17.30	14.67	
	5.69	7.51	7.20	7.20	7.81	7.13	5.81	
URBAN, ADT>6K	**963**	**1193**	**1214**	**1167**	**1251**	**1519**	**1331**	**8638**
	2.00	2.48	2.52	2.42	2.60	3.16	2.77	17.95
	11.15	13.81	14.05	13.51	14.48	17.59	15.41	
	13.98	19.02	20.58	18.80	19.17	18.96	15.98	
TOTAL	**6888**	**6271**	**5900**	**6206**	**6527**	**8010**	**8327**	**48,129**
	14.31	**13.03**	**12.26**	**12.89**	**13.56**	**16.64**	**17.30**	**100.00**

Table J-12. Crashes by Time.

Dev, ADT	TIME					
Frequency Percent Row Percent Col Percent	MIDNIGHT-12:59 AM	1-1:59 AM	2-2:59 AM	3-3:59 AM	4-4:59 AM	5-5:59 AM
RURAL, ADT<=2K	**512**	**474**	**415**	**288**	**272**	**334**
	1.06	0.98	0.86	0.60	0.57	0.69
	3.50	3.24	2.84	1.97	1.86	2.28
	35.83	37.92	35.47	33.57	38.15	34.90
RURAL, ADT=2-6K	**440**	**391**	**343**	**268**	**257**	**320**
	0.91	0.81	0.71	0.56	0.53	0.66
	3.10	2.75	2.42	1.89	1.81	2.25
	30.79	31.28	29.32	31.24	36.04	33.44
RURAL, ADT>6K	**180**	**150**	**159**	**146**	**86**	**152**
	0.37	0.31	0.33	0.30	0.18	0.32
	2.66	2.22	2.35	2.16	1.27	2.25
	12.60	12.00	13.59	17.02	12.06	15.88
URBAN, ADT<=2K	**22**	**15**	**22**	**11**	**9**	**11**
	0.05	0.03	0.05	0.02	0.02	0.02
	3.65	2.49	3.65	1.83	1.50	1.83
	1.54	1.20	1.88	1.28	1.26	1.15
URBAN, ADT=2-6K	**99**	**58**	**59**	**47**	**30**	**49**
	0.21	0.12	0.12	0.10	0.06	0.10
	3.00	1.76	1.79	1.42	0.91	1.48
	6.93	4.64	5.04	5.48	4.21	5.12
URBAN, ADT>6K	**176**	**162**	**172**	**98**	**59**	**91**
	0.37	0.34	0.36	0.20	0.12	0.19
	2.04	1.88	1.99	1.13	0.68	1.05
	12.32	12.96	14.70	11.42	8.27	9.51
TOTAL	**1429**	**1250**	**1170**	**858**	**713**	**957**
	2.97	**2.60**	**2.43**	**1.78**	**1.48**	**1.99**

Table J-12. Crashes by Time (continued).

Dev, ADT	TIME					
Frequency Percent Row Percent Col Percent	6-6:59 AM	7-7:59 AM	8-8:59 AM	9-9:59 AM	10-10:59 AM	11-11:59 AM
RURAL, ADT<=2K	**469**	**711**	**521**	**447**	**510**	**605**
	0.97	1.48	1.08	0.93	1.06	1.26
	3.21	4.86	3.56	3.06	3.49	4.14
	31.23	29.13	28.13	29.25	29.29	29.89
RURAL, ADT=2-6K	**480**	**746**	**562**	**455**	**521**	**576**
	1.00	1.55	1.17	0.95	1.08	1.20
	3.38	5.25	3.96	3.20	3.67	4.06
	31.96	30.56	30.35	29.78	29.93	28.46
RURAL, ADT>6K	**207**	**333**	**259**	**251**	**255**	**263**
	0.43	0.69	0.54	0.52	0.53	0.55
	3.06	4.92	3.83	3.71	3.77	3.89
	13.78	13.64	13.98	16.43	14.65	12.99
URBAN, ADT<=2K	**25**	**32**	**30**	**18**	**26**	**23**
	0.05	0.07	0.06	0.04	0.05	0.05
	4.15	5.32	4.98	2.99	4.32	3.82
	1.66	1.31	1.62	1.18	1.49	1.14
URBAN, ADT=2-6K	**87**	**171**	**118**	**96**	**118**	**157**
	0.18	0.36	0.25	0.20	0.25	0.33
	2.64	5.18	3.58	2.91	3.58	4.76
	5.79	7.01	6.37	6.28	6.78	7.76
URBAN, ADT>6K	**234**	**448**	**362**	**261**	**311**	**400**
	0.49	0.93	0.75	0.54	0.65	0.83
	2.71	5.19	4.19	3.02	3.60	4.63
	15.58	18.35	19.55	17.08	17.86	19.76
TOTAL	**1502**	**2441**	**1852**	**1528**	**1741**	**2024**
	3.12	**5.07**	**3.85**	**3.17**	**3.62**	**4.21**

Table J-12. Crashes by Time (continued).

Dev, ADT	TIME					
Frequency Percent Row Percent Col Percent	NOON-12:59 PM	1-1:59 PM	2-2:59 PM	3-3:59 PM	4-4:59 PM	5-5:59 PM
RURAL, ADT<=2K	**604**	**646**	**683**	**904**	**901**	**938**
	1.25	1.34	1.42	1.88	1.87	1.95
	4.13	4.42	4.67	6.18	6.16	6.41
	25.99	27.13	26.09	28.50	26.59	26.91
RURAL, ADT=2-6K	**692**	**714**	**836**	**904**	**945**	**991**
	1.44	1.48	1.74	1.88	1.96	2.06
	4.87	5.03	5.89	6.37	6.66	6.98
	29.78	29.99	31.93	28.50	27.88	28.43
RURAL, ADT>6K	**308**	**370**	**355**	**464**	**495**	**515**
	0.64	0.77	0.74	0.96	1.03	1.07
	4.55	5.47	5.25	6.86	7.31	7.61
	13.25	15.54	13.56	14.63	14.61	14.77
URBAN, ADT<=2K	**28**	**28**	**32**	**38**	**38**	**45**
	0.06	0.06	0.07	0.08	0.08	0.09
	4.65	4.65	5.32	6.31	6.31	7.48
	1.20	1.18	1.22	1.20	1.12	1.29
URBAN, ADT=2-6K	**185**	**172**	**210**	**211**	**249**	**266**
	0.38	0.36	0.44	0.44	0.52	0.55
	5.61	5.21	6.36	6.39	7.55	8.06
	7.96	7.22	8.02	6.65	7.35	7.63
URBAN, ADT>6K	**507**	**451**	**502**	**651**	**761**	**731**
	1.05	0.94	1.04	1.35	1.58	1.52
	5.87	5.22	5.81	7.54	8.81	8.46
	21.82	18.94	19.17	20.52	22.46	20.97
TOTAL	**2324**	**2381**	**2618**	**3172**	**3389**	**3486**
	4.83	**4.95**	**5.44**	**6.59**	**7.04**	**7.24**

Table J-12. Crashes by Time (continued).

Dev, ADT	TIME						
Frequency Percent Row Percent Col Percent	6-6:59 PM	7-7:59 PM	8-8:59 PM	9-9:59 PM	10-10:59 PM	11-11:59 PM	TOTAL
RURAL, ADT<=2K	**934**	**743**	**727**	**742**	**674**	**568**	**14,622**
	1.94	1.54	1.51	1.54	1.40	1.18	30.38
	6.39	5.08	4.97	5.07	4.61	3.88	
	28.89	30.89	33.60	34.35	37.91	36.55	
RURAL, ADT=2-6K	**918**	**660**	**607**	**617**	**518**	**438**	**14,199**
	1.91	1.37	1.26	1.28	1.08	0.91	29.5
	6.47	4.65	4.27	4.35	3.65	3.08	
	28.39	27.44	28.05	28.56	29.13	28.19	
RURAL, ADT>6K	**486**	**344**	**319**	**281**	**194**	**196**	**6768**
	1.01	0.71	0.66	0.58	0.40	0.41	14.06
	7.18	5.08	4.71	4.15	2.87	2.90	
	15.03	14.30	14.74	13.01	10.91	12.61	
URBAN, ADT<=2K	**29**	**31**	**24**	**31**	**13**	**21**	**602**
	0.06	0.06	0.05	0.06	0.03	0.04	1.25
	4.82	5.15	3.99	5.15	2.16	3.49	
	0.90	1.29	1.11	1.44	0.73	1.35	
URBAN, ADT=2-6K	**222**	**186**	**130**	**165**	**108**	**107**	**3300**
	0.46	0.39	0.27	0.34	0.22	0.22	6.86
	6.73	5.64	3.94	5.00	3.27	3.24	
	6.87	7.73	6.01	7.64	6.07	6.89	
URBAN, ADT>6K	**644**	**441**	**357**	**324**	**271**	**224**	**8638**
	1.34	0.92	0.74	0.67	0.56	0.47	17.95
	7.46	5.11	4.13	3.75	3.14	2.59	
	19.92	18.34	16.50	15.00	15.24	14.41	
TOTAL	**3233**	**2405**	**2164**	**2160**	**1778**	**1554**	**48,120**
	6.72	**5.00**	**4.50**	**4.49**	**3.69**	**3.23**	**100.00**

Table J-13. Crashes by Vehicle Movement.

Dev, ADT	VEHICLE MOVEMENTS / MANNER OF COLLISION					
Frequency Percent Row Percent Col Percent	Single Motor Vehicle Straight	Single Motor Vehicle Right Turn	Single Motor Vehicle Left Turn	Single Motor Vehicle Backing	Single Motor Vehicle Other	Angle Both Straight
RURAL, ADT<=2K	**9891**	**71**	**98**	**11**	**3**	**1322**
	20.55	0.15	0.20	0.02	0.01	2.75
	67.64	0.49	0.67	0.08	0.02	9.04
	45.52	25.09	28.08	39.29	25.00	21.85
RURAL, ADT=2-6K	**6806**	**68**	**74**	**10**	**4**	**1580**
	14.14	0.14	0.15	0.02	0.01	3.28
	47.93	0.48	0.52	0.07	0.03	11.13
	31.32	24.03	21.20	35.71	33.33	26.11
RURAL, ADT>6K	**2101**	**34**	**38**	**4**	**5**	**740**
	4.37	0.07	0.08	0.01	0.01	1.54
	31.04	0.50	0.56	0.06	0.07	10.93
	9.67	12.01	10.89	14.29	41.67	12.23
URBAN, ADT<=2K	**242**	**5**	**4**	**0**	**0**	**137**
	0.50	0.01	0.01	0.00	0.00	0.28
	40.20	0.83	0.66	0.00	0.00	22.76
	1.11	1.77	1.15	0.00	0.00	2.26
URBAN, ADT=2-6K	**1027**	**27**	**46**	**1**	**0**	**659**
	2.13	0.06	0.10	0.00	0.00	1.37
	31.12	0.82	1.39	0.03	0.00	19.97
	4.73	9.54	13.18	3.57	0.00	10.89
URBAN, ADT>6K	**1664**	**78**	**89**	**2**	**0**	**1613**
	3.46	0.16	0.18	0.00	0.00	3.35
	19.26	0.90	1.03	0.02	0.00	18.67
	7.66	27.56	25.50	7.14	0.00	26.66
TOTAL	**21,731**	**283**	**349**	**28**	**12**	**6051**
	45.15	**0.59**	**0.73**	**0.06**	**0.02**	**12.57**

Table J-13. Crashes by Vehicle Movement (continued).

Dev, ADT	VEHICLE MOVEMENTS / MANNER OF COLLISION					
Frequency Percent Row Percent Col Percent	Angle 1 Straight 2 Backing	Angle 1 Straight 2 Stopped	Angle 1 Straight 2 Right Turn	Angle 1 Straight 2 Left Turn	Angle Both Right Turn	Angle 1 Right Turn 2 Left Turn
RURAL, ADT<=2K	**28**	**46**	**60**	**351**	**0**	**1**
	0.06	0.10	0.12	0.73	0.00	0.00
	0.19	0.31	0.41	2.40	0.00	0.01
	31.46	28.05	17.80	15.93		25.00
RURAL, ADT=2-6K	**31**	**48**	**96**	**543**	**0**	**1**
	0.06	0.10	0.20	1.13	0.00	0.00
	0.22	0.34	0.68	3.82	0.00	0.01
	34.83	29.27	28.49	24.65		25.00
RURAL, ADT>6K	**12**	**23**	**65**	**405**	**0**	**0**
	0.02	0.05	0.14	0.84	0.00	0.00
	0.18	0.34	0.96	5.98	0.00	0.00
	13.48	14.02	19.29	18.38		0.00
URBAN, ADT<=2K	**0**	**6**	**2**	**39**	**0**	**0**
	0.00	0.01	0.00	0.08	0.00	0.00
	0.00	1.00	0.33	6.48	0.00	0.00
	0.00	3.66	0.59	1.77		0.00
URBAN, ADT=2-6K	**11**	**13**	**31**	**194**	**0**	**0**
	0.02	0.03	0.06	0.40	0.00	0.00
	0.33	0.39	0.94	5.88	0.00	0.00
	12.36	7.93	9.20	8.81		0.00
URBAN, ADT>6K	**7**	**28**	**83**	**671**	**0**	**2**
	0.01	0.06	0.17	1.39	0.00	0.00
	0.08	0.32	0.96	7.77	0.00	0.02
	7.87	17.07	24.63	30.46		50.00
TOTAL	**89**	**164**	**337**	**2203**	**0**	**4**
	0.18	**0.34**	**0.70**	**4.58**	**0.00**	**0.01**

Table J-13. Crashes by Vehicle Movement.

Dev, ADT	VEHICLE MOVEMENTS / MANNER OF COLLISION					
Frequency Percent Row Percent Col Percent	Angle 1 Right Turn 2 Stopped	Angle Both Left Turn	Angle 1 Left Turn 2 Stopped	Same Direction Both Straight Rear End	Same Direction Both Straight Sideswipe	Same Direction 1 Straight 2 Stopped
RURAL, ADT<=2K	**6**	**0**	**4**	**374**	**49**	**337**
	0.01	0.00	0.01	0.78	0.10	0.70
	0.04	0.00	0.03	2.56	0.34	2.30
	16.22	0.00	16.67	16.18	16.17	8.39
RURAL, ADT=2-6K	**9**	**7**	**8**	**690**	**81**	**892**
	0.02	0.01	0.02	1.43	0.17	1.85
	0.06	0.05	0.06	4.86	0.57	6.28
	24.32	30.43	33.33	29.86	26.73	22.21
RURAL, ADT>6K	**5**	**5**	**4**	**524**	**63**	**870**
	0.01	0.01	0.01	1.09	0.13	1.81
	0.07	0.07	0.06	7.74	0.93	12.85
	13.51	21.74	16.67	22.67	20.79	21.66
URBAN, ADT<=2K	**1**	**1**	**0**	**19**	**5**	**36**
	0.00	0.00	0.00	0.04	0.01	0.07
	0.17	0.17	0.00	3.16	0.83	5.98
	2.70	4.35	0.00	0.82	1.65	0.90
URBAN, ADT=2-6K	**5**	**1**	**2**	**147**	**13**	**358**
	0.01	0.00	0.00	0.31	0.03	0.74
	0.15	0.03	0.06	4.45	0.39	10.85
	13.51	4.35	8.33	6.36	4.29	8.91
URBAN, ADT>6K	**11**	**9**	**6**	**557**	**92**	**1524**
	0.02	0.02	0.01	1.16	0.19	3.17
	0.13	0.10	0.07	6.45	1.07	17.64
	29.73	39.13	25.00	24.10	30.36	37.94
TOTAL	**37**	**23**	**24**	**2311**	**303**	**4017**
	0.08	**0.05**	**0.05**	**4.80**	**0.63**	**8.35**

Table J-13. Crashes by Vehicle Movement (continued).

Dev, ADT	VEHICLE MOVEMENTS / MANNER OF COLLISION					
Frequency Percent Row Percent Col Percent	Same Direction 1 Straight 2 Right Turn	Same Direction 1 Straight 2 Left Turn	Same Direction Both Right Turn	Same Direction 1 Right Turn 2 Left Turn	Same Direction 1 Right Turn 2 Stopped	Same Direction Both Left Turn
RURAL, ADT<=2K	**107**	**531**	**2**	**0**	**1**	**0**
	0.22	1.10	0.00	0.00	0.00	0.00
	0.73	3.63	0.01	0.00	0.01	0.00
	23.26	24.50	12.50		12.50	0.00
RURAL, ADT=2-6K	**152**	**810**	**4**	**0**	**0**	**2**
	0.32	1.68	0.01	0.00	0.00	0.00
	1.07	5.70	0.03	0.00	0.00	0.01
	33.04	37.38	25.00		0.00	14.29
RURAL, ADT>6K	**74**	**384**	**3**	**0**	**0**	**5**
	0.15	0.80	0.01	0.00	0.00	0.01
	1.09	5.67	0.04	0.00	0.00	0.07
	16.09	17.72	18.75		0.00	35.71
URBAN, ADT<=2K	**7**	**29**	**0**	**0**	**0**	**0**
	0.01	0.06	0.00	0.00	0.00	0.00
	1.16	4.82	0.00	0.00	0.00	0.00
	1.52	1.34	0.00		0.00	0.00
URBAN, ADT=2-6K	**39**	**146**	**2**	**0**	**2**	**0**
	0.08	0.30	0.00	0.00	0.00	0.00
	1.18	4.42	0.06	0.00	0.06	0.00
	8.48	6.74	12.50		25.00	0.00
URBAN, ADT>6K	**81**	**267**	**5**	**0**	**5**	**7**
	0.17	0.55	0.01	0.00	0.01	0.01
	0.94	3.09	0.06	0.00	0.06	0.08
	17.61	12.32	31.25		62.50	50.00
TOTAL	**460**	**2167**	**16**	**0**	**8**	**14**
	0.96	**4.50**	**0.03**	**0.00**	**0.02**	**0.03**

Table J-13. Crashes by Vehicle Movement (continued).

Dev, ADT	VEHICLE MOVEMENTS / MANNER OF COLLISION					
Frequency Percent Row Percent Col Percent	Same Direction 1 Left Turn 2 Stopped	Opposite Directions Both Straight	Opposite Directions 1 Straight 2 Backing	Opposite Directions 1 Straight 2 Stopped	Opposite Directions 1 Straight 2 Right Turn	Opposite Directions 1 Straight 2 Left Turn
RURAL, ADT<=2K	**0**	**746**	**3**	**20**	**4**	**525**
	0.00	1.55	0.01	0.04	0.01	1.09
	0.00	5.10	0.02	0.14	0.03	3.59
	0.00	22.54	11.54	28.17	36.36	13.36
RURAL, ADT=2-6K	**0**	**1287**	**8**	**20**	**4**	**921**
	0.00	2.67	0.02	0.04	0.01	1.91
	0.00	9.06	0.06	0.14	0.03	6.49
	0.00	38.88	30.77	28.17	36.36	23.43
RURAL, ADT>6K	**1**	**695**	**10**	**11**	**2**	**653**
	0.00	1.44	0.02	0.02	0.00	1.36
	0.01	10.27	0.15	0.16	0.03	9.65
	100.00	21.00	38.46	15.49	18.18	16.61
URBAN, ADT<=2K	**0**	**23**	**0**	**1**	**0**	**45**
	0.00	0.05	0.00	0.00	0.00	0.09
	0.00	3.82	0.00	0.17	0.00	7.48
	0.00	0.69	0.00	1.41	0.00	1.14
URBAN, ADT=2-6K	**0**	**148**	**2**	**0**	**1**	**418**
	0.00	0.31	0.00	0.00	0.00	0.87
	0.00	4.48	0.06	0.00	0.03	12.67
	0.00	4.47	7.69	0.00	9.09	10.63
URBAN, ADT>6K	**0**	**411**	**3**	**19**	**0**	**1369**
	0.00	0.85	0.01	0.04	0.00	2.84
	0.00	4.76	0.03	0.22	0.00	15.85
	0.00	12.42	11.54	26.76	0.00	34.83
TOTAL	**1**	**3310**	**26**	**71**	**11**	**3931**
	0.00	**6.88**	**0.05**	**0.15**	**0.02**	**8.17**

Table J-13. Crashes by Vehicle Movement (continued).

Dev, ADT	VEHICLE MOVEMENTS / MANNER OF COLLISION					
Frequency Percent Row Percent Col Percent	Opposite Directions 1 Backing 2 Stopped	Opposite Directions 1 Right Turn 2 Left Turn	Opposite Directions 1 Right Turn 2 Stopped	Opposite Directions Both Left Turn	Opposite Directions 1 Left Turn 2 Stopped	Other 1 Straight 2 Parked
RURAL, ADT<=2K	**0**	**2**	**1**	**1**	**0**	**20**
	0.00	0.00	0.00	0.00	0.00	0.04
	0.00	0.01	0.01	0.01	0.00	0.14
	0.00	13.33	25.00	14.29		21.05
RURAL, ADT=2-6K	**4**	**2**	**0**	**1**	**0**	**34**
	0.01	0.00	0.00	0.00	0.00	0.07
	0.03	0.01	0.00	0.01	0.00	0.24
	36.36	13.33	0.00	14.29		35.79
RURAL, ADT>6K	**2**	**3**	**0**	**1**	**0**	**22**
	0.00	0.01	0.00	0.00	0.00	0.05
	0.03	0.04	0.00	0.01	0.00	0.33
	18.18	20.00	0.00	14.29		23.16
URBAN, ADT<=2K	**0**	**0**	**0**	**0**	**0**	**0**
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00		0.00
URBAN, ADT=2-6K	**0**	**0**	**1**	**0**	**0**	**5**
	0.00	0.00	0.00	0.00	0.00	0.01
	0.00	0.00	0.03	0.00	0.00	0.15
	0.00	0.00	25.00	0.00		5.26
URBAN, ADT>6K	**5**	**8**	**2**	**4**	**0**	**14**
	0.01	0.02	0.00	0.01	0.00	0.03
	0.06	0.09	0.02	0.05	0.00	0.16
	45.45	53.33	50.00	57.14		14.74
TOTAL	**11**	**15**	**4**	**7**	**0**	**95**
	0.02	**0.03**	**0.01**	**0.01**	**0.00**	**0.20**

Table J-13. Crashes by Vehicle Movement (continued).

Dev, ADT	VEHICLE MOVEMENTS / MANNER OF COLLISION						
Frequency Percent Row Percent Col Percent	Other 1 Right Turn 2 Parked	Other 1 Left Turn 2 Parked	Other 1 Parked 2 Stopped	Other Both Parked	Other Both Backing	Other All Others	TOTAL
RURAL, ADT<=2K	**0**	**0**	**0**	**0**	**0**	**7**	**14,622**
	0.00	0.00	0.00	0.00	0.00	0.01	30.38
	0.00	0.00	0.00	0.00	0.00	0.05	
						43.75	
RURAL, ADT=2-6K	**0**	**0**	**0**	**0**	**0**	**2**	**14,199**
	0.00	0.00	0.00	0.00	0.00	0.00	29.50
	0.00	0.00	0.00	0.00	0.00	0.01	
						12.50	
RURAL, ADT>6K	**0**	**0**	**0**	**0**	**0**	**4**	**6768**
	0.00	0.00	0.00	0.00	0.00	0.01	14.06
	0.00	0.00	0.00	0.00	0.00	0.06	
						25.00	
URBAN, ADT<=2K	**0**	**0**	**0**	**0**	**0**	**0**	**602**
	0.00	0.00	0.00	0.00	0.00	0.00	1.25
	0.00	0.00	0.00	0.00	0.00	0.00	
						0.00	
URBAN, ADT=2-6K	**0**	**0**	**0**	**0**	**0**	**1**	**3300**
	0.00	0.00	0.00	0.00	0.00	0.00	6.86
	0.00	0.00	0.00	0.00	0.00	0.03	
						6.25	
URBAN, ADT>6K	**0**	**0**	**0**	**0**	**0**	**2**	**8638**
	0.00	0.00	0.00	0.00	0.00	0.00	17.95
	0.00	0.00	0.00	0.00	0.00	0.02	
						12.50	
TOTAL	**0**	**0**	**0**	**0**	**0**	16	**48,129**
	0.00	**0.00**	**0.00**	**0.00**	**0.00**	**0.03**	**100.00**

Table J-14. Crashes by Other Factors.

Dev, ADT	OTHER FACTOR					
Frequency Percent Row Percent Col Percent	No Code Applicable	Lost Control, Skidded	Passenger Interfered	Attention Diverted	Object Projecting from Vehicle	Foot Slipped off Brake
RURAL, ADT<=2K	**10,331**	**139**	**43**	**597**	**4**	**7**
	21.47	0.29	0.09	1.24	0.01	0.01
	70.65	0.95	0.29	4.08	0.03	0.05
	34.48	36.29	50.59	41.34	40.00	38.89
RURAL, ADT=2-6K	**8932**	**152**	**23**	**431**	**5**	**4**
	18.56	0.32	0.05	0.90	0.01	0.01
	62.91	1.07	0.16	3.04	0.04	0.03
	29.81	39.69	27.06	29.85	50.00	22.22
RURAL, ADT>6K	**3632**	**38**	**5**	**172**	**0**	**1**
	7.55	0.08	0.01	0.36	0.00	0.00
	53.66	0.56	0.07	2.54	0.00	0.01
	12.12	9.92	5.88	11.91	0.00	5.56
URBAN, ADT<=2K	**407**	**1**	**2**	**12**	**0**	**0**
	0.85	0.00	0.00	0.02	0.00	0.00
	67.61	0.17	0.33	1.99	0.00	0.00
	1.36	0.26	2.35	0.83	0.00	0.00
URBAN, ADT=2-6K	**2081**	**11**	**5**	**82**	**0**	**2**
	4.32	0.02	0.01	0.17	0.00	0.00
	63.06	0.33	0.15	2.48	0.00	0.06
	6.95	2.87	5.88	5.68	0.00	11.11
URBAN, ADT>6K	**4581**	**42**	**7**	**150**	**1**	**4**
	9.52	0.09	0.01	0.31	0.00	0.01
	53.03	0.49	0.08	1.74	0.01	0.05
	15.29	10.97	8.24	10.39	10.00	22.22
TOTAL	**29,964**	**383**	**85**	**1444**	**10**	**18**
	62.26	**0.80**	**0.18**	**3.00**	**0.02**	**0.04**

Table J-14. Crashes by Other Factors (continued).

Dev, ADT	OTHER FACTOR					
Frequency Percent Row Percent Col Percent	Gusty Winds	Vehicle Passing on Left	Vehicle Passing on Right	Vehicle Changing Lane	Improperly Parked Vehicle	Vehicle Forward from Parking
RURAL, ADT<=2K	**16**	**302**	**24**	**18**	**16**	**21**
	0.03	0.63	0.05	0.04	0.03	0.04
	0.11	2.07	0.16	0.12	0.11	0.14
	30.19	28.93	12.12	10.34	26.23	23.08
RURAL, ADT=2-6K	**22**	**436**	**64**	**33**	**23**	**31**
	0.05	0.91	0.13	0.07	0.05	0.06
	0.15	3.07	0.45	0.23	0.16	0.22
	41.51	41.76	32.32	18.97	37.70	34.07
RURAL, ADT>6K	**3**	**165**	**62**	**36**	**8**	**19**
	0.01	0.34	0.13	0.07	0.02	0.04
	0.04	2.44	0.92	0.53	0.12	0.28
	5.66	15.80	31.31	20.69	13.11	20.88
URBAN, ADT<=2K	**0**	**13**	**4**	**2**	**2**	**1**
	0.00	0.03	0.01	0.00	0.00	0.00
	0.00	2.16	0.66	0.33	0.33	0.17
	0.00	1.25	2.02	1.15	3.28	1.10
URBAN, ADT=2-6K	**3**	**57**	**11**	**10**	**5**	**5**
	0.01	0.12	0.02	0.02	0.01	0.01
	0.09	1.73	0.33	0.30	0.15	0.15
	5.66	5.46	5.56	5.75	8.20	5.49
URBAN, ADT>6K	**9**	**71**	**33**	**75**	**7**	**14**
	0.02	0.15	0.07	0.16	0.01	0.03
	0.10	0.82	0.38	0.87	0.08	0.16
	16.98	6.80	16.67	43.10	11.48	15.38
TOTAL	**53**	**1044**	**198**	**174**	**61**	**91**
	0.11	**2.17**	**0.41**	**0.36**	**0.13**	**0.1**

Table J-14. Crashes by Other Factors (continued).

Dev, ADT	OTHER FACTOR					
Frequency Percent Row Percent Col Percent	Vehicle Backward from Parking	Vehicle Entering Driveway	Vehicle Leaving Driveway	Vision Obstructed by Standing Vehicle	Vision Obstructed by Moving Vehicle	Vision Obstructed by Embank-ment
RURAL, ADT<=2K	**0**	**446**	**210**	**12**	**13**	**1**
	0.00	0.93	0.44	0.02	0.03	0.00
	0.00	3.05	1.44	0.08	0.09	0.01
	0.00	21.17	15.20	12.63	10.32	33.33
RURAL, ADT=2-6K	**1**	**714**	**308**	**17**	**26**	**2**
	0.00	1.48	0.64	0.04	0.05	0.00
	0.01	5.03	2.17	0.12	0.18	0.01
	33.33	33.89	22.29	17.89	20.63	66.67
RURAL, ADT>6K	**0**	**377**	**274**	**14**	**30**	**0**
	0.00	0.78	0.57	0.03	0.06	0.00
	0.00	5.57	4.05	0.21	0.44	0.00
	0.00	17.89	19.83	14.74	23.81	0.00
URBAN, ADT<=2K	**0**	**23**	**14**	**1**	**3**	**0**
	0.00	0.05	0.03	0.00	0.01	0.00
	0.00	3.82	2.33	0.17	0.50	0.00
	0.00	1.09	1.01	1.05	2.38	0.00
URBAN, ADT=2-6K	**1**	**143**	**101**	**12**	**8**	**0**
	0.00	0.30	0.21	0.02	0.02	0.00
	0.03	4.33	3.06	0.36	0.24	0.00
	33.33	6.79	7.31	12.63	6.35	0.00
URBAN, ADT>6K	**1**	**404**	**475**	**39**	**46**	**0**
	0.00	0.84	0.99	0.08	0.10	0.00
	0.01	4.68	5.50	0.45	0.53	0.00
	33.33	19.17	34.37	41.05	36.51	0.00
TOTAL	**3**	**2107**	**1382**	**95**	**126**	**3**
	0.01	**4.38**	**2.87**	**0.20**	**0.26**	**0.01**

Table J-14. Crashes by Other Factors (continued).

Dev, ADT	OTHER FACTOR					
Frequency Percent Row Percent Col Percent	Vision Obstructed by Commercial Sign	Vision Obstructed by Highway Sign	Vision Obstructed by Glare	Vision Obstructed by Hillcrest	Vision Obstructed by Trees	Vision Obstructed by Other
RURAL, ADT<=2K	**1**	**2**	**81**	**15**	**5**	**156**
	0.00	0.00	0.17	0.03	0.01	0.32
	0.01	0.01	0.55	0.10	0.03	1.07
	100.00	50.00	30.68	55.56	35.71	40.52
RURAL, ADT=2-6K	**0**	**1**	**81**	**8**	**5**	**108**
	0.00	0.00	0.17	0.02	0.01	0.22
	0.00	0.01	0.57	0.06	0.04	0.76
	0.00	25.00	30.68	29.63	35.71	28.05
RURAL, ADT>6K	**0**	**1**	**41**	**1**	**1**	**52**
	0.00	0.00	0.09	0.00	0.00	0.11
	0.00	0.01	0.61	0.01	0.01	0.77
	0.00	25.00	15.53	3.70	7.14	13.51
URBAN, ADT<=2K	**0**	**0**	**1**	**1**	**0**	**7**
	0.00	0.00	0.00	0.00	0.00	0.01
	0.00	0.00	0.17	0.17	0.00	1.16
	0.00	0.00	0.38	3.70	0.00	1.82
URBAN, ADT=2-6K	**0**	**0**	**23**	**1**	**1**	**23**
	0.00	0.00	0.05	0.00	0.00	0.05
	0.00	0.00	0.70	0.03	0.03	0.70
	0.00	0.00	8.71	3.70	7.14	5.97
URBAN, ADT>6K	**0**	**0**	**37**	**1**	**2**	**39**
	0.00	0.00	0.08	0.00	0.00	0.08
	0.00	0.00	0.43	0.01	0.02	0.45
	0.00	0.00	14.02	3.70	14.29	10.13
TOTAL	**1**	**4**	**264**	**27**	**14**	**385**
	0.00	**0.01**	**0.55**	**0.06**	**0.03**	**0.80**

Table J-14. Crashes by Other Factors (continued).

Dev, ADT	OTHER FACTOR					
Frequency Percent Row Percent Col Percent	Swerved to Change Lanes	Swerved, Not Specified	Swerved, Surface or Visibility	Swerved, Traffic Control	Swerved, Pedestrian or Cyclist	Swerved, Animal
RURAL, ADT<=2K	**25**	**172**	**2**	**3**	**5**	**587**
	0.05	0.36	0.00	0.01	0.01	1.22
	0.17	1.18	0.01	0.02	0.03	4.01
	18.38	33.33	100.00	60.00	25.00	55.12
RURAL, ADT=2-6K	**50**	**195**	**0**	**1**	**10**	**298**
	0.10	0.41	0.00	0.00	0.02	0.62
	0.35	1.37	0.00	0.01	0.07	2.10
	36.76	37.79	0.00	20.00	50.00	27.98
RURAL, ADT>6K	**17**	**71**	**0**	**1**	**2**	**78**
	0.04	0.15	0.00	0.00	0.00	0.16
	0.25	1.05	0.00	0.01	0.03	1.15
	12.50	13.76	0.00	20.00	10.00	7.32
URBAN, ADT<=2K	**2**	**2**	**0**	**0**	**0**	**12**
	0.00	0.00	0.00	0.00	0.00	0.02
	0.33	0.33	0.00	0.00	0.00	1.99
	1.47	0.39	0.00	0.00	0.00	1.13
URBAN, ADT=2-6K	**9**	**31**	**0**	**0**	**0**	**47**
	0.02	0.06	0.00	0.00	0.00	0.10
	0.27	0.94	0.00	0.00	0.00	1.42
	6.62	6.01	0.00	0.00	0.00	4.41
URBAN, ADT>6K	**33**	**45**	**0**	**0**	**3**	**43**
	0.07	0.09	0.00	0.00	0.01	0.09
	0.38	0.52	0.00	0.00	0.03	0.50
	24.26	8.72	0.00	0.00	15.00	4.04
TOTAL	**136**	**516**	**2**	**5**	**20**	**1065**
	0.28	**1.07**	**0.00**	**0.01**	**0.04**	**2.21**

Table J-14. Crashes by Other Factors (continued).

Dev, ADT	OTHER FACTOR					
Frequency Percent Row Percent Col Percent	Swerved, Object in Road	Swerved, Slow Vehicle	Swerved, Vehicle Entering Road	Swerved, Avoiding Vehicle in Wrong Lane	Swerved, Avoiding Previous Accident	Slowed, Not Specified
RURAL, ADT<=2K	**37**	**58**	**81**	**181**	**3**	**99**
	0.08	0.12	0.17	0.38	0.01	0.21
	0.25	0.40	0.55	1.24	0.02	0.68
	40.22	18.01	31.15	41.61	75.00	21.57
RURAL, ADT=2-6K	**35**	**129**	**85**	**153**	**0**	**136**
	0.07	0.27	0.18	0.32	0.00	0.28
	0.25	0.91	0.60	1.08	0.00	0.96
	38.04	40.06	32.69	35.17	0.00	29.63
RURAL, ADT>6K	**14**	**67**	**34**	**42**	**1**	**76**
	0.03	0.14	0.07	0.09	0.00	0.16
	0.21	0.99	0.50	0.62	0.01	1.12
	15.22	20.81	13.08	9.66	25.00	16.56
URBAN, ADT<=2K	**0**	**4**	**5**	**4**	**0**	**4**
	0.00	0.01	0.01	0.01	0.00	0.01
	0.00	0.66	0.83	0.66	0.00	0.66
	0.00	1.24	1.92	0.92	0.00	0.87
URBAN, ADT=2-6K	**3**	**20**	**21**	**17**	**0**	**26**
	0.01	0.04	0.04	0.04	0.00	0.05
	0.09	0.61	0.64	0.52	0.00	0.79
	3.26	6.21	8.08	3.91	0.00	5.66
URBAN, ADT>6K	**3**	**44**	**34**	**38**	**0**	**118**
	0.01	0.09	0.07	0.08	0.00	0.25
	0.03	0.51	0.39	0.44	0.00	1.37
	3.26	13.66	13.08	8.74	0.00	25.71
TOTAL	**92**	**322**	**260**	**435**	**4**	**459**
	0.19	**0.67**	**0.54**	**0.90**	**0.01**	**0.95**

Table J-14. Crashes by Other Factors (continued).

Dev, ADT	OTHER FACTOR					
Frequency Percent Row Percent Col Percent	Slowed, Surface or Visibility	Slowed, Traffic Control	Slowed, Pedestrian or Cyclist	Slowed, Animal	Slowed, Object in Road	Slowed, Slow Vehicle
RURAL, ADT<=2K	**4**	**49**	**1**	**14**	**3**	**75**
	0.01	0.10	0.00	0.03	0.01	0.16
	0.03	0.34	0.01	0.10	0.02	0.51
	44.44	5.56	11.11	31.82	25.00	5.70
RURAL, ADT=2-6K	**4**	**118**	**2**	**18**	**5**	**241**
	0.01	0.25	0.00	0.04	0.01	0.50
	0.03	0.83	0.01	0.13	0.04	1.70
	44.44	13.38	22.22	40.91	41.67	18.33
RURAL, ADT>6K	**1**	**118**	**2**	**6**	**0**	**286**
	0.00	0.25	0.00	0.01	0.00	0.59
	0.01	1.74	0.03	0.09	0.00	4.23
	11.11	13.38	22.22	13.64	0.00	21.75
URBAN, ADT<=2K	**0**	**12**	**0**	**1**	**1**	**11**
	0.00	0.02	0.00	0.00	0.00	0.02
	0.00	1.99	0.00	0.17	0.17	1.83
	0.00	1.36	0.00	2.27	8.33	0.84
URBAN, ADT=2-6K	**0**	**111**	**2**	**2**	**0**	**88**
	0.00	0.23	0.00	0.00	0.00	0.18
	0.00	3.36	0.06	0.06	0.00	2.67
	0.00	12.59	22.22	4.55	0.00	6.69
URBAN, ADT>6K	**0**	**474**	**2**	**3**	**3**	**614**
	0.00	0.98	0.00	0.01	0.01	1.28
	0.00	5.49	0.02	0.03	0.03	7.11
	0.00	53.74	22.22	6.82	25.00	46.69
TOTAL	**9**	**882**	**9**	**44**	**12**	**1315**
	0.02	**1.83**	**0.02**	**0.09**	**0.02**	**2.73**

Table J-14. Crashes by Other Factors (continued).

Dev, ADT	OTHER FACTOR					
Frequency Percent Row Percent Col Percent	Slowed, Vehicle Entering Road	Slowed, Vehicle in Wrong Lane	Slowed, Avoiding Previous Accident	Slowed, Turning Right	Slowed, Turning Left	School Bus Related Accident
RURAL, ADT<=2K	**9**	**5**	**1**	**45**	**265**	**46**
	0.02	0.01	0.00	0.09	0.55	0.10
	0.06	0.03	0.01	0.31	1.81	0.31
	20.45	23.81	3.33	21.53	12.48	16.91
RURAL, ADT=2-6K	**15**	**7**	**11**	**65**	**657**	**97**
	0.03	0.01	0.02	0.14	1.37	0.20
	0.11	0.05	0.08	0.46	4.63	0.68
	34.09	33.33	36.67	31.10	30.95	35.66
RURAL, ADT>6K	**8**	**4**	**6**	**37**	**560**	**50**
	0.02	0.01	0.01	0.08	1.16	0.10
	0.12	0.06	0.09	0.55	8.27	0.74
	18.18	19.05	20.00	17.70	26.38	18.38
URBAN, ADT<=2K	**0**	**0**	**0**	**2**	**22**	**2**
	0.00	0.00	0.00	0.00	0.05	0.00
	0.00	0.00	0.00	0.33	3.65	0.33
	0.00	0.00	0.00	0.96	1.04	0.74
URBAN, ADT=2-6K	**3**	**2**	**2**	**13**	**162**	**24**
	0.01	0.00	0.00	0.03	0.34	0.05
	0.09	0.06	0.06	0.39	4.91	0.73
	6.82	9.52	6.67	6.22	7.63	8.82
URBAN, ADT>6K	**9**	**3**	**10**	**47**	**457**	**53**
	0.02	0.01	0.02	0.10	0.95	0.11
	0.10	0.03	0.12	0.54	5.29	0.61
	20.45	14.29	33.33	22.49	21.53	19.49
TOTAL	**44**	**21**	**30**	**209**	**2123**	**272**
	0.09	**0.04**	**0.06**	**0.43**	**4.41**	**0.57**

Table J-14. Crashes by Other Factors (continued).

Dev, ADT	OTHER FACTOR					
Frequency Percent Row Percent Col Percent	Highway Construction Unrelated to Construction	Highway Construction Related to Construction	Other Construction Area Unrelated to Construction	Other Construction Area Related to Construction	Accident on Beach	TOTAL
RURAL, ADT<=2K	**302**	**85**	**0**	**5**	**0**	**14,622**
	0.63	0.18	0.00	0.01	0.00	30.38
	2.07	0.58	0.00	0.03	0.00	
	19.09	27.42	0.00	35.71		
RURAL, ADT=2-6K	**358**	**79**	**0**	**3**	**0**	**14,199**
	0.74	0.16	0.00	0.01	0.00	29.50
	2.52	0.56	0.00	0.02	0.00	
	22.63	25.48	0.00	21.43		
RURAL, ADT>6K	**292**	**60**	**0**	**3**	**0**	**6768**
	0.61	0.12	0.00	0.01	0.00	14.06
	4.31	0.89	0.00	0.04	0.00	
	18.46	19.35	0.00	21.43		
URBAN, ADT<=2K	**23**	**1**	**0**	**0**	**0**	**602**
	0.05	0.00	0.00	0.00	0.00	1.25
	3.82	0.17	0.00	0.00	0.00	
	1.45	0.32	0.00	0.00		
URBAN, ADT=2-6K	**111**	**19**	**0**	**2**	**0**	**3300**
	0.23	0.04	0.00	0.00	0.00	6.86
	3.36	0.58	0.00	0.06	0.00	
	7.02	6.13	0.00	14.29		
URBAN, ADT>6K	**496**	**66**	**1**	**1**	**0**	**8638**
	1.03	0.14	0.00	0.00	0.00	17.95
	5.74	0.76	0.01	0.01	0.00	
	31.35	21.29	100.00	7.14		
TOTAL	**1582**	**310**	**1**	**14**	**0**	**48,129**
	3.29	**0.64**	**0.00**	**0.03**	**0.00**	**100.00**

CRASHES BY THREE DISTRICT GROUPS

Tables K-1 to K-14 provide the crash frequencies and distributions for on-system, rural two-lane highways by three district groups. The source of the data was the Traffic Accident Database provided by the Texas Department of Public Safety and the Texas Department of Transportation. The data are from 1997 to 1999 for low-volume (ADT ≤ 2000), rural two-lane highways.

Table K-1. Crashes by Accident Severity.

District	Accident Severity			
Frequency Percent Row Percent Col Percent	**Non-incapacitating Injury**	**Incapacitating Injury**	**Fatal**	**TOTAL**
HIGH-RATE DISTRICT	**4107**	**1949**	**578**	**6634**
	28.09	13.33	3.95	45.37
	61.91	29.38	8.71	
	45.99	44.83	43.01	
MID-RATE DISTRICT	**3204**	**1581**	**476**	**5261**
	21.91	10.81	3.26	35.98
	60.90	30.05	9.05	
	35.88	36.36	35.42	
LOW-RATE DISTRICT	**1619**	**818**	**290**	**2727**
	11.07	5.59	1.98	18.65
	59.37	30.00	10.63	
	18.13	18.81	21.58	
TOTAL	**8930**	**4348**	**1344**	14622
	61.07	**29.74**	**9.19**	100

APPENDIX K: CRASHES BY DISTRICT GROUPS

Table K-2. Crashes by Intersection Related.

District	Intersection Related				
Frequency Percent Row Percent Col Percent	Intersection	Intersection Related	Driveway Access	Non Intersection	TOTAL
HIGH-RATE DISTRICT	**1025**	**578**	**696**	**4335**	**0**
	7.01	3.95	4.76	29.65	0.00
	15.45	8.71	10.49	65.35	0.00
	45.60	42.94	54.85	44.42	
MID-RATE DISTRICT	**874**	**535**	**426**	**3426**	**0**
	5.98	3.66	2.91	23.43	0.00
	16.61	10.17	8.10	65.12	0.00
	38.88	39.75	33.57	35.11	
LOW-RATE DISTRICT	**349**	**233**	**147**	**1998**	**0**
	2.39	1.59	1.01	13.66	0.00
	12.80	8.54	5.39	73.27	0.00
	15.52	17.31	11.58	20.47	
TOTAL	**2248**	**1346**	**1269**	**9759**	**0**
	15.37	**9.21**	**8.68**	**66.74**	**0.00**

Table K-3. Crashes by First Harmful Event.

District	First Harmful Event					
Frequency Percent Row Percent Col Percent	Other Non-Collision	Overturned	Pedestrian	Other Motor Vehicle in Transit	RR Train	Parked Car
HIGH-RATE DISTRICT	**44**	**1746**	**59**	**2139**	**9**	**39**
	0.30	11.94	0.40	14.63	0.06	0.27
	0.66	26.32	0.89	32.24	0.14	0.59
	36.07	41.48	40.69	47.03	25.71	54.17
MID-RATE DISTRICT	**43**	**1403**	**65**	**1677**	**16**	**19**
	0.29	9.60	0.44	11.47	0.11	0.13
	0.82	26.67	1.24	31.88	0.30	0.36
	35.25	33.33	44.83	36.87	45.71	26.39
LOW-RATE DISTRICT	**35**	**1060**	**21**	**732**	**10**	**14**
	0.24	7.25	0.14	5.01	0.07	0.10
	1.28	38.87	0.77	26.84	0.37	0.51
	28.69	25.18	14.48	16.09	28.57	19.44
TOTAL	**122**	**4209**	**145**	**4548**	**35**	**72**
	0.83	**28.79**	**0.99**	**31.10**	**0.24**	**0.49**

Table K-3. Crashes by First Harmful Event (continued).

District	First Harmful Event				
Frequency Percent Row Percent Col Percent	Pedalcyclist	Animal	Fixed Object	Other Object	TOTAL
HIGH-RATE DISTRICT	**29**	**240**	**2301**	**28**	**0**
	0.20	1.64	15.74	0.19	0.00
	0.44	3.62	34.68	0.42	0.00
	40.85	37.68	48.55	63.64	
MID-RATE DISTRICT	**26**	**241**	**1760**	**11**	**0**
	0.18	1.65	12.04	0.08	0.00
	0.49	4.58	33.45	0.21	0.00
	36.62	37.83	37.14	25.00	
LOW-RATE DISTRICT	**16**	**156**	**678**	**5**	**0**
	0.11	1.07	4.64	0.03	0.00
	0.59	5.72	24.86	0.18	0.00
	22.54	24.49	14.31	11.36	
TOTAL	**71**	**637**	**4739**	**44**	**0**
	0.49	**4.36**	**32.41**	**0.30**	**0.00**

Table K-4. Crashes by Object Struck.

District	Object Struck						
Frequency Percent Row Percent Col Percent	No Code Applicable	Vehicle Over-turned	Hole in Road	Vehicle Jack-knifed	Person Fell or Jumped from Vehicle	Vehicle Hit Train on Parallel Tracks	Train Moving Forward
HIGH-RATE DISTRICT	**3218**	**100**	**3**	**9**	**30**	**1**	**9**
	22.01	0.68	0.02	0.06	0.21	0.01	0.06
	48.51	1.51	0.05	0.14	0.45	0.02	0.14
	44.32	43.48	37.50	27.27	44.12	100.00	26.47
MID-RATE DISTRICT	**2577**	**72**	**4**	**12**	**24**	**0**	**15**
	17.62	0.49	0.03	0.08	0.16	0.00	0.10
	48.98	1.37	0.08	0.23	0.46	0.00	0.29
	35.49	31.30	50.00	36.36	35.29	0.00	44.12
LOW-RATE DISTRICT	**1466**	**58**	**1**	**12**	**14**	**0**	**10**
	10.03	0.40	0.01	0.08	0.10	0.00	0.07
	53.76	2.13	0.04	0.44	0.51	0.00	0.37
	20.19	25.22	12.50	36.36	20.59	0.00	29.41
TOTAL	**7261**	**230**	**8**	**33**	**68**	**1**	**34**
	49.66	**1.57**	**0.05**	**0.23**	**0.47**	**0.01**	**0.23**

Table K-4. Crashes by Object Struck (continued).

District	Object Struck						
Frequency Percent Row Percent Col Percent	Train Backing	Train Standing Still	Train/ Action Unknown	Highway Sign	Curb	Culvert/ Headwall	Guardrail
HIGH-RATE DISTRICT	**0**	**0**	**0**	**241**	**6**	**383**	**67**
	0.00	0.00	0.00	1.65	0.04	2.62	0.46
	0.00	0.00	0.00	3.63	0.09	5.77	1.01
		0.00		44.14	42.86	52.68	38.73
MID-RATE DISTRICT	**0**	**1**	**0**	**219**	**5**	**236**	**61**
	0.00	0.01	0.00	1.50	0.03	1.61	0.42
	0.00	0.02	0.00	4.16	0.10	4.49	1.16
		100.00		40.11	35.71	32.46	35.26
LOW-RATE DISTRICT	**0**	**0**	**0**	**86**	**3**	**108**	**45**
	0.00	0.00	0.00	0.59	0.02	0.74	0.31
	0.00	0.00	0.00	3.15	0.11	3.96	1.65
		0.00		15.75	21.43	14.86	26.01
TOTAL	**0**	**1**	**0**	**546**	**14**	**727**	**173**
	0.00	**0.01**	**0.00**	**3.73**	**0.10**	**4.97**	**1.18**

Table K-4. Crashes by Object Struck (continued).

District	Object Struck						
Frequency Percent Row Percent Col Percent	RR Signal Pole	RR Crossing Gates	Signal Pole/Post	Signal Light/Wires	Work Zone Barricade	Luminaire Pole	Utility Pole
HIGH-RATE DISTRICT	**4**	**2**	**5**	**0**	**1**	**9**	**112**
	0.03	0.01	0.03	0.00	0.01	0.06	0.77
	0.06	0.03	0.08	0.00	0.02	0.14	1.69
	50.00	66.67	38.46		33.33	56.25	37.33
MID-RATE DISTRICT	**3**	**1**	**7**	**0**	**1**	**4**	**124**
	0.02	0.01	0.05	0.00	0.01	0.03	0.85
	0.06	0.02	0.13	0.00	0.02	0.08	2.36
	37.50	33.33	53.85		33.33	25.00	41.33
LOW-RATE DISTRICT	**1**	**0**	**1**	**0**	**1**	**3**	**64**
	0.01	0.00	0.01	0.00	0.01	0.02	0.44
	0.04	0.00	0.04	0.00	0.04	0.11	2.35
	12.50	0.00	7.69		33.33	18.75	21.33
TOTAL	**8**	**3**	**13**	**0**	**3**	**16**	**300**
	0.05	**0.02**	**0.09**	**0.00**	**0.02**	**0.11**	**2.05**

Table K-4. Crashes by Object Struck (continued).

District	Object Struck						
Frequency Percent Row Percent Col Percent	Mailbox	Tree/Shrub	Fence	House/ Building	Commercial Sign	Other Fixed Object	Maintenance Barricade or Materials
HIGH-RATE DISTRICT	**89**	**879**	**837**	**16**	**2**	**128**	**1**
	0.61	6.01	5.72	0.11	0.01	0.88	0.01
	1.34	13.25	12.62	0.24	0.03	1.93	0.02
	53.94	62.30	42.44	36.36	28.57	37.87	50.00
MID-RATE DISTRICT	**67**	**460**	**762**	**16**	**4**	**136**	**1**
	0.46	3.15	5.21	0.11	0.03	0.93	0.01
	1.27	8.74	14.48	0.30	0.08	2.59	0.02
	40.61	32.60	38.64	36.36	57.14	40.24	50.00
LOW-RATE DISTRICT	**9**	**72**	**373**	**12**	**1**	**74**	**0**
	0.06	0.49	2.55	0.08	0.01	0.51	0.00
	0.33	2.64	13.68	0.44	0.04	2.71	0.00
	5.45	5.10	18.91	27.27	14.29	21.89	0.00
TOTAL	**165**	**1411**	**1972**	**44**	**7**	**338**	**2**
	1.13	**9.65**	**13.49**	**0.30**	**0.05**	**2.31**	**0.01**

Table K-4. Crashes by Object Struck (continued).

District	Object Struck						
Frequency Percent Row Percent Col Percent	Median Barrier	End of Bridge	Side of Bridge	Pier at Underpass	Top of Underpass	Bridge Crossing Gate	Attenuation Device
HIGH-RATE DISTRICT	**2**	**23**	**57**	**1**	**0**	**0**	**0**
	0.01	0.16	0.39	0.01	0.00	0.00	0.00
	0.03	0.35	0.86	0.02	0.00	0.00	0.00
	28.57	37.10	34.97	20.00			
MID-RATE DISTRICT	**2**	**29**	**69**	**2**	**0**	**0**	**0**
	0.01	0.20	0.47	0.01	0.00	0.00	0.00
	0.04	0.55	1.31	0.04	0.00	0.00	0.00
	28.57	46.77	42.33	40.00			
LOW-RATE DISTRICT	**3**	**10**	**37**	**2**	**0**	**0**	**0**
	0.02	0.07	0.25	0.01	0.00	0.00	0.00
	0.11	0.37	1.36	0.07	0.00	0.00	0.00
	42.86	16.13	22.70	40.00			
TOTAL	**7**	**62**	**163**	**5**	**0**	**0**	**0**
	0.05	**0.42**	**1.11**	**0.03**	**0.00**	**0.00**	**0.00**

Table K-4. Crashes by Object Struck (continued).

District	Object Struck						
Frequency Percent Row Percent Col Percent	**Rocks from Trucks**	**Debris on Road**	**Object from Another Vehicle**	**Previously Wrecked Vehicle**	**Other Machinery**	**Other Object**	**Concrete Traffic Barrier**
HIGH-RATE DISTRICT	**0**	**8**	**4**	**9**	**2**	**18**	**0**
	0.00	0.05	0.03	0.06	0.01	0.12	0.00
	0.00	0.12	0.06	0.14	0.03	0.27	0.00
		66.67	66.67	47.37	40.00	48.65	0.00
MID-RATE DISTRICT	**0**	**3**	**1**	**6**	**1**	**17**	**2**
	0.00	0.02	0.01	0.04	0.01	0.12	0.01
	0.00	0.06	0.02	0.11	0.02	0.32	0.04
		25.00	16.67	31.58	20.00	45.95	66.67
LOW-RATE DISTRICT	**0**	**1**	**1**	**4**	**2**	**2**	**1**
	0.00	0.01	0.01	0.03	0.01	0.01	0.01
	0.00	0.04	0.04	0.15	0.07	0.07	0.04
		8.33	16.67	21.05	40.00	5.41	33.33
TOTAL	**0**	**12**	**6**	**19**	**5**	**37**	**3**
	0.00	**0.08**	**0.04**	**0.13**	**0.03**	**0.25**	**0.02**

Table K-4. Crashes by Object Struck (continued).

District	Object Struck							
Frequency Percent Row Percent Col Percent	**Delineator Post**	**Retaining Wall**	**HOV Lane Gate**	**Guard Post**	**Fire Hydrant**	**Ditch (Earth)**	**Embank-ment**	**TOTAL**
HIGH-RATE DISTRICT	**46**	**3**	**0**	**0**	**0**	**145**	**164**	**6634**
	0.31	0.02	0.00	0.00	0.00	0.99	1.12	**45.37**
	0.69	0.05	0.00	0.00	0.00	2.19	2.47	
	24.34	42.86		0.00	0.00	40.39	44.93	
MID-RATE DISTRICT	**61**	**2**	**0**	**0**	**3**	**128**	**123**	**5261**
	0.42	0.01	0.00	0.00	0.02	0.88	0.84	**35.98**
	1.16	0.04	0.00	0.00	0.06	2.43	2.34	
	32.28	28.57		0.00	100.00	35.65	33.70	
LOW-RATE DISTRICT	**82**	**2**	**0**	**2**	**0**	**86**	**78**	**2727**
	0.56	0.01	0.00	0.01	0.00	0.59	0.53	**18.65**
	3.01	0.07	0.00	0.07	0.00	3.15	2.86	
	43.39	28.57		100.00	0.00	23.96	21.37	
TOTAL	**189**	**7**	**0**	**2**	**3**	**359**	**365**	**14,622**
	1.29	**0.05**	**0.00**	**0.01**	**0.02**	**2.46**	**2.50**	**100.00**

Table K-5. Crashes by Alignment.

District	Alignment						
Percent Frequency Row Percent Col Percent	Straight, Level	Straight, Grade	Straight, Hillcrest	Curve, Level	Curve, Grade	Curve, Hillcrest	TOTAL
HIGH-RATE DISTRICT	**4021**	**23**	**97**	**2462**	**10**	**21**	**6634**
	27.50	0.16	0.66	16.84	0.07	0.14	**45.37**
	60.61	0.35	1.46	37.11	0.15	0.32	
	41.82	46.00	58.08	52.09	45.45	50.00	
MID-RATE DISTRICT	**3567**	**18**	**51**	**1609**	**5**	**11**	**5261**
	24.39	0.12	0.35	11.00	0.03	0.08	**35.98**
	67.80	0.34	0.97	30.58	0.10	0.21	
	37.10	36.00	30.54	34.05	22.73	26.19	
LOW-RATE DISTRICT	**2027**	**9**	**19**	**655**	**7**	**10**	**2727**
	13.86	0.06	0.13	4.48	0.05	0.07	**18.65**
	74.33	0.33	0.70	24.02	0.26	0.37	
	21.08	18.00	11.38	13.86	31.82	23.81	
TOTAL	**9615**	**50**	**167**	**4726**	**22**	**42**	**14,622**
	65.76	**0.34**	**1.14**	**32.32**	**0.15**	**0.29**	**100.00**

Table K-6. Crashes by Degree of Curve.

District	Degree of Curve						
Frequency Percent Row Percent Col Percent	Unknown	No Curve	0.1 to 1.9	2.0 to 3.9	4.0 to 5.9	6.0 to 7.9	8.0 to 9.9
HIGH-RATE DISTRICT	**249**	**3663**	**333**	**705**	**618**	**342**	**179**
	1.70	25.05	2.28	4.82	4.23	2.34	1.22
	3.75	55.22	5.02	10.63	9.32	5.16	2.70
	41.43	41.38	47.91	50.94	51.72	60.42	63.03
MID-RATE DISTRICT	**251**	**3242**	**263**	**448**	**422**	**180**	**84**
	1.72	22.17	1.80	3.06	2.89	1.23	0.57
	4.77	61.62	5.00	8.52	8.02	3.42	1.60
	41.76	36.62	37.84	32.37	35.31	31.80	29.58
LOW-RATE DISTRICT	**101**	**1948**	**99**	**231**	**155**	**44**	**21**
	0.69	13.32	0.68	1.58	1.06	0.30	0.14
	3.70	71.43	3.63	8.47	5.68	1.61	0.77
	16.81	22.00	14.24	16.69	12.97	7.77	7.39
TOTAL	**601**	**8853**	**695**	**1384**	**1195**	**566**	**284**
	4.11	**60.55**	**4.75**	**9.47**	**8.17**	**3.87**	**1.94**

Table K-6. Crashes by Degree of Curve (continued).

District	Degree of Curve							
Frequency Percent Row Percent Col Percent	10.0 to 11.9	12.0 to 13.9	14.0 to 15.9	16.0 to 17.9	18.0 and Over	TOTAL	0 to 3.9	4 to 18+
HIGH-RATE DISTRICT	**209**	**59**	**61**	**17**	**199**	**6634**	**1038**	**1684**
	1.43	0.40	0.42	0.12	1.36	45.37		
	3.15	0.89	0.92	0.26	3.00		15.65	25.38
	45.83	55.14	55.45	54.84	58.53			
MID-RATE DISTRICT	**180**	**41**	**40**	**12**	**98**	**5261**	**711**	**1057**
	1.23	0.28	0.27	0.08	0.67	35.98		
	3.42	0.78	0.76	0.23	1.86		13.51	20.09
	39.47	38.32	36.36	38.71	28.82			
LOW-RATE DISTRICT	**67**	**7**	**9**	**2**	**43**	**2727**	**330**	**348**
	0.46	0.05	0.06	0.01	0.29	18.65		
	2.46	0.26	0.33	0.07	1.58		12.10	12.76
	14.69	6.54	8.18	6.45	12.65			
TOTAL	**456**	**107**	**110**	**31**	**340**	**14,622**		
	3.12	**0.73**	**0.75**	**0.21**	**2.33**	**100.00**		

Table K-7. Crashes by Weather.

District	Weather			
Frequency Percent Row Percent Col Percent	Clear (Cloudy)	Raining	Snowing	Fog
HIGH-RATE DISTRICT	**5930**	**520**	**10**	**161**
	40.56	3.56	0.07	1.10
	89.39	7.84	0.15	2.43
	45.43	49.20	17.54	40.76
MID-RATE DISTRICT	**4692**	**364**	**10**	**174**
	32.09	2.49	0.07	1.19
	89.18	6.92	0.19	3.31
	35.94	34.44	17.54	44.05
LOW-RATE DISTRICT	**2432**	**173**	**37**	**60**
	16.63	1.18	0.25	0.41
	89.18	6.34	1.36	2.20
	18.63	16.37	64.91	15.19
TOTAL	**13,054**	**1057**	**57**	**395**
	89.28	**7.23**	**0.39**	**2.70**

Table K-7. Crashes by Weather (continued).

District	Weather				
Frequency Percent Row Percent Col Percent	**Blowing Dust**	**Smoke**	**Other**	**Sleeting**	**TOTAL**
HIGH-RATE DISTRICT	**0**	**2**	**1**	**10**	**6634**
	0.00	0.01	0.01	0.07	**45.37**
	0.00	0.03	0.02	0.15	
	0.00	40.00	9.09	26.32	
MID-RATE DISTRICT	**1**	**1**	**4**	**15**	**5261**
	0.01	0.01	0.03	0.10	**35.98**
	0.02	0.02	0.08	0.29	
	20.00	20.00	36.36	39.47	
LOW-RATE DISTRICT	**4**	**2**	**6**	**13**	**2727**
	0.03	0.01	0.04	0.09	**18.65**
	0.15	0.07	0.22	0.48	
	80.00	40.00	54.55	34.21	
TOTAL	**5**	**5**	**11**	**38**	**14,622**
	0.03	**0.03**	**0.08**	**0.26**	**100.00**

Table K-8. Crashes by Surface Condition.

District	Surface Condition					
Frequency Percent Row Percent Col Percent	**Dry**	**Wet**	**Muddy**	**Snowy**	**Icy**	**TOTAL**
HIGH-RATE DISTRICT	**5655**	**949**	**2**	**28**	**0**	**6634**
	38.67	6.49	0.01	0.19	0.00	**45.37**
	85.24	14.31	0.03	0.42	0.00	
	45.10	49.71	28.57	16.77		
MID-RATE DISTRICT	**4527**	**684**	**3**	**47**	**0**	**5261**
	30.96	4.68	0.02	0.32	0.00	**35.98**
	86.05	13.00	0.06	0.89	0.00	
	36.10	35.83	42.86	28.14		
LOW-RATE DISTRICT	**2357**	**276**	**2**	**92**	**0**	**2727**
	16.12	1.89	0.01	0.63	0.00	**18.65**
	86.43	10.12	0.07	3.37	0.00	
	18.80	14.46	28.57	55.09		
TOTAL	**12,539**	**1909**	**7**	**167**	**0**	**14,622**
	85.75	**13.06**	**0.05**	**1.14**	**0.00**	**100.00**

Table K-9. Crashes by Light Condition.

District	Light Condition					
Frequency Percent Row Percent Col Percent	Daylight	Dawn	Dark Not Lighted	Dark Lighted	Dusk	TOTAL
HIGH-RATE DISTRICT	**3828**	**123**	**2383**	**171**	**129**	**6634**
	26.18	0.84	16.30	1.17	0.88	**45.37**
	57.70	1.85	35.92	2.58	1.94	
	45.91	45.72	44.59	43.96	45.74	
MID-RATE DISTRICT	**2919**	**90**	**2000**	**144**	**108**	**5261**
	19.96	0.62	13.68	0.98	0.74	**35.98**
	55.48	1.71	38.02	2.74	2.05	
	35.01	33.46	37.43	37.02	38.30	
LOW-RATE DISTRICT	**1591**	**56**	**961**	**74**	**45**	**2727**
	10.88	0.38	6.57	0.51	0.31	**18.65**
	58.34	2.05	35.24	2.71	1.65	
	19.08	20.82	17.98	19.02	15.96	
TOTAL	**8338**	**269**	**5344**	**389**	**282**	**14,622**
	57.02	**1.84**	**36.55**	**2.66**	**1.93**	**100.00**

Table K-10. Crashes by Month.

District	Month						
Frequency Percent Row Percent Col Percent	January	February	March	April	May	June	July
HIGH-RATE DISTRICT	**466**	**455**	**514**	**555**	**598**	**495**	**628**
	3.19	3.11	3.52	3.80	4.09	3.39	4.29
	7.02	6.86	7.75	8.37	9.01	7.46	9.47
	44.05	46.24	44.20	46.37	44.86	41.53	45.61
MID-RATE DISTRICT	**385**	**353**	**429**	**421**	**489**	**472**	**489**
	2.63	2.41	2.93	2.88	3.34	3.23	3.34
	7.32	6.71	8.15	8.00	9.29	8.97	9.29
	36.39	35.87	36.89	35.17	36.68	39.60	35.51
LOW-RATE DISTRICT	**207**	**176**	**220**	**221**	**246**	**225**	**260**
	1.42	1.20	1.50	1.51	1.68	1.54	1.78
	7.59	6.45	8.07	8.10	9.02	8.25	9.53
	19.57	17.89	18.92	18.46	18.45	18.88	18.88
TOTAL	**1058**	**984**	**1163**	**1197**	**1333**	**1192**	**1377**
	7.24	**6.73**	**7.95**	**8.19**	**9.12**	**8.15**	**9.42**

Table K-10. Crashes by Month (continued).

District	Month					
Frequency Percent Row Percent Col Percent	August	September	October	November	December	TOTAL
HIGH-RATE DISTRICT	**571**	**553**	**605**	**588**	**606**	**6634**
	3.91	3.78	4.14	4.02	4.14	**45.37**
	8.61	8.34	9.12	8.86	9.13	
	46.84	46.16	45.45	45.69	47.23	
MID-RATE DISTRICT	**420**	**440**	**485**	**445**	**433**	**5261**
	2.87	3.01	3.32	3.04	2.96	**35.98**
	7.98	8.36	9.22	8.46	8.23	
	34.45	36.73	36.44	34.58	33.75	
LOW-RATE DISTRICT	**228**	**205**	**241**	**254**	**244**	**2727**
	1.56	1.40	1.65	1.74	1.67	**18.65**
	8.36	7.52	8.84	9.31	8.95	
	18.70	17.11	18.11	19.74	19.02	
TOTAL	**1219**	**1198**	**1331**	**1287**	**1283**	**14,622**
	8.34	**8.19**	**9.10**	**8.80**	**8.77**	**100.00**

Table K-11. Crashes by Day of Week.

District	Day of Week							
Frequency Percent Row Percent Col Percent	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	TOTAL
HIGH-RATE DISTRICT	**1090**	**781**	**740**	**855**	**837**	**1111**	**1220**	**6634**
	7.45	5.34	5.06	5.85	5.72	7.60	8.34	**45.37**
	16.43	11.77	11.15	12.89	12.62	16.75	18.39	
	44.51	43.10	44.77	47.79	45.29	47.89	44.35	
MID-RATE DISTRICT	**902**	**635**	**614**	**599**	**681**	**809**	**1021**	**5261**
	6.17	4.34	4.20	4.10	4.66	5.53	6.98	**35.98**
	17.15	12.07	11.67	11.39	12.94	15.38	19.41	
	36.83	35.04	37.14	33.48	36.85	34.87	37.11	
LOW-RATE DISTRICT	**457**	**396**	**299**	**335**	**330**	**400**	**510**	**2727**
	3.13	2.71	2.04	2.29	2.26	2.74	3.49	**18.65**
	16.76	14.52	10.96	12.28	12.10	14.67	18.70	
	18.66	21.85	18.09	18.73	17.86	17.24	18.54	
TOTAL	**2449**	**1812**	**1653**	**1789**	**1848**	**2320**	**2751**	**14,622**
	16.75	**12.39**	**11.30**	**12.23**	**12.64**	**15.87**	**18.81**	**100.00**

Table K-12. Crashes by Time.

District	Time					
Frequency Percent Row Percent Col Percent	Midnight - 12:59 AM	1-1:59 AM	2-2:59 AM	3-3:59 AM	4-4:59 AM	5-5:59 AM
HIGH-RATE DISTRICT	**214**	**193**	**176**	**112**	**107**	**146**
	1.46	1.32	1.20	0.77	0.73	1.00
	3.23	2.91	2.65	1.69	1.61	2.20
	41.80	40.72	42.41	38.89	39.34	43.71
MID-RATE DISTRICT	**198**	**201**	**164**	**110**	**102**	**114**
	1.35	1.37	1.12	0.75	0.70	0.78
	3.76	3.82	3.12	2.09	1.94	2.17
	38.67	42.41	39.52	38.19	37.50	34.13
LOW-RATE DISTRICT	**100**	**80**	**75**	**66**	**63**	**74**
	0.68	0.55	0.51	0.45	0.43	0.51
	3.67	2.93	2.75	2.42	2.31	2.71
	19.53	16.88	18.07	22.92	23.16	22.16
TOTAL	**512**	**474**	**415**	**288**	**272**	**334**
	3.50	**3.24**	**2.84**	**1.97**	**1.86**	**2.28**

Table K-12. Crashes by Time (continued).

District	Time					
Frequency Percent Row Percent Col Percent	6-6:59 AM	7-7:59 AM	8-8:59 AM	9-9:59 AM	10-10:59 AM	11-11:59 AM
HIGH-RATE DISTRICT	**202**	**344**	**226**	**202**	**248**	**260**
	1.38	2.35	1.55	1.38	1.70	1.78
	3.04	5.19	3.41	3.04	3.74	3.92
	43.07	48.38	43.38	45.19	48.63	42.98
MID-RATE DISTRICT	**171**	**244**	**181**	**151**	**166**	**223**
	1.17	1.67	1.24	1.03	1.14	1.53
	3.25	4.64	3.44	2.87	3.16	4.24
	36.46	34.32	34.74	33.78	32.55	36.86
LOW-RATE DISTRICT	**96**	**123**	**114**	**94**	**96**	**122**
	0.66	0.84	0.78	0.64	0.66	0.83
	3.52	4.51	4.18	3.45	3.52	4.47
	20.47	17.30	21.88	21.03	18.82	20.17
TOTAL	**469**	**711**	**521**	**447**	**510**	**605**
	3.21	**4.86**	**3.56**	**3.06**	**3.49**	**4.14**

Table K-12. Crashes by Time (continued).

District	Time					
Frequency Percent Row Percent Col Percent	NOON-12:59 PM	1-1:59 PM	2-2:59 PM	3-3:59 PM	4-4:59 PM	5-5:59 PM
HIGH-RATE DISTRICT	**274**	**291**	**313**	**440**	**432**	**429**
	1.87	1.99	2.14	3.01	2.95	2.93
	4.13	4.39	4.72	6.63	6.51	6.47
	45.36	45.05	45.83	48.67	47.95	45.74
MID-RATE DISTRICT	**211**	**242**	**229**	**320**	**297**	**345**
	1.44	1.66	1.57	2.19	2.03	2.36
	4.01	4.60	4.35	6.08	5.65	6.56
	34.93	37.46	33.53	35.40	32.96	36.78
LOW-RATE DISTRICT	**119**	**113**	**141**	**144**	**172**	**164**
	0.81	0.77	0.96	0.98	1.18	1.12
	4.36	4.14	5.17	5.28	6.31	6.01
	19.70	17.49	20.64	15.93	19.09	17.48
TOTAL	**604**	**646**	**683**	**904**	**901**	**938**
	4.13	**4.42**	**4.67**	**6.18**	**6.16**	**6.41**

Table K-12. Crashes by Time (continued).

District	Time						
Frequency Percent Row Percent Col Percent	6-6:59 PM	7-7:59 PM	8-8:59 PM	9-9:59 PM	10-10:59 PM	11-11:59 PM	TOTAL
HIGH-RATE DISTRICT	**441**	**321**	**345**	**351**	**303**	**264**	**6634**
	3.02	2.20	2.36	2.40	2.07	1.81	**45.37**
	6.65	4.84	5.20	5.29	4.57	3.98	
	47.22	43.20	47.46	47.30	44.96	46.48	
MID-RATE DISTRICT	**333**	**279**	**277**	**241**	**248**	**214**	**5261**
	2.28	1.91	1.89	1.65	1.70	1.46	**35.98**
	6.33	5.30	5.27	4.58	4.71	4.07	
	35.65	37.55	38.10	32.48	36.80	37.68	
LOW-RATE DISTRICT	**160**	**143**	**105**	**150**	**123**	**90**	**2727**
	1.09	0.98	0.72	1.03	0.84	0.62	**18.65**
	5.87	5.24	3.85	5.50	4.51	3.30	
	17.13	19.25	14.44	20.22	18.25	15.85	
TOTAL	**934**	**743**	**727**	**742**	**674**	**568**	**14,622**
	6.39	**5.08**	**4.97**	**5.07**	**4.61**	**3.88**	**100.00**

Table K-13. Crashes by Vehicle Movement.

District	Vehicle Movements / Manner of Collision					
Frequency Percent Row Percent Col Percent	Single Motor Vehicle Straight	Single Motor Vehicle Right Turn	Single Motor Vehicle Left Turn	Single Motor Vehicle Backing	Single Motor Vehicle Other	Angle Both Straight
HIGH-RATE DISTRICT	**4427**	**26**	**36**	**5**	**1**	**592**
	30.28	0.18	0.25	0.03	0.01	4.05
	66.73	0.39	0.54	0.08	0.02	8.92
	44.76	36.62	36.73	45.45	33.33	44.78
MID-RATE DISTRICT	**3515**	**23**	**40**	**4**	**2**	**527**
	24.04	0.16	0.27	0.03	0.01	3.60
	66.81	0.44	0.76	0.08	0.04	10.02
	35.54	32.39	40.82	36.36	66.67	39.86
LOW-RATE DISTRICT	**1949**	**22**	**22**	**2**	**0**	**203**
	13.33	0.15	0.15	0.01	0.00	1.39
	71.47	0.81	0.81	0.07	0.00	7.44
	19.70	30.99	22.45	18.18	0.00	15.36
TOTAL	**9891**	**71**	**98**	**11**	**3**	**1322**
	67.64	**0.49**	**0.67**	**0.08**	**0.02**	**9.04**

Table K-13. Crashes by Vehicle Movement (continued).

District	Vehicle Movements / Manner of Collision					
Frequency Percent Row Percent Col Percent	Angle 1 Straight 2 Backing	Angle 1 Straight 2 Stopped	Angle 1 Straight 2 Right Turn	Angle 1 Straight 2 Left Turn	Angle Both Right Turn	Angle 1 Right Turn 2 Left Turn
HIGH-RATE DISTRICT	**19**	**17**	**28**	**178**	**0**	**0**
	0.13	0.12	0.19	1.22	0.00	0.00
	0.29	0.26	0.42	2.68	0.00	0.00
	67.86	36.96	46.67	50.71		0.00
MID-RATE DISTRICT	**9**	**22**	**21**	**124**	**0**	**1**
	0.06	0.15	0.14	0.85	0.00	0.01
	0.17	0.42	0.40	2.36	0.00	0.02
	32.14	47.83	35.00	35.33		100.00
LOW-RATE DISTRICT	**0**	**7**	**11**	**49**	**0**	**0**
	0.00	0.05	0.08	0.34	0.00	0.00
	0.00	0.26	0.40	1.80	0.00	0.00
	0.00	15.22	18.33	13.96		0.00
TOTAL	**28**	**46**	**60**	**351**	**0**	**1**
	0.19	**0.31**	**0.41**	**2.40**	**0.00**	**0.01**

Table K-13. Crashes by Vehicle Movement (continued).

District	Vehicle Movements / Manner of Collision					
Frequency Percent Row Percent Col Percent	Angle 1 Right Turn 2 Stopped	Angle Both Left Turn	Angle 1 Left Turn 2 Stopped	Same Direction Both Straight Rear End	Same Direction Both Straight Sideswipe	Same Direction 1 Straight 2 Stopped
HIGH-RATE DISTRICT	**2**	**0**	**2**	**173**	**29**	**174**
	0.01	0.00	0.01	1.18	0.20	1.19
	0.03	0.00	0.03	2.61	0.44	2.62
	33.33		50.00	46.26	59.18	51.63
MID-RATE DISTRICT	**3**	**0**	**2**	**128**	**10**	**109**
	0.02	0.00	0.01	0.88	0.07	0.75
	0.06	0.00	0.04	2.43	0.19	2.07
	50.00		50.00	34.22	20.41	32.34
LOW-RATE DISTRICT	**1**	**0**	**0**	**73**	**10**	**54**
	0.01	0.00	0.00	0.50	0.07	0.37
	0.04	0.00	0.00	2.68	0.37	1.98
	16.67		0.00	19.52	20.41	16.02
TOTAL	**6**	**0**	**4**	**374**	**49**	**337**
	0.04	**0.00**	**0.03**	**2.56**	**0.34**	**2.30**

Table K-13. Crashes by Vehicle Movement (continued).

District	Vehicle Movements / Manner of Collision					
Frequency Percent Row Percent Col Percent	Same Direction 1 Straight 2 Right Turn	Same Direction 1 Straight 2 Left Turn	Same Direction Both Right Turn	Same Direction 1 Right Turn 2 Left Turn	Same Direction 1 Right Turn 2 Stopped	Same Direction Both Left Turn
HIGH-RATE DISTRICT	**42**	**220**	**0**	**0**	**1**	**0**
	0.29	1.50	0.00	0.00	0.01	0.00
	0.63	3.32	0.00	0.00	0.02	0.00
	39.25	41.43	0.00		100.00	
MID-RATE DISTRICT	**36**	**207**	**2**	**0**	**0**	**0**
	0.25	1.42	0.01	0.00	0.00	0.00
	0.68	3.93	0.04	0.00	0.00	0.00
	33.64	38.98	100.00		0.00	
LOW-RATE DISTRICT	**29**	**104**	**0**	**0**	**0**	**0**
	0.20	0.71	0.00	0.00	0.00	0.00
	1.06	3.81	0.00	0.00	0.00	0.00
	27.10	19.59	0.00		0.00	
TOTAL	**107**	**531**	**2**	**0**	**1**	**0**
	0.73	**3.63**	**0.01**	**0.00**	**0.01**	**0.00**

Table K-13. Crashes by Vehicle Movement (continued).

District	Vehicle Movements / Manner of Collision					
Frequency Percent Row Percent Col Percent	Same Direction 1 Left Turn 2 Stopped	Opposite Directions Both Straight	Opposite Directions 1 Straight 2 Backing	Opposite Directions 1 Straight 2 Stopped	Opposite Directions 1 Straight 2 Right Turn	Opposite Directions 1 Straight 2 Left Turn
HIGH-RATE DISTRICT	**0**	**378**	**2**	**9**	**2**	**257**
	0.00	2.59	0.01	0.06	0.01	1.76
	0.00	5.70	0.03	0.14	0.03	3.87
		50.67	66.67	45.00	50.00	48.95
MID-RATE DISTRICT	**0**	**253**	**0**	**8**	**1**	**203**
	0.00	1.73	0.00	0.05	0.01	1.39
	0.00	4.81	0.00	0.15	0.02	3.86
		33.91	0.00	40.00	25.00	38.67
LOW-RATE DISTRICT	**0**	**115**	**1**	**3**	**1**	**65**
	0.00	0.79	0.01	0.02	0.01	0.44
	0.00	4.22	0.04	0.11	0.04	2.38
		15.42	33.33	15.00	25.00	12.38
TOTAL	**0**	**746**	**3**	**20**	**4**	**525**
	0.00	**5.10**	**0.02**	**0.14**	**0.03**	**3.59**

Table K-13. Crashes by Vehicle Movement (continued).

District	Vehicle Movements / Manner of Collision					
Frequency Percent Row Percent Col Percent	Opposite Directions 1 Backing 2 Stopped	Opposite Directions 1 Right Turn 2 Left Turn	Opposite Directions 1 Right Turn 2 Stopped	Opposite Directions Both Left Turn	Opposite Directions 1 Left Turn 2 Stopped	Other 1 Straight 2 Parked
HIGH-RATE DISTRICT	**0**	**1**	**0**	**0**	**0**	**7**
	0.00	0.01	0.00	0.00	0.00	0.05
	0.00	0.02	0.00	0.00	0.00	0.11
		50.00		0.00		35.00
MID-RATE DISTRICT	**0**	**1**	**1**	**1**	**0**	**8**
	0.00	0.01	0.01	0.01	0.00	0.05
	0.00	0.02	0.02	0.02	0.00	0.15
		50.00		100.00		40.00
LOW-RATE DISTRICT	**0**	**0**	**0**	**0**	**0**	**5**
	0.00	0.00	0.00	0.00	0.00	0.03
	0.00	0.00	0.00	0.00	0.00	0.18
		0.00		0.00		25.00
TOTAL	**0**	**2**	**1**	**1**	**0**	**20**
	0.00	**0.01**	**0.01**	**0.01**	**0.00**	**0.14**

Table K-13. Crashes by Vehicle Movement (continued).

District	Vehicle Movements / Manner of Collision						
Frequency Percent Row Percent Col Percent	Other 1 Right Turn 2 Parked	Other 1 Left Turn 2 Parked	Other 1 Parked 2 Stopped	Other Both Parked	Other Both Backing	Other All Others	TOTAL
HIGH-RATE DISTRICT	**0**	**0**	**0**	**0**	**0**	**6**	**6634**
	0.00	0.00	0.00	0.00	0.00	0.04	**45.37**
	0.00	0.00	0.00	0.00	0.00	0.09	
						85.71	
MID-RATE DISTRICT	**0**	**0**	**0**	**0**	**0**	**0**	**5261**
	0.00	0.00	0.00	0.00	0.00	0.00	**35.98**
	0.00	0.00	0.00	0.00	0.00	0.00	
						0.00	
LOW-RATE DISTRICT	**0**	**0**	**0**	**0**	**0**	**1**	**2727**
	0.00	0.00	0.00	0.00	0.00	0.01	**18.65**
	0.00	0.00	0.00	0.00	0.00	0.04	
						14.29	
TOTAL	**0**	**0**	**0**	**0**	**0**	**7**	**14,622**
	0.00	**0.00**	**0.00**	**0.00**	**0.00**	**0.05**	**100.00**

Table K-14. Crashes by Other Factor.

District	Other Factor					
Frequency Percent Row Percent Col Percent	No Code Applicable	Lost Control, Skidded	Passenger Interfered	Attention Diverted	Object Projecting from Vehicle	Foot Slipped Off Brake
HIGH-RATE DISTRICT	**4688**	**32**	**18**	**238**	**1**	**7**
	32.06	0.22	0.12	1.63	0.01	0.05
	70.67	0.48	0.27	3.59	0.02	0.11
	45.38	23.02	41.86	39.87	25.00	100.00
MID-RATE DISTRICT	**3691**	**42**	**15**	**226**	**3**	**0**
	25.24	0.29	0.10	1.55	0.02	0.00
	70.16	0.80	0.29	4.30	0.06	0.00
	35.73	30.22	34.88	37.86	75.00	0.00
LOW-RATE DISTRICT	**1952**	**65**	**10**	**133**	**0**	**0**
	13.35	0.44	0.07	0.91	0.00	0.00
	71.58	2.38	0.37	4.88	0.00	0.00
	18.89	46.76	23.26	22.28	0.00	0.00
TOTAL	**10,331**	**139**	**43**	**597**	**4**	**7**
	70.65	**0.95**	**0.29**	**4.08**	**0.03**	**0.05**

Table K-14. Crashes by Other Factor (continued).

District	Other Factor					
Frequency Percent Row Percent Col Percent	Gusty Winds	Vehicle Passing On Left	Vehicle Passing On Right	Vehicle Changing Lane	Improperly Parked Vehicle	Vehicle Forward from Parking
HIGH-RATE DISTRICT	**2**	**131**	**11**	**8**	**8**	**6**
	0.01	0.90	0.08	0.05	0.05	0.04
	0.03	1.97	0.17	0.12	0.12	0.09
	12.50	43.38	45.83	44.44	50.00	28.57
MID-RATE DISTRICT	**6**	**109**	**6**	**4**	**5**	**8**
	0.04	0.75	0.04	0.03	0.03	0.05
	0.11	2.07	0.11	0.08	0.10	0.15
	37.50	36.09	25.00	22.22	31.25	38.10
LOW-RATE DISTRICT	**8**	**62**	**7**	**6**	**3**	**7**
	0.05	0.42	0.05	0.04	0.02	0.05
	0.29	2.27	0.26	0.22	0.11	0.26
	50.00	20.53	29.17	33.33	18.75	33.33
TOTAL	**16**	**302**	**24**	**18**	**16**	**21**
	0.11	**2.07**	**0.16**	**0.12**	**0.11**	**0.14**

Table K-14. Crashes by Other Factor (continued).

District	Other Factor					
Frequency Percent Row Percent Col Percent	Vehicle Backward from Parking	Vehicle Entering Driveway	Vehicle Leaving Driveway	Vision Obstructed by Standing Vehicle	Vision Obstructed by Moving Vehicle	Vision Obstructed by Embank-ment
HIGH-RATE DISTRICT	**0**	**230**	**112**	**5**	**6**	**1**
	0.00	1.57	0.77	0.03	0.04	0.01
	0.00	3.47	1.69	0.08	0.09	0.02
		51.57	53.33	41.67	46.15	100.00
MID-RATE DISTRICT	**0**	**160**	**70**	**7**	**6**	**0**
	0.00	1.09	0.48	0.05	0.04	0.00
	0.00	3.04	1.33	0.13	0.11	0.00
		35.87	33.33	58.33	46.15	0.00
LOW-RATE DISTRICT	**0**	**56**	**28**	**0**	**1**	**0**
	0.00	0.38	0.19	0.00	0.01	0.00
	0.00	2.05	1.03	0.00	0.04	0.00
		12.56	13.33	0.00	7.69	0.00
TOTAL	**0**	**446**	**210**	**12**	**13**	**1**
	0.00	**3.05**	**1.44**	**0.08**	**0.09**	**0.01**

Table K-14. Crashes by Other Factor (continued).

District	Other Factor					
Frequency Percent Row Percent Col Percent	Vision Obstructed by Commercial Sign	Vision Obstructed by Highway Sign	Vision Obstructed by Glare	Vision Obstructed by Hillcrest	Vision Obstructed by Trees	Vision Obstructed by Other
HIGH-RATE DISTRICT	**1**	**0**	**42**	**10**	**1**	**61**
	0.01	0.00	0.29	0.07	0.01	0.42
	0.02	0.00	0.63	0.15	0.02	0.92
	100.00	0.00	51.85	66.67	20.00	39.10
MID-RATE DISTRICT	**0**	**1**	**30**	**3**	**3**	**69**
	0.00	0.01	0.21	0.02	0.02	0.47
	0.00	0.02	0.57	0.06	0.06	1.31
	0.00	50.00	37.04	20.00	60.00	44.23
LOW-RATE DISTRICT	**0**	**1**	**9**	**2**	**1**	**26**
	0.00	0.01	0.06	0.01	0.01	0.18
	0.00	0.04	0.33	0.07	0.04	0.95
	0.00	50.00	11.11	13.33	20.00	16.67
TOTAL	**1**	**2**	**81**	**15**	**5**	**156**
	0.01	**0.01**	**0.55**	**0.10**	**0.03**	**1.07**

Table K-14. Crashes by Other Factor (continued).

District	Other Factor					
Frequency Percent Row Percent Col Percent	Swerved to Change Lanes	Swerved, Not Specified	Swerved, Surface or Visibility	Swerved, Traffic Control	Swerved, Pedestrian or Cyclist	Swerved, Animal
HIGH-RATE DISTRICT	**9**	**84**	**1**	**0**	**2**	**265**
	0.06	0.57	0.01	0.00	0.01	1.81
	0.14	1.27	0.02	0.00	0.03	3.99
	36.00	48.84	50.00	0.00	40.00	45.14
MID-RATE DISTRICT	**13**	**66**	**1**	**2**	**3**	**209**
	0.09	0.45	0.01	0.01	0.02	1.43
	0.25	1.25	0.02	0.04	0.06	3.97
	52.00	38.37	50.00	66.67	60.00	35.60
LOW-RATE DISTRICT	**3**	**22**	**0**	**1**	**0**	**113**
	0.02	0.15	0.00	0.01	0.00	0.77
	0.11	0.81	0.00	0.04	0.00	4.14
	12.00	12.79	0.00	33.33	0.00	19.25
TOTAL	**25**	**172**	**2**	**3**	**5**	**587**
	0.17	**1.18**	**0.01**	**0.02**	**0.03**	**4.01**

Table K-14. Crashes by Other Factor (continued).

District	Other Factor					
Frequency Percent Row Percent Col Percent	Swerved, Object in Road	Swerved, Slow Vehicle	Swerved, Vehicle Entering Road	Swerved, Avoiding Vehicle in Wrong Lane	Swerved, Avoiding Previous Accident	Slowed, Not Specified
HIGH-RATE DISTRICT	**19**	**31**	**33**	**101**	**0**	**37**
	0.13	0.21	0.23	0.69	0.00	0.25
	0.29	0.47	0.50	1.52	0.00	0.56
	51.35	53.45	40.74	55.80	0.00	37.37
MID-RATE DISTRICT	**11**	**19**	**40**	**59**	**3**	**45**
	0.08	0.13	0.27	0.40	0.02	0.31
	0.21	0.36	0.76	1.12	0.06	0.86
	29.73	32.76	49.38	32.60	100.00	45.45
LOW-RATE DISTRICT	**7**	**8**	**8**	**21**	**0**	**17**
	0.05	0.05	0.05	0.14	0.00	0.12
	0.26	0.29	0.29	0.77	0.00	0.62
	18.92	13.79	9.88	11.60	0.00	17.17
TOTAL	**37**	**58**	**81**	**181**	**3**	**99**
	0.25	**0.40**	**0.55**	**1.24**	**0.02**	**0.68**

Table K-14. Crashes by Other Factor (continued).

District	Other Factor					
Frequency Percent Row Percent Col Percent	Slowed, Surface or Visibility	Slowed, Traffic Control	Slowed, Pedestrian or Cyclist	Slowed, Animal	Slowed, Object in Road	Slowed, Slow Vehicle
HIGH-RATE DISTRICT	**2**	**16**	**1**	**7**	**3**	**46**
	0.01	0.11	0.01	0.05	0.02	0.31
	0.03	0.24	0.02	0.11	0.05	0.69
	50.00	32.65	100.00	50.00	100.00	61.33
MID-RATE DISTRICT	**1**	**26**	**0**	**4**	**0**	**22**
	0.01	0.18	0.00	0.03	0.00	0.15
	0.02	0.49	0.00	0.08	0.00	0.42
	25.00	53.06	0.00	28.57	0.00	29.33
LOW-RATE DISTRICT	**1**	**7**	**0**	**3**	**0**	**7**
	0.01	0.05	0.00	0.02	0.00	0.05
	0.04	0.26	0.00	0.11	0.00	0.26
	25.00	14.29	0.00	21.43	0.00	9.33
TOTAL	**4**	**49**	**1**	**14**	**3**	**75**
	0.03	**0.34**	**0.01**	**0.10**	**0.02**	**0.51**

Table K-14. Crashes by Other Factor (continued).

District	Other Factor					
Frequency Percent Row Percent Col Percent	Slowed, Vehicle Entering Road	Slowed, Vehicle in Wrong Lane	Slowed, Avoiding Previous Accident	Slowed, Turning Right	Slowed, Turning Left	School Bus Related Accident
HIGH-RATE DISTRICT	**5**	**1**	**0**	**23**	**144**	**24**
	0.03	0.01	0.00	0.16	0.98	0.16
	0.08	0.02	0.00	0.35	2.17	0.36
	55.56	20.00	0.00	51.11	54.34	52.17
MID-RATE DISTRICT	**3**	**2**	**1**	**12**	**79**	**16**
	0.02	0.01	0.01	0.08	0.54	0.11
	0.06	0.04	0.02	0.23	1.50	0.30
	33.33	40.00	100.00	26.67	29.81	34.78
LOW-RATE DISTRICT	**1**	**2**	**0**	**10**	**42**	**6**
	0.01	0.01	0.00	0.07	0.29	0.04
	0.04	0.07	0.00	0.37	1.54	0.22
	11.11	40.00	0.00	22.22	15.85	13.04
TOTAL	**9**	**5**	**1**	**45**	**265**	**46**
	0.06	**0.03**	**0.01**	**0.31**	**1.81**	**0.31**

Table K-14. Crashes by Other Factor (continued).

District	Other Factor					
Frequency Percent Row Percent Col Percent	Highway Construction Unrelated to Construction	Highway Construction Related to Construction	Other Construction Area Unrelated to Construction	Other Construction Area Related to Construction	Accident on Beach	TOTAL
HIGH-RATE DISTRICT	**125**	**34**	**0**	**2**	**0**	**0**
	0.85	0.23	0.00	0.01	0.00	**0.00**
	1.88	0.51	0.00	0.03	0.00	**0.00**
	41.39	40.00		40.00		
MID-RATE DISTRICT	**126**	**32**	**0**	**2**	**0**	**0**
	0.86	0.22	0.00	0.01	0.00	**0.00**
	2.39	0.61	0.00	0.04	0.00	**0.00**
	41.72	37.65		40.00		
LOW-RATE DISTRICT	**51**	**19**	**0**	**1**	**0**	**0**
	0.35	0.13	0.00	0.01	0.00	**0.00**
	1.87	0.70	0.00	0.04	0.00	**0.00**
	16.89	22.35		20.00		
TOTAL	**302**	**85**	**0**	**5**	**0**	**0**
	2.07	**0.58**	**0.00**	**0.03**	**0.00**	**0.00**