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16. Abstract

This three-year research effort was undertaken to identify factors that influence the number and severity of roadway departure crashes on rural two-lane highways in Texas and provide engineering countermeasures to reduce this type of crash. The study objectives were accomplished by analyzing crash, traffic flow, and geometric data between 2003 and 2008 and conducting site visits at 20 sites having the highest crash rates at four TxDOT districts.

The study results showed that the proportion of roadway departures varied from 25 percent to 52 percent for all crashes occurring on the rural two-lane highway network. Proportionally more crashes occur on horizontal curves than on tangents and during nighttime. Distracted driving and speeding were found to be important contributing factors.

To help reduce the number and severity of roadway departures, the research team proposed several medium- to low-cost countermeasures that can realistically be implemented by TxDOT. These countermeasures were grouped into three categories: targeted for horizontal curves, general applications, and new and innovative treatments. For each treatment, the information focused on the general characteristics, key design features, safety effectiveness, cost (when available), and additional resources where the reader can find more detailed information about the treatment. More than 25 treatments were described for reducing roadway departure crashes.

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ANALYSIS OF ROADWAY DEPARTURE CRASHES ON TWO-LANE RURAL ROADS IN TEXAS

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DISCLAIMER

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

This report is not intended for construction, bidding, or permit purposes. The researcher in charge of the project was Dominique Lord.

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- Mr. Herbert Bickley, P.E., TxDOT Lufkin District.
- Ms. Angie Ortegon, P.E., TxDOT San Angelo District.
- Mr. Lance Simmons, P.E., TxDOT Atlanta District.
- Ms. Kelli Williams, P.E., TxDOT Odessa District.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1:
INTRODUCTION

INTRODUCTION

Nearly 80 percent of the roadways that are operated and maintained by the Texas Department of Transportation (TxDOT) are two-lane highways located in rural areas. Between 1997 and 2001, more than 12,000 fatal collisions occurred on Texas highways, with about 40 percent of those happening on rural two-lane roads. The crash statistics have shown that about 50 percent of these crashes are categorized as single-vehicle crashes (1,900 crashes). These statistics are also reflected elsewhere in the United States. For instance, the Federal Highway Administration (FHWA) reported that departure crashes account for 39 percent of all fatal crashes in the United States. The FHWA Office of Safety has named roadway departure crashes as one of its primary focus areas in the proposed Strategic Highway Safety Plan for reducing the number and severity of crashes in the US. This is also reflected in the latest Strategic Highway Research Program (SHRP2), which seeks to reduce roadway departures as one of its top safety-related goals. The high crash rates and fatality rates occurring on rural two-lane highways results are a high cost to all Texas motorists in terms of both lives and dollars and have prompted TxDOT to begin a statewide review of roadway departure crashes.

A thorough understanding of contributing factors leading to roadway departures on two-lane highways will allow TxDOT to proactively implement crash remediation measures saving lives and money. This research study presents a comprehensive investigation focused on causal and geometric design features associated with roadway departures on two-lane rural roads. In short, the investigation provides information on where, when (e.g., time of day), and why this type of crash occurs. Furthermore, this research builds on recent work by the FHWA on this category of single-vehicle collisions.

PROJECT OBJECTIVES

This research effort was undertaken to address two objectives:

1. Identify contributing factors associated with roadway departures on rural two-lane highways in Texas.
2. Provide engineering countermeasures to reduce the number and injury related to this type of crash.

RESEARCH METHODOLOGY

This research primarily has two components—analyses based on crash data collected between 2003 and 2008 using state databases, and a detailed engineering study based on a sample of rural two-lane highway segments located in four different districts in Texas. The first component sought to identify global factors that influence this type of crash by region and district. The second component focused on identifying factors that may not be captured by the state databases, but can be extracted from site visits and the analysis of original crash reports. Input from the various districts was also obtained for this component.

The research team conducted the analyses using traditional and advanced statistical tools for estimating potential causal factors. Six tasks were performed to satisfy the objectives listed above. The tasks were:

1. Examine related material.
2. Assemble crash data by district.
3. Synthesize assembled data to identify crash patterns and trends on rural two-lane roads.
4. Contact districts.
5. Investigate causative factors.
6. Establish potential remedial engineering countermeasures.
7. Summarize research findings and prepare research reports.

ORGANIZATION OF REPORT

This report is organized into nine chapters and three appendices, as described below:

- Chapter 1—Introduction: Provides an introduction to the research topic and presents project objectives, methodology, and report organization.
- Chapter 2—Literature Review: Provides a summary of previous research of relevance to the topic of this study.
- Chapter 3—Data Collection: Provides an overview of the data collection and data reduction processes performed for the safety analyses.
- Chapter 4—Statistical Analysis and Findings: Provides a discussion of the findings and conclusions related to the safety analysis of the state databases.
- Chapter 5—Crash Report Analysis and Findings: Offers a discussion of the findings and conclusions related to the detailed analysis of the crash reports.
- Chapter 6—Operational and Geometric Design Features Analysis and Findings: Presents the findings and conclusions related to the top 20 sites identified in the four TxDOT districts.
- Chapter 7—Engineering Countermeasures: Provides a discussion and list of countermeasures for reducing roadway departure crashes.
- Chapter 8—Conclusions and Further Work: Summarizes the key conclusions of the work as well as future opportunities.
- Chapter 9—References: Contains a list of references cited throughout the report.
- Appendix A—Crash Variables Used in the Electronic Database.
- Appendix B—Definitions of Roadway Departure Crashes.
- Appendix C—Characteristics of Key Highway and Operational Features for the Four Districts.

CHAPTER 2: LITERATURE REVIEW

INTRODUCTION

This chapter documents the literature review performed on roadway departure or run-off-the-road (ROR) crashes. It summarizes key studies that have been conducted in the United States and elsewhere that are relevant to this project. Over 190 studies, documents, research papers, and publications have been consulted and reviewed. Chapter 9 presents a condensed list of these relevant documents.

This chapter is divided into three sections. The first section describes the characteristics and the magnitude of the problem associated with roadway departure crashes. The second section summarizes contributing factors of roadway departure crashes that have been reported in the literature. The third section outlines countermeasures previously evaluated for reducing the number and severity of roadway departure crashes. Proposed countermeasures that are suitable for this project are described in greater detail in Chapter 6.

CHARACTERISTICS OF ROADWAY DEPARTURES

Researchers have identified roadway departure crashes as an important leading cause of traffic fatalities on highways and have consequently been identified as a significant problem in traffic safety. In 1999, using data from the Fatality Analysis Reporting System (FARS), Neuman et al. (2003) reported that nearly 39 percent of all fatal crashes (all road types) were classified as single-vehicle ROR crashes. Torbic et al. (2009) reported a slightly lower value in their study of safety effects of rumble strips. According to FHWA (2006), over 25,000 people in 2005 were killed because drivers left their lane and crashed with an oncoming vehicle, rolled over, or hit an object located along the highway. Of all these fatalities, it is estimated that about 17,000 were the results of a single-vehicle ROR crash; this type of crash accounts for about 60 percent of all fatalities on the U.S. highway network. Examining these characteristics more closely, about 80 percent of ROR fatalities occurred on rural roadways, with about 90 percent of those rural crashes occurring on two-lane highways alone. Moreover, more recent statistics show that the proportion of fatal ROR crashes has been steadily increasing (SAIC, 2005). It is estimated that the societal costs associated with ROR crashes are 2.53 times more compared to other accidents (Zegeer et al., 1981). The social costs amount to more than 1 trillion dollars per year.

Crashes involving a vehicle leaving the traveled way have also been gaining attention outside the United States. According to World Health Organization (WHO) statistics, about 1.2 million people died annually worldwide due to road accidents, and the number is expected to rise by 67 percent by the year 2020 (Mobileye Technologies Ltd., 2006). Another study summarized the characteristics of rural road safety around the world, and reported that about 75,000 people are killed every year on rural roads in *Organisation for Economic Co-operation and Development* (OECD) countries, and the social costs attributed to these crashes are approximately equal to $120 billion per year (Hasson, 1999). At the international level, 75 percent of all crashes happen on the rural roads and are defined within three main crash types: single-vehicle crash, head-on crash, and crash at intersections. Moreover, single-vehicle crashes constitute 35 percent or more of all fatal rural road crashes.

CONTRIBUTING FACTORS

This section summarizes studies that have examined potential contributing factors associated with roadway departure crashes. The section is divided into three topics. The first topic is related to highway design characteristics. The second topic is associated with human factors. The third topic covers other factors, such as time of day and the vehicle.

Highway Design

Lane Width

Several researchers have investigated the safety effects associated with lane width and roadway departures. Overall, the studies tend to show that narrower lane widths are associated with an increase in roadway departures, at least for lane width below 12 ft. For instance, an examination of the effects of lane width showed that as the lane width increases to 11 ft, crash rates tend to decrease on two-lane roadways regardless of width of the shoulder (Zegeer et al., 1981). However, as the lane width increases beyond 11 ft, a slight increase in crash rates was reported (Zegeer et al., 1981). Fitzpatrick et al. (2005) found a decreasing number of segment crashes for increasing lane width up to the limit of the study (12-ft lanes).

Hauer (2000a) argued that the driver's adaptation may nullify the benefits linked to widening roads. According to this researcher, the common belief associated with the fact that a wider lane width can improve safety is based on two assumptions. The first assumption states that the average separation between vehicles will become larger when the lane is wider; thus, the wider separation can provide a buffer to avoid slightly random deviations of vehicles from the normal path inside the lane. However, drivers adapt to changes in roadway characteristics. High speed and careless driving may be induced by wider lane widths, so the net benefits may become null because of the negative effects associated with a driver's adaptation. The second assumption is that a narrow lane may allow a car to run off the road more easily, which may increase the risk for the driver to overturn or roll over. Finally, Hauer (2000a) indicated that when the lane width changes, other highway features tend to also be modified, so the isolation of the safety effect of lane width is actually difficult to measure.

Shoulder Width and Type

Several studies have also examined the relationships between shoulder width and type and ROR crashes. The studies usually tend to indicate that increasing the shoulder width decreases the crash rate. For instance, Zegeer and Deacon (1987) reported that shoulder width had a notable effect on accident rate. They developed a model to predict the crash rate as a function of lane width, shoulder width, and shoulder type. Ornek and Drakopoulos (2007) analyzed crash data on rural highways in Wisconsin. The authors noted that the ROR crash rate was higher on undivided highways than on divided highways. In addition, for rural two-lane undivided highways, wider paved and unpaved shoulder widths were associated with the lowest ROR crash rate.

Similar to lane width, not everyone agrees that wider shoulder widths are always safer. Hauer (2000b) noted that wider shoulder widths may reduce ROR crashes, but an increase in other types of crashes could be observed, particularly for shoulder widths larger than 8 ft. For large shoulder widths, some drivers could use the shoulder as a de facto driving lane.

Shoulder type can also have an effect on ROR crashes. According to Harkey et al. (2007), who summarized several studies on this topic, gravel, composite, and turf shoulders could experience an increase of 3 percent, 7 percent, and 14 percent more crashes, respectively, compared to paved shoulders.

Roadside Design

An NCHRP report prepared by Neuman et al. (2003) summarized the effects of roadside features on the severity of ROR crashes. The top four roadside features that led to fatal crashes were as follows: overturn (42 percent), an impact with a tree (26 percent), an impact with a utility pole (7 percent), and an impact with a ditch or embankment (5 percent). Neuman et al. (2003) noted that objects located near the roadside may harm the errant drivers more seriously than objects located further away (as expected), especially on high-speed roads.

The grade of the sideslope can be an important contributing factor for ROR crashes. Less steep sideslopes increase the likelihood for a driver of an errant vehicle to regain control of the vehicle after it leaves the traveled way. According to Zegeer et al. (1988), flattening a sideslope from 1:2 to 1:7 or flatter could reduce ROR crashes by about 27 percent. The benefits, although still positive, decrease as the changes become smaller (e.g., 1:5 to 1:7).

Pavement Edge Drop-Off

When a vehicle leaves the traveled way, pavement edge drop-off poses a potential safety hazard because vertical differences between surfaces can affect vehicle stability and reduce a driver's ability to handle the vehicle. Using data from Iowa and Missouri and performing regression analyses, Hallmark et al. (2006) noted that the risk of crashes becomes problematic when the edge drop-off is larger than 2.0 inches. Thus, the authors suggested that the maintenance threshold should be maintained at a dimension less than 2.0 inches.

Glennon (1987) reviewed previous documents and research studies that examined the relationship between crash rate and various roadway characteristics, such as drop-off height, material of shoulder, vehicle departure angle, reentry angle, speed, and lane width. Glennon noted that a 5-inch drop-off height was the practical maximum to prevent hazardous undercarriage contact on most vehicles.

Horizontal Curvature and Grades

It is generally assumed that vehicles will more easily leave their lane on a curve rather than tangent section because of the centrifugal force that acts on the vehicle when it enters the curve. However, the split between ROR crashes that leave the traveled way in a curve and on a tangent segment is about even (Zegeer et al., 1987). In other words, looking at the raw data, there seems to be no difference between the number of crashes occurring on tangents and on curves. However, when exposure is included into the comparison and since total length of tangent segments is much larger than those related to horizontal curves, the risk for someone to leave the traveled way in a curve is about 1.5 to 4 times higher than on a tangent segment (Glennon et al., 1985).

In a subsequent study, Zegeer et al. (1988) found that terrain, grade, and horizontal curvature were positively associated with the number of crashes. For instance, tighter curves usually experience more crashes. Hauer (2000d) indicated that using a larger radius and longer tangent length will decrease the risk of ROR crashes. However, Hauer (2000b) reported that the number of accidents tends to increase when a long tangent is followed by a horizontal curve with larger degree of curve (i.e., sharp curve). In a previous study, Fink and Krammes (1995) reported that the degree of curvature was a good predictor of accident rates on horizontal curves.

For vertical grades, some researchers have reported that steeper grades are associated with an increase in crashes (Zegeer et al., 1988; Hauer, 2000c). The effects of grades on safety are more substantial for vehicles traveling downhill (due to the increase in speed) and can become problematic if a horizontal curve is located at the bottom of the vertical grade (Hauer, 2000c).

Driveways

The objective of a recent study was to develop accident modification factors for driveways on rural highways in Texas (Fitzpatrick et al., 2008). Researchers evaluated 2,354 centerline miles of rural two-lane highways and 402 centerline miles of rural four-lane highways. Negative binomial regression was used to determine the effects of independent variables on crashes. Crashes were examined in terms of driveway and segment crashes for three years (1999–2001). Figure 1 illustrates the results of the study. For example, when there are 10 driveways per mile on a segment of highway, the accident modification factor (AMF) was found to be 1.18 for two-lane highways and 1.03 for four-lane highways. Said in another manner, 18 percent more segment crashes are predicted on two-lane rural highways when the driveway density is 10 rather than 3 driveways/mile. Note that the study examined the relationship between driveways and segment or driveway crashes, not ROR crashes.

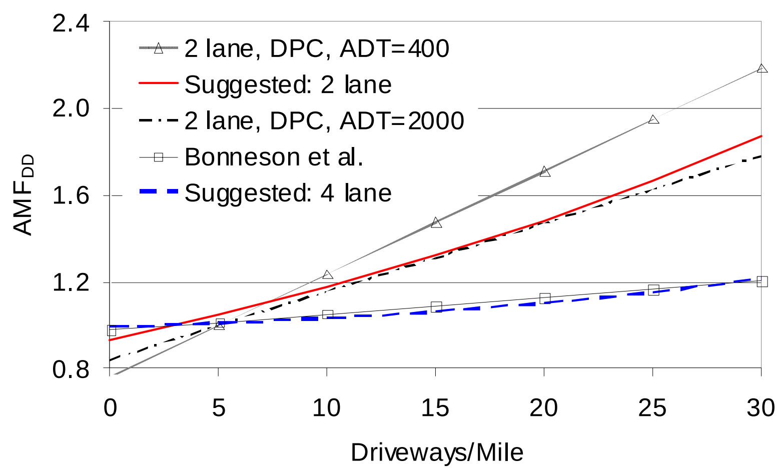


Figure 1. Accident Modification Factor for Driveway Density (Fitzpatrick et al., 2008).

No studies specifically examined the influence of intersections on ROR crashes; however, several looked at other factors influencing crashes at rural intersections. For example, Glennon (1987) conducted an extensive literature review and reported that providing good sight distance could decrease the crash rate by 33 percent. The change in alignment at intersections was only cost-effective on highways with high traffic volumes. Agent (1988) collected and analyzed data at 65 rural intersections in Kentucky and noted that many crashes occurred at unsignalized intersections, despite the fact adequate sight distance was provided at these intersections.

Pavement Surface

The lack of pavement friction can cause vehicles to skid and run off the road. Based on a study performed in New York, Neuman et al. (2003) reported that low skid resistance increases crash risk on wet pavement by 50 percent. These authors also analyzed FARS data from 1999 and found that 11 percent of single-vehicle ROR fatal crashes occurred on wet surfaces. They noted that 3 percent of this type of crash happened when the road was covered with snow or ice, but these percentages do not account for changes in exposure (i.e., the number of days of adverse pavement conditions). Finally, Neuman et al. (2003) noted that several methods could be used to improve the skid resistance, including changing pavement aggregates, adding overlays, or adding texture on the surface among others. However, their effects may vary with location, traffic volume, rainfall, pavement structure, and temperature.

Traffic Volume

Cleveland et al. (1985) indicated that run-off-the-road crashes will increase as the ADT increases. The relationship was found to be non-linear, where the exponent for the traffic flow variable varied between 0.5 and 0.9 (e.g., $Crashes / year = \alpha F^{\beta}$, $\beta = 0.5$ to 0.9). This means that the number of crashes increases at a decreasing rate as traffic flow increases. Cleveland et al. (1985) suggested that for improving traffic safety, engineers should treat geometric and roadside elements as clusters rather than analyzing each highway component individually.

Human Factors

Speeding

Davis et al. (2006) summarized the literature related to the relationship between speed and ROR crashes on rural two-lane highways. They also conducted two case-control studies using Bayesian relative risk regression and data collected in Australia and Minnesota. They found that the U-shape relationship between speed and crash risk (i.e., for people who travel faster and slower than what is average on the road), commonly found in the literature, is usually not supported by data for this type of crash. However, Davis et al. (2006) indicated that the relative risk of a serious or fatal ROR crash clearly tended to increase as speed increased. In a recent study, Liu and Ye (2011) reported that 25 percent of the driver-related factors were attributed to driver decision errors, most of which included speeding drivers.

Alcohol and Drugs

A few researchers examined the characteristics of roadway departures as a function of alcohol and drugs. For example, McGinnis et al. (2001) examined the effects of various driver characteristics on the risk of roadway departure crashes using the FARS data for the years 1975, 1980, 1985, 1990, 1996, and 1997. In 50 percent of fatal ROR crashes in which the age of the male driver was between 20 and 39, the driver was intoxicated. These results indicated that alcohol plays an important role in roadway departure crashes.

In another study, Dissanayake (2003) studied ROR crashes involving younger drivers between the ages of 16 and 25 years old, using a binary logistic regression with data collected in 1997 and 1998 in Florida. He reported that several factors were positively associated with ROR crashes, including the influence of alcohol or drugs, gender, and speed. However, other variables, such as weather conditions, residence, and the physical condition of the driver (other than alcohol or drugs) were found to be insignificant.

Age and Gender

McGinnis et al. (2001) analyzed FARS data and found that male drivers have a higher ROR crash rate than female drivers. Compared to mid-age female drivers, the ROR rate for teenage males is about 20 times higher and for teenage females 9 times higher. As for older drivers, the ROR crash rate was also found to be higher than mid-age (male and female) drivers.

Other Factors

Time of Day (Night Time)

In his analysis of the FARS database (described above), McGinnis et al. (2001) reported that more than 50 percent of ROR crashes occurred in dark conditions.

Vehicle Type

Compared to passenger cars, trucks usually have a high center of gravity. Hence, this type of vehicle has a greater risk of rolling over in the event of an ROR crash. To this effect, Farmer and Lund (2002) examined FARS crash data for the 1995–1998 period and found that light trucks (pickups, vans, and SUVs) were twice as likely as cars to roll over, following a roadway departure. Using the same database, McGinnis et al. (2001) also noted that the number of light trucks involved in a rollover crash increased by 130 percent between 1975 and 1997. This increase was attributed to the growing use of light trucks over the years.

COUNTERMEASURES

This section briefly summarizes countermeasures that have been proposed in the literature for reducing the number and severity of roadway departure crashes. Chapter 7 describes a more detailed analysis of suitable countermeasures that are specifically tailored for this project. The first subsection describes studies related to treatments or countermeasures related to modifying highway design features. The second subsection summarized key studies on countermeasures related to the driver.

Highway Design

Since the problem associated with roadway departure crashes on rural roads has existed for many years, many researchers have proposed different countermeasures or strategies for reducing the number and severity caused by this type of crash. For example, in the 1960s, Foody and Taylor (1966) studied the safety effects of road delineation applied to sharp curves. More recently, several National Cooperative Highway Research Program (NCHRP) projects have examined the application of countermeasures that could be used for reducing crashes caused by roadway departures. NCHRP *Report 500, Volume 6: A Guide for Addressing Run-Off-Road Collisions*, prepared by Neuman et al. (2003), summarized a significant number of documents and synthesized the latest knowledge related to countermeasures that could be used for minimizing ROR crashes. They grouped the countermeasures according to three general objectives: 1) keep vehicles from encroaching on the roadside; 2) minimize the likelihood of crash or overturning if the vehicle leaves the traveled way; and, 3) reduce the severity of a crash. Each countermeasure was evaluated and rated as "Tried," "In Experimental Stage," or "Proven." Other reports that also provided countermeasures related to roadway departures include studies by Torbic et al. (2004), Lacy et al. (2004), and McGee and Hanscom (2006). Several government organizations have also produced relevant manuals and resource material related to the implementation of countermeasures for reducing roadway departures; those resources include: Highway Safety Manual (AASHTO, 2010), Toolbox of Countermeasures and Their Potential Effectiveness for Roadway Departure Crashes (FHWA, 2007a), and AASHTO's Driving Down Lane-Departure Crashes website (http://www.transportation1.org/lanedeparture/keepingdrivers.html).

Lane and Shoulder Widening

Zegeer et al. (1981) and Zegeer and Council (1995) reported that widening lane and shoulder widths could significantly reduce crashes. For instance, widening the traveled way (lane and shoulder width) by 4 ft could reduce related crashes (i.e., head-on and ROR) by up to 20 percent. Given the high construction costs associated with road and shoulder widening projects, Zegeer et al. (1981) recommended that such projects be undertaken when the annual number of crashes exceeds more than 5 or 6, and the b/c ratio should be greater than 1. In addition, they noted that shoulder and pavement widening projects were only cost-effective when the existing shoulder width was less than 4 ft and for segments having more than 1,000 vehicles per day. Neuman et al. (2003) summarized past research on this topic and developed crash reduction factors (CRFs) as a function of lane and shoulder widths, as shown in Table 1.

Table 1. Effectiveness of Shoulder Widening (Neuman et al., 2003).

Shoulder Widening (both sides) (ft)	Percent Crash Reduction		
	Lane Widening	Paved Shoulder Widening	Unpaved Shoulder Widening
2	5	4	3
4	12	8	7
6	17	12	10
8	21	15	13
10		19	16
12		21	18
14		25	21
16		28	24
18		31	26
20		33	29

Recognizing that traffic volumes (average daily traffic or ADT) may influence the magnitude of changes in safety for lane and shoulder widening projects, Griffin and Mak (1987) analyzed crash data in Texas and separated projects into four groups: ADT less than 400, ADT between 401 and 700, ADT between 701 and 1,000, and ADT between 1,001 and 1,500 vehicles per day. The results of their analysis showed that single-vehicle crashes decreased with an increase in lane width when the ADT was larger than 400 vehicles per day. They also reported a reduction of up to 50 percent when the paved surface was increased by 4 ft. Agent et al. (2001) analyzed crash data (1996-1998) in Kentucky and noted that adding a shoulder and increasing shoulder width are very effective at reducing roadway departure crashes.

Shoulder Rumble Strips

The main function of rumble strips is to produce sound and vibration to alert errant drivers when their vehicles leave the traveled way. Although rumble strips have various design standards (see http://safety.fhwa.dot.gov/programs/rumble.htm), the most common designs have crosswise grooves located on the shoulder that are about 0.5 inches deep, 7.0 inches apart, and are cut in groups of four or five.

Neuman et al. (2003) reviewed the previous studies on this topic and summarized the expected effectiveness of shoulder rumble strips for minimizing ROR crashes. Examining several studies conducted by FHWA, state agencies, and others, Neuman et al. (2003) reported that rumble strips could reduce the ROR crash rate by 20 to 50 percent on urban and rural freeways. It is anticipated that a reduction in ROR crashes would also be observed on rural two-lane highways.

Other researchers have also recently examined the safety effects of shoulder rumble strips. For instance, Perrin (2006) analyzed crash data on interstate highways in Utah and found a reduction of 10 percent in crash-related costs for facilities containing rumble strips. Patel et al. (2007) conducted a before-after study using the empirical Bayes (EB) method in Minnesota and showed that rumble strips could reduce all single-vehicle crashes by 13 percent and injury single-vehicle crashes by 18 percent.

Finley et al. (2009) reviewed rumble strip placement on two-lane undivided highways in Texas and its effects on the position of vehicles within the travel lane. Field studies indicated that centerline rumble strips on highways with lane widths as narrow as 10 ft did not adversely impact the lateral placement of vehicles in the travel lane; at locations with smaller (1 to 2 ft) shoulder widths, drivers positioned the center of their vehicles closer to the center of the lane. Similar effects were found at locations with both edgeline and centerline rumble strips. They concluded that lateral offsets that position the center of 16-inch shoulder rumble strips in the middle of shoulders at least 4 ft wide should provide enough remaining shoulder width for the typical distracted driver to correct an errant vehicle trajectory before leaving the paved roadway surface.

In summary, although the rumble strips seem less effective on rural highways than on freeways (FHWA, 2007b), this treatment is still an effective approach for reducing ROR crashes. It should be pointed out that shoulder rumble strips could be unsafe for bicyclists (Daniel, 2007). To reduce these potential negative effects, periodic gaps should be used along highways that have rumble strips to provide bicyclists with more opportunities to change position. Similarly, Daniel (2007) suggested that rumble strips should not be used for shoulders less than 8 ft wide.

Raised Pavement Marking

Raised pavement markers (RPMs) can provide drivers a clear delineation of the roads and enhance their ability to track the roadway, especially in dark or during wet weather conditions. RPMs usually provide tactile and auditory warnings when the driver leaves the traveled way, similar to rumble strips. By providing these warnings, the objective is to enable drivers to regain control of the vehicle before it runs off the road.

Since the 1960s, several studies have examined the effects of RPMs on safety. Taylor et al. (1972) conducted an experiment to evaluate the effects of RPMs on rural curves. They found that RPMs combined with painted edge line delineation reduced the vehicle placement variability and caused drivers to travel closer to the centerline. However, because the costs of RPMS ($0.36/ft in 1972 dollars) are four times more than those of regular painted lines ($0.09/ft), Taylor recommended installing RPMs on curves that were subject to a high crash history.

In a recent study, the American Traffic Safety Services Association (ATSSA) (2006) summarized studies on RPMs and reported that the total number of crashes could be reduced by 10 percent and wet-related crashes by 33 percent. Table 2 summarizes the studies analyzed by ATSSA.

Table 2. Safety Effects of RPMs (ATSSA, 2006).

Study	Year	Location	Key Study Results
Wright, et al. (1982)	1970	Georgia	1. RPMs reduced nighttime crashes by 22% compared with daytime crashes at the same sites. 2. RPMs reduced single-vehicle crashes by 12% more than other nighttime crash types.
Neuman, et al. (2003)	1970	Ohio	1. RPMs reduced the total and injury crashes by 9% and 15%, respectively. 2. RPMs provided positive benefits for different kinds of driving conditions, including dark (a reduction of 5%) and wet weather (a reduction from 6% to 11%). 3. The ratio of benefit and cost of RPMs was 6.5 to 1.
Neuman, et al (2003).	1980	New Jersey	The calculated benefit-cost ratios ranged from 15.49 to 1 to 25.51 to 1.
New York State Department of Transportation (1997)	1990	New York	1. RPMs decreased the total number of crashes by 7%, nighttime crashes by 26%, and nighttime wet weather crashes by 33%. 2. For guidance related crashes (e.g., run-off-road, head-on, encroachment, and sideswipe), RPMs reduced all crashes by 23% and nighttime crashes by 39%.
Bahar, et al. (NCHRP Project 5-17)	2004	six states	In New York, RPMs reduced the total number of crashes by 10%, nighttime crashes by 13%, wet weather crashes by 20%, and wet and nighttime crashes by 24%.

Adding Pavement Marking

Sun et al. (2006) examined the impact of pavement edge delineation on vehicular lateral position on narrow rural two-lane highways in Louisiana. They reported that drivers tended to drive away from the pavement edge after installation of edge delineation. In another study, Neuman et al. (2003) noted that the effectiveness of better pavement marking on a high-crash site on two-lane highways could decrease ROR crashes by 10 percent to 15 percent.

Traffic Signs

Traffic signs have been used as treatments for high-risk locations. They are utilized to attract driver attention so that drivers can take proper action to stay within the traveled way. However, traffic signs are not very efficient for drunk drivers. According to Gawron and Ranney (1990), who studied the effects of spot treatments on drivers who were under the influence of alcohol in a driving simulator, none of the following signs worked to prevent a driver to run-off-the-road: flashing beacons, chevrons, and post delineators.

Roadside Delineators

Neuman et al. (2003) mentioned that enhanced delineation on sharp curves can reduce ROR crashes. Examining several studies in the U.S. and other countries, they reported that post-mounted delineators could reduce ROR crashes by 15 percent on curves. In addition, this treatment was found to be cost-effective for narrow, hilly roads, and roads with many horizontal curves or that barely meet the minimum design standards.

Skid-Resistive Pavement Design

Neuman et al. (2003) noted that the skid resistance, such as asphalt mixture, pavement overlays, and pavement grooving, can reduce the likelihood for a driver to leave the traveled way. However, according to these authors, the exact effects on ROR crashes are not known, since previous studies examined the effects of skid-resistant pavement for all crash types.

Clear Zone and Object Removal

Widening clear zone and removing roadside objects can provide more recovery area for errant drivers or reduce the severity of run-off-road crashes in the event of an impact. Neuman et al. (2003) summarized previous research studies on clear zones and safety. Table 3 lists the reductions for different recovery distances.

Table 3. Safety Effects of Widening Clear Zones (Neuman et al., 2003).

Recovery Distance (ft)	Percent Reduction in Related Crash Types (%)
5	13
8	21
10	25
12	29
15	35
20	44

The AASHTO Roadside Design Guide (2002) provides guidance on how to determine the suitable clear zone that considers the combination of vehicular speed, volume, and slope (see Figure 2).

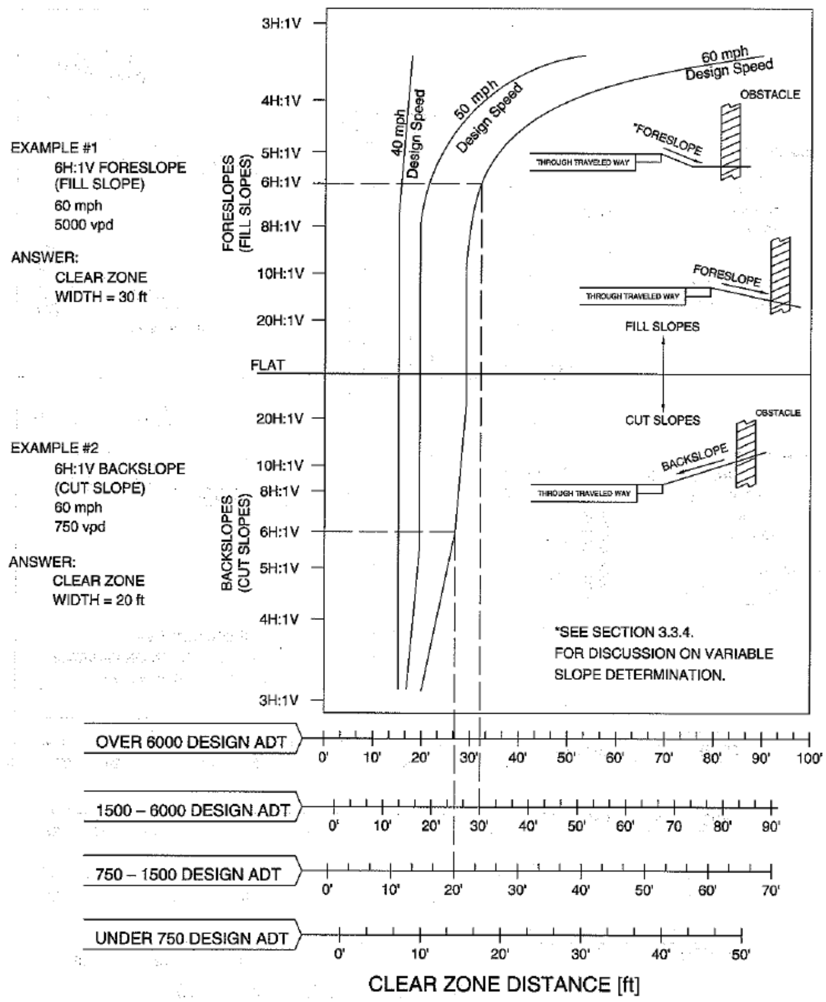


Figure 2. Clear Zone Distance Curves (AASHTO, 2002).

In Canada, Hildebrand et al. (2007) evaluated 70 highway sections in New Brunswick and reported that ROR collision rates could be reduced by 40 percent to 60 percent when the clear zone is extended from less than 6 m (20 ft) to between 6 and 10 m (32 ft) and from 6 m to greater than 10 m, respectively.

Install Guardrail

Paulsen et al. (2003) performed various crash tests and showed that energy-absorbing terminals greatly reduce the velocity of small vehicles. A 75 percent reduction in speed was observed for head-on impacts and approximately 50 percent when the terminal was struck at an angle of 15 degrees. As expected, installing a guardrail will reduce ROR crashes, but it also adds a roadside object.

Utility Poles

Lacy et al. (2004) proposed three methods to reduce crashes involving utility poles. They include placing utilities underground, relocating poles further away, and decreasing the number of poles along the corridor.

Flatten Sideslopes

Zegeer and Council (1995) reported that roadside improvement could reduce crashes by 19 to 52 percent when flattening sideslope from 3:1 to 7:1. They also reported that increasing clear zone by 20 ft and flattening sideslope (from 2:1 to 7:1) can reduce crashes by 44 to 27 percent.

Improving Horizontal Curves

Neuman et al. (2003) summarized previous research on the effectiveness of flattening horizontal curves for different scenarios. Table 4 indicates that by reducing the degree of curve, the number of ROR crashes diminishes. Lacy et al. (2004) also examined the safety effectiveness of modifying horizontal curves. The modifications included an increase in the length of the radius, providing spiral transition curves, and eliminating compound curves. Table 5, taken from that document, summarizes the relationship between spiral transitions and ROR crashes.

Table 4. Effectiveness of Curve Flattening (Neuman et al., 2003).

Original Degree of Curve	New Degree of Curve	Percent Reduction (%) Total Crashes
30	25	15–17
	20	31–33
	15	46–50
	10	61–67
	5	78–83
25	20	17–20
	15	35–40
	10	53–60
	5	72–80
20	15	20–25
	10	41–50
	5	64–75
15	10	24–33
	5	50–66
	3	63–79
10	5	28–49
	3	42–69

Table 5. Effectiveness of Curve Flattening (Lacy et al., 2004).

Degree of Curve	Radius of Curve (ft)	Central Angle Degrees Length of curve (mi)	Length of Curve (mi)	Percent Reduction (%)	
				w/ spiral	w/o spiral
38	150	150	0.07	5.5	5.6
11	500	20	0.03	3.9	4.1
6	1000	20	0.07	1.7	1.8
3	2000	20	0.13	1.1	1.2
2	3000	20	0.2	1.0	1.1

Human Factors

Enforcement

Neuman et al. (2003) indicated that well-designed and well-operated law enforcement programs could have an important effect on highway safety, such as reducing vehicle speeds, increasing seat belts use, and reducing the number of impaired drivers. However, the effect of enforcement can be either positive (i.e., the desired reduction occurs on a greater part of the system) or negative (i.e., the problem moves to another location). To improve effectiveness, enforcement programs should be combined with a media campaign.

Media Campaign

Neuman et al. (2003) reported that many highway safety programs can be effectively enhanced with a properly designed public information and education (PI&E) campaign. Usually, media campaigns put an emphasis on an entire jurisdiction or a significant part of it rather than at a specific location. Media campaigns for reducing roadway departures are not very common. However, the Governor's Traffic Safety Advisory Commission (GTSAC) (GTSAC, 2005) in Michigan put forward some recommendations for developing a statewide media campaign to reduce ROR crashes. The GTSAC recommends the following:

- Promote by local agencies, and conduct a pilot study in one or two specific local agencies.
- Include a media strategy.
- Attract public attention using newspaper, radio, TV ads, etc.
- Use the media to explain the details about improvements, operational treatments, or safety arguments for enforcement activity.
- Use information on the best approaches from states and local jurisdictions to enhance media campaign materials.

Intelligent Transportation Systems (ITS)

Many researchers have evaluated the effectiveness of ITS for helping drivers maintain control of their vehicle and avoid running off the road. For instance, Sayer et al. (2005) conducted an experiment to examine the efficiency of Lateral Drift Warning (LDW) and Curve Speed

Warning Systems (CSW) on a fleet of instrumented vehicles. These systems were designed to minimize the risk of roadway departures and excessive speed. The results showed that auditory warnings provided better response than haptic warnings (vibrations). However, they noted that a system that only focused on roadway departures was not likely to be cost-effective. Thus, a system that could also warn of other potentially hazardous situations would be more cost effective. Rimini-Doering et al. (2005) examined the effectiveness of the Lane Departure Warning (LDW) system and found that the LDW system can prevent up to 85 percent of the lane departure events caused by a driver falling asleep behind the wheel. Mobileye Technologies Ltd. (2006) also summarized the possible benefits of ITS on traffic safety. This company offers several warning systems, including one for preventing roadway departures. This system, designed to act as "audible rumble strips," produces a rumble sound up to 0.5 s before an unintentional departure from the lane or the highway altogether.

CHAPTER SUMMARY

This chapter has documented the literature review related to roadway departure crashes. Over 190 studies, documents, research papers, publications were consulted and reviewed, and the key studies were summarized into three sections on crash characteristics, contributing factors, and potential countermeasures. The review has illustrated the following key findings:

- Roadway departure crashes are a significant problem in the U.S. and across the globe; most such crashes occur on rural two-lane highways, and they often cause severe and fatal injuries.
- A variety of geometric design characteristics can have an influence on roadway departures, including narrow lane and shoulder widths, pavement edge drop-off (above 2 inches), horizontal alignment, and poor pavement surface conditions.
- Alcohol, drugs, speeding, and the age and gender of the driver can influence the risk of roadway departures; many ROR crashes are alcohol-related.
- A variety of methods, approaches, and devices for reducing the risk of roadway departures have been examined; they include lane and shoulder widening, the use of shoulder rumble strips and raised pavement marking, and providing skid-resistant pavement. Most provide a good potential for reducing incidents associated with a vehicle that leaves the traveled way.
- Media campaigns, enforcement, and the application of ITS have been used for reducing roadway departures. Media campaigns for ROR crashes are not common, but the State of Michigan has proposed an approach for developing such campaigns. ITS offers great potential for lowering the risk for a driver to run-off-the-road; however, existing technologies are very expensive and are currently not cost-effective.

CHAPTER 3: DATA COLLECTION

INTRODUCTION

As discussed in Chapter 1, the analyses were divided into two components: one based on crash data collected between 2003 and 2008 using state databases and one based on site visits. This chapter describes how the data were extracted, collected, and assembled for the two components.

DATA COLLECTION – STATE DATABASE

This section explains the process that was used for extracting the data from the state database. As discussed above, the data were extracted for the time period 2003–2008 from TxDOT's Crash Record Information System (CRIS) (see Appendix A for the variable definition). This system collects data on all crashes that occurred on the state-maintained highway network. The system also includes information collected in other databases, such as the Road-Highway Inventory Network (RHiNo).

To properly account for all the crashes to be considered in the study, the research team developed a specific definition of a roadway departure crash on a two-lane rural road. The process of establishing that definition is discussed in greater detail in Appendix B. The definition that was used within this project is the following:

- *Collision* ≤ 5 (this code refers to crashes other than motor-vehicle-to-motor-vehicle).
- *Roadway* = 2, 3, or 4 (these codes refer to crashes that are reported to be other than on the travel lane of the roadway).
- Number_ of_ lane = 2.
- Rural_Urban = 1 (this code refers to rural roads).

The total number of crashes was collected and categorized into the five severity levels:

- Fatal (K).
- Incapacitating-injury (A).
- Non-incapacitating injury (B).
- Minor injury (C).
- Property damage only (O).

Table 6 summarizes the changes in the number of miles and two-lane rural highway segments from 2003 to 2007 (note: the same network for 2007 was used for 2008). As seen in Table 6, a few districts experienced a decrease in the number of segments categorized as two-lane rural highways over time while a few other districts experienced an increase. However, for some districts, the total number of miles remained the same, while the number of segments changed. This could possibly be attributed to a realignment or modification in the segment boundaries.

Table 6. Roadway Characteristics for Two-Lane Rural Highways from 2003 to 2007.

ID	District	2003		2004		2005		2006		2007	
		Sites	Miles	Sites	Miles	Sites	Miles	Sites	Miles	Sites	Miles
1	PAR	3,548	2,662	3,539	2,649	3,574	2,667	3,632	2,688	3,663	2,679
2	FTW	1,767	1,955	1,769	1,955	1,777	1,951	1,808	1,950	1,819	1,940
3	WFS	1,725	2,300	1,783	2,300	1,850	2,297	1,860	2,303	1,856	2,288
4	AMA	2,164	3,081	2,147	3,082	2,152	3,082	2,202	3,050	2,178	3,035
5	LBB	2,418	4,141	2,429	4,155	2,557	4,155	2,585	4,154	2,599	4,148
6	ODA	1,133	2,202	1,101	2,164	1,103	2,163	1,093	2,161	1,095	2,166
7	SJT	1,576	2,767	1,577	2,763	1,580	2,760	1,540	2,709	1,527	2,697
8	ABL	1,996	2,812	1,957	2,812	1,964	2,814	1,970	2,815	2,029	2,813
9	WAC	2,540	2,660	2,545	2,656	2,551	2,656	2,583	2,655	2,572	2,635
10	TYL	3,574	2,873	3,605	2,848	3,639	2,850	3,632	2,860	3,727	2,868
11	LFK	2,498	2,451	2,513	2,458	2,450	2,464	2,494	2,462	2,468	2,418
12	HOU	1,037	1053	1,041	1,055	1,043	1,049	1,062	1,048	1,045	1,037
13	YKM	2,904	2,967	2,861	2,945	2,927	2,939	2,891	2,904	2,860	2,903
14	AUS	1,364	1,971	1,357	1,972	1,366	1,974	1,358	1,972	1,359	1,965
15	SAT	1,799	2,545	1,799	2,541	1,795	2,536	2,455	2,507	2,521	2,488
16	CRP	1,759	2,024	1,770	2,015	1,816	2,007	1,803	2,002	1,833	1,998
17	BRY	2,476	2,474	2,474	2,472	2,474	2,471	2,485	2,464	2,486	2,451
18	DAL	2,213	1,700	2,164	1,693	2,183	1,695	2,199	1,689	2,213	1,690
19	ATL	2,264	1,989	2,282	1,994	2,283	1,996	2,318	1,996	2,323	1,980
20	BMT	1,456	1,666	1,502	1,663	1,863	1,659	1,869	1,648	1,884	1,642
21	PHR	1,234	1,416	1,205	1,410	1,372	1,403	1,374	1,403	1,378	1,401
22	LRD	1,415	1,826	1,418	1,844	1,445	1,844	1,450	1,843	1,443	1,835
23	BWD	2,009	2,330	2,009	2,330	2,018	2,329	1,999	2,307	2,002	2,307
24	ELP	646	1,279	662	1,277	668	1,276	659	1,261	677	1,262
25	CHS	1,729	2,226	1,835	2,226	1,842	2,225	1,867	2,221	1,853	2,214
Total		49,244	57,367	49,344	57,279	50,292	57,262	51,188	57,070	51,410	56,859

Table 7 summarizes the number of sites and mileage used in this study for each district. All sites less than 0.10 mi were deleted from the database. In addition, only segments that contained no median (0 ft) and shoulder width less than or equal to 26 ft (both sides) were included in this study.

Table 7. Roadway Characteristics for Two-Lane Rural Highways Used in the Study.

ID	District	Number of Sites	Length (miles)	Percent of Total Length
1	Paris	3,139	2,631	5%
2	Fort Worth	1,399	1,886	3%
3	Wichita Falls	1,535	2,260	4%
4	Amarillo	1,666	2,993	5%
5	Lubbock	2,103	3,883	7%
6	Odessa	837	2,155	4%
7	San Angelo	1,293	2,677	5%
8	Abilene	1,624	2,783	5%
9	Waco	2,157	2,583	5%
10	Tyler	2,798	2,763	5%
11	Lufkin	1,947	2,363	4%
12	Houston	847	1,014	2%
13	Yoakum	2,323	2,850	5%
14	Austin	1,059	1,808	3%
15	San Antonio	1,976	2,430	4%
16	Corpus Christi	1,424	1,972	4%
17	Bryan	1,881	2,336	4%
18	Dallas	1,726	1,663	3%
19	Atlanta	1,843	1,896	3%
20	Beaumont	1,433	1,574	3%
21	Pharr	1,036	1,346	2%
22	Laredo	1,086	1,801	3%
23	Brownwood	1,537	2,245	4%
24	El Paso	510	1,239	2%
25	Childress	1,465	2,181	4%
Total		40,644	55,332	100%

DATA COLLECTION – SITE VISITS

This section describes the engineering study and associated tasks used to analyze the factors influencing roadway departure crashes on various two-lane roads throughout Texas. Building on the work accomplished in previous tasks in this project, the research team selected a sample of two-lane roadways in four TxDOT districts for study. The team compiled data on crashes, geometric characteristics, bridges and curves, roadway segments, and traffic characteristics from the CRIS, RHiNo, P-HINI, and GEO-HINI databases; they then collected a variety of roadway characteristics data on-site during field visits to either confirm or supplement the data obtained from the databases. Using the information in the combined dataset of field and database information, the research team then analyzed the data to look for trends and patterns that would suggest causes for, and corresponding countermeasures to, run-off-the-road crashes on two-lane highways in Texas. The content of this section is presented in four parts: database preparation, field data collection, compilation of merged database, and summary of findings.

Database Preparation

The first task in this effort was to determine what crashes to include in the study. Based on the work described in Appendix B, the research team used the definition of a single-vehicle ROR crash as described by TxDOT. That definition states that a crash is an applicable crash if it occurs off of the travel lane of the roadway and the vehicle collides with an object other than another motor vehicle.

The next task was to decide which roads to study. With input from the Project Monitoring Committee (PMC), the team decided to study roadways in the Odessa, San Angelo, Atlanta, and Lufkin Districts, as shown in Figure 3. Using these districts in both the eastern and western parts of the state would provide a variety of terrain and roadside environment, and it would help to identify any possible differences due to geography. Within each district, every control section was ranked by the number of run-off-road crashes per million vehicle miles (MVM) traveled during the period 2003–2008. For the actual field study, the research team emphasized control sections ranked among the 20 highest crash rates, along with any sites specifically recommended by the PMC. Ultimately, sites were chosen for further study because of the rate of ROR crashes per million vehicle miles, because of the total number of ROR crashes (based on a minimum of 5 crashes), a combination of the two, input from the PMC, or geographical proximity to other selected sites. Table 8 through Table 11 show a summary of information on the ranked sites in each district.

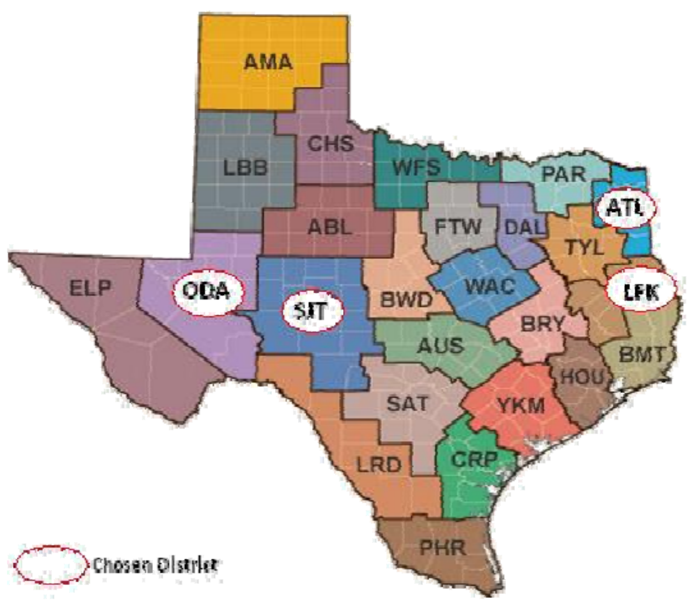


Figure 3. Districts Selected for Field Study.

Table 8. Summary of Sites Considered for Field Study in the Atlanta District.

District Rank	County	Route	Control Section	Length (mi)	ROR KABC Crashes / MVM 2003–08	Chosen for Field Study
1	Upshur	FM 1404	1386-01	3.832	1.60	X
2	Hartley	FM 3001	3041-03	1.709	1.31	X
3	Cass	FM 995	1216-03	9.848	1.15	
4	Camp	FM 3384	0248-08	2.748	0.92	
5	Cass	FM 1399	0546-08	15.503	0.92	
6	Upshur	FM 726	1895-01	3.828	0.91	X
7	Hartley	FM 450	1382-03	4.530	0.89	X
8	Morris	FM 144	0750-01	9.163	0.84	
9	Hartley	FM 968	1575-02	18.352	0.81	X
10	Upshur	FM 726	1896-01	2.850	0.75	X
11	Panola	FM 699	0394-03	14.366	0.74	X
12	Camp	FM 1519	0633-05	7.048	0.73	
13	Hartley	FM 1997	1919-02	10.663	0.72	
14	Bowie	FS 1398	1381-01	4.261	0.67	
15	Panola	FM 124	0732-01	8.960	0.66	
16	Cass	FM 96	1572-01	9.757	0.65	
17	Hartley	FM 449	0640-06	18.326	0.63	X
18	Panola	FM 999	1222-02	10.730	0.62	
19	Titus	FM 899	1176-02	2.700	0.61	
20	Upshur	FM 2088	0964-02	8.233	0.61	

Table 9. Summary of Sites Considered for Field Study in the Lufkin District.

District Rank	County	Route	Control Section	Length (mi)	ROR KABC Crashes / MVM 2003–08	Chosen for Field Study
1	Nacogdoches	FM 698	1074-01	5.090	2.19	
2	San Jacinto	FM 2693	0756-04	3.884	1.99	X
3	San Augustine	SH 21	0119-01	1.355	1.94	
4	Polk	FM 352	0929-01	3.481	1.50	
5	Polk	FM 1987	1877-01	7.211	1.33	
6	Trinity	FM 2262	2117-01	12.181	1.25	
7	Angelina	FM 1669	1675-01	6.242	1.20	X
8	San Jacinto	FM 946	0939-05	5.739	1.19	X
9	Trinity	FM 357	0931-04	11.400	1.18	
10	Polk	FM 3277	3471-01	2.923	1.17	X
11	Polk	FM 2610	2591-01	4.962	1.14	
12	Nacogdoches	FM 1087	0926-05	10.939	1.13	
13	Polk	FM 1276	1408-01	11.000	1.11	
14	Shelby	FM 2261	1409-03	6.764	1.09	
15	Shelby	FM 139	0742-01	25.229	1.07	
16	Angelina	FM 1194	2961-01	1.754	1.02	
17	San Jacinto	FM 3128	3198-01	2.441	1.01	
18	Polk	FM 350	0654-02	10.426	1.00	
19	Angelina	FM 843	1164-01	5.153	0.99	X
20	Polk	FM 942	1193-01	20.190	0.97	X

Table 10. Summary of Sites Considered for Field Study in the Odessa District.

District Rank	County	Route	Control Section	Length (mi)	ROR KABC Crashes / MVM 2003–08	Chosen for Field Study
1	Ward	FM 1927	1824-01	14.685	0.41	X
2	Reeves	US-285	0139-05	9.717	0.34	X
3	Reeves	SH 17	0103-01	3.994	0.32	X
4	Ward	BI 20	0004-01	5.204	0.31	X
5	Andrews	FM 1788	1718-04	13.728	0.24	X
6	Ward	SH 115	0354-02	8.675	0.23	X
7	Reeves	US-285	0139-04	16.382	0.22	
8	Midland	FM 1788	1718-07	6.708	0.21	
9	Loving	SH 302	0479-03	16.660	0.21	X
10	Winkler	SH 302	0479-04	14.368	0.20	X
11	Reeves	US-285	0139-03	20.930	0.19	
12	Upton	US-385	0229-04	8.934	0.18	
13	Andrews	FM 181	0961-03	12.623	0.17	
14	Martin	SH 349	0380-07	16.024	0.16	X
15	Upton	SH 329	0600-05	29.580	0.15	
16	Ector	SH 302	0463-07	6.220	0.15	
17	Midland	SH 349	0380-10	12.580	0.14	
18	Upton	US-67	0076-07	8.114	0.14	
19	Crane	FM 1053	0866-02	19.238	0.14	
20	Winkler	SH 115	0354-04	20.048	0.13	
21	Andrews	FM 1788	1718-05	17.722	0.11	X
NOTE: Site 14 is located in the San Angelo District, but is maintained by the Odessa District.						

Table 11. Summary of Sites Considered for Field Study in the San Angelo District.

District Rank	County	Route	Control Section	Length (mi)	ROR KABC Crashes / MVM 2003–08	Chosen for Field Study
1	Real	RM 337	0792-02	11.955	2.71	X
2	Real	RM 336	0554-01	25.070	2.20	X
3	Real	RM 337	0792-01	21.032	0.80	X
4	Kimble	US-377	0148-03	9.650	0.71	X
5	Kimble	RM 385	0829-01	32.348	0.53	
6	Real	SH 41	0201-06	18.187	0.52	X
7	Crockett	SH 349	0556-02	7.247	0.43	
8	Coke	SH 158	0406-02	15.719	0.36	
9	Kimble	FM 2169	2007-01	14.143	0.35	X
10	Real	FM 1120	0554-02	7.525	0.34	X
11	Crockett	US-190	2279-02	26.985	0.34	
12	Crockett	SH 163	0412-02	10.919	0.30	
13	Tom Green	FM 388	2284-01	9.962	0.29	
14	Coke	US-277	0407-01	4.082	0.26	
15	Kimble	US-290	0112-01	13.071	0.26	
16	Menard	US-83	0035-05	11.764	0.26	
17	Edwards	US-377 / SH 41	0201-05	17.124	0.25	
18	Tom Green	FM 2288	2141-02	5.892	0.25	
19	Coke	US-277	0264-05	13.337	0.24	
20	Crockett	SH 137	0558-10	29.360	0.24	
21	Martin	SH 349	0380-07	16.024	0.16	X
NOTE: Site 21 is located in the San Angelo District, but is maintained by the Odessa District.						

To determine appropriate sites to select for study and prepare a field data collection protocol, team members searched through multiple TxDOT databases to compile information on all two-lane highways in the four districts.

CRIS

The research team used the Crash Records Information System to obtain the database of characteristics for each crash that occurred on the study sites during the study period. Each row of the database contains the record for one crash, and each column of the database is a variable describing a characteristic of each crash (e.g., location, date, time, crash severity, etc.). There are a total of 149 variables in the system. Researchers identified the location of each crash by checking the CONTROL_SECTION and PRIMARY ROAD MILEPOINT variables. They also identified the severity and type of each crash by using three variables contained in the database. They are COLLISION ROAD_RELAT and CRASH_SEV. The crashes were extracted as single-vehicle ROR KABC crashes by using the following code: COLLISION<=5, ROAD_RELAT=2 or 3 or 4, and CRASH_SEV=1 or 2 or 3 or 4. The description of these variables is shown in Table 12.

Table 12. Description of CRIS Variable Definitions.

Codes Of Variables	Explanation of Codes
COLLISION < 5	Type of crash was other than motor-vehicle-with-motor-vehicle
ROAD_RELAT = 2, 3, 4	Crash occurred at a location that was not on the travel lane of the roadway
CRASH_SEV = 1, 2, 3, 4	KABC crashes

A search of the CRIS database revealed 867 of these crashes that occurred in the 20 control sections with the highest crash rates in each of the four districts; the records for these crashes were extracted for analysis.

RHiNo

The research team used the RHiNo database to collect roadway segment information on the study sites. In a format similar to CRIS, RHiNo is a database that contains the record for one road segment in each row, and each column is a variable related to a characteristic of this segment (e.g., roadway width, shoulder width, traffic volumes, etc.). There are 134 variables in the RHiNo database to describe each roadway segment.

Data from the RHiNo database allowed the research team to calculate the number of vehicle miles traveled (VMT) every year on each control section in the four districts. The VMT values were then used with CRIS data to calculate the crash rates on each control section to determine which control sections had the highest crash rates. ADT_CURRENT and LENGTH_OF_SECTION are two variables contained in the RHiNo database and n is the number of segments in each control section. The number of vehicle miles traveled every year for each control section was calculated by using Equation 1, and the crash rate was calculated from Equation 2.

$$VMT = 365 * \sum_{1}^{n} adt_{current} \times length_{of_{section}} \quad (1)$$

$$\text{Crash Rate} = \text{Number of Crashes} / VMT \quad (2)$$

The location of each segment was identified by checking three variables: CONTROL_SECTION, BEGIN_MILEPOINT, and END_MILEPOINT. Based on previous safety research and engineering judgment, the research team identified another 25 variables related to segment characteristics, such as FUNCTIONAL_SYSTEM and PCT_SINGLE_TRK_ADT, to create a RHiNo dataset to be used in analysis. Figure 4 shows an example of a portion of the RHiNo dataset.

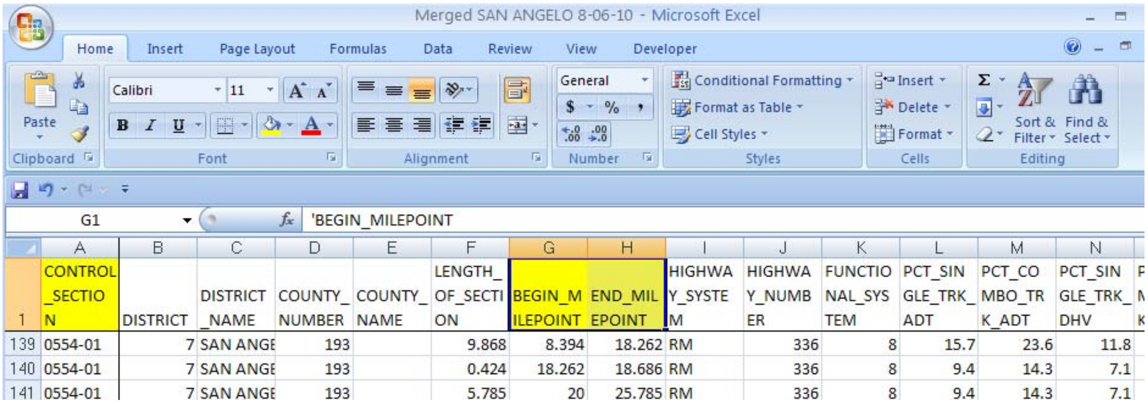


Figure 4. Sample of RHiNo Database.

P-HINI

P-HINI is a supplementary database based on RHiNo and contains information on at-grade intersections. The research team used the P-HINI database to collect information about intersections of roads on the state highway system. There are 83 variables in the P-HINI database and most of them are identical to variables in RHiNo. The location of each major intersection in all the road segments can be identified by control section (C_SEC) and milepoint (MPT). The intersecting highway is identified by the system classification (INT_HSYS) and route number (INT_HNUM). An example from the P-HINI dataset is shown in Figure 5.

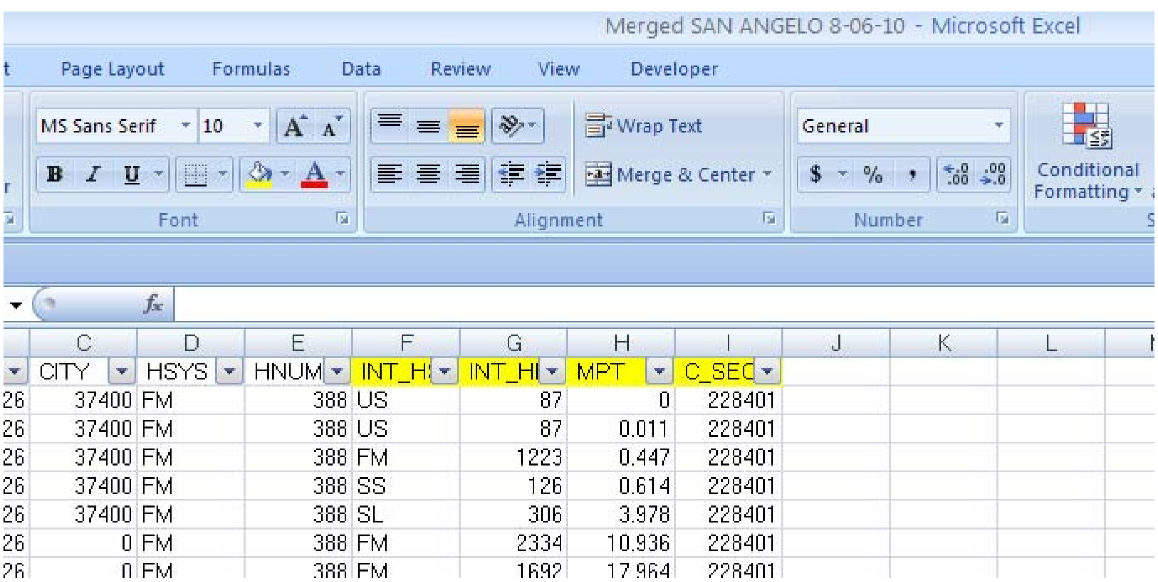
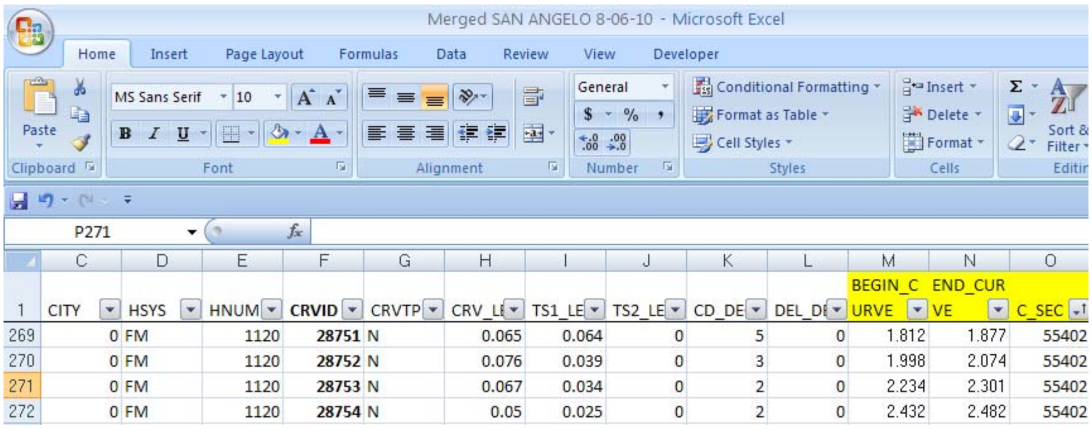


Figure 5. Sample of P-HINI Database.

GEO-HINI

GEO-HINI is another supplementary database based on the RHiNo database. The research team used the GEO-HINI database to collect information about each curve in a segment; each column in the database is a variable related to a characteristic of this curve. There are 76 variables contained in this dataset, and many are identical to those contained in the RHiNo database. Ten variables were identified and selected from this dataset such as BEGIN_CURVE, END_CURVE, CRV_TP, C_SEC, CRV_LEN, and CD_DEG to identify the location of each curve and some important characteristics related to curves. The location of each tangent and curve in all the road segments can be identified by checking variables BEGIN_CURVE, END_CURVE, and C_SEC. The other important information such as the type, length, and degree of the curve can also be identified by checking the remaining seven variables (see Figure 6).



1	CITY	HSYS	HNUM	CRVID	CRVTP	CRV_LE	TS1_LE	TS2_LE	CD_DE	DEL_DE	BEGIN_CURVE	END_CURVE	C_SEC
269	0	FM	1120	28751	N	0.065	0.064	0	5	0	1.812	1.877	55402
270	0	FM	1120	28752	N	0.076	0.039	0	3	0	1.998	2.074	55402
271	0	FM	1120	28753	N	0.067	0.034	0	2	0	2.234	2.301	55402
272	0	FM	1120	28754	N	0.05	0.025	0	2	0	2.432	2.482	55402

Figure 6. Sample of GEO-HINI Database.

FIELD DATA COLLECTION

Though the research team was able to compile a wide variety of site characteristics and information through in-office efforts, it was necessary to visit each site to determine and record specific characteristics of the roadways. The characteristics of emphasis were sideslope rating and lateral clearance, which were measured in multiple locations at each site, though other characteristics were also recorded.

Procedure

The procedure for collecting the data primarily involved a crew of three team members driving an instrumented vehicle multiple times in each direction of travel through the study sites while the equipment and the team members collected the required data. As the vehicle traveled through the site, GPS data were recorded and synchronized with text inputs that describe parts of the road, such as lateral clearances and location of intersections. The video system also synchronized the feed from two video cameras that recorded images of the road during the drives through the study sites. Other characteristics of the road were also recorded in handwritten form, using the worksheet shown in Figure 7. The basic procedure was as follows:

- Optional first pass (if not already completed through information from database): establish locations of beginning and ending point from roadway signs, roadways of interest, and county/city limits.
- First Data pass:
  - Dewetron Operator counts driveways and access points using a manual clicker-counter.

    - Technician counts curves, notes advisory speed signs, and verifies that milepoints of curve boundaries noted in the database agree with readings from the vehicle's odometer.
    - Driver takes measurements of lane, shoulder, and pavement width at two to three locations using a measuring wheel.
- Second Data pass: Dewetron Operator collects lateral clearance readings and Technician records sideslope ratings for one side of the roadway. While stopped for lateral clearance measurements throughout the site, Driver takes pictures of roadway (from within the travel lane when visibility permits, from the driver's seat of the vehicle with the window down when visibility is limited).
- Third Data pass: Collect data on opposite side of the roadway using the same procedure as the second pass.

The sideslope rating is a way to estimate the hazard that the sideslope area poses to a driver that runs off the road. Sideslope ratings were assigned on a five-point scale, as follows:

1. Little grade, if any; generous area to correct for ROR.
2. Some rise or fall with low grade, but still highly correctible at highway speeds.
3. Definite rise or fall with moderate grade, (e.g., drainage ditch), probably not correctible at moderate to high speeds, good possibility for non-injury.
4. Definite rise or fall with high grade and possible guardrail, similar to bridge over a shallow creek: not correctible, and high chance of B injury at highway speed.
5. High grade and significant elevation change, such as a cut into a cliff; not correctible and high chance of KA injury at highway speed.

Figure 8 through Figure 12 show examples of each sideslope rating. Ratings for each segment were made independent of the presence of obstructions or potential objects for collision (e.g., trees, guardrails, etc.). Those objects were considered in the measurement of lateral clearance in the field data collection.

A description of the equipment and more details on the responsibilities of each of the team members' roles are provided in the following sections.

SITE CHARACTERISTICS WORKSHEET– 6031

District	County	Control Section	Site Number
Highway	Date/Time:	Data Collector(s):	
Area Type:	Res Comm Ind Farm Park/Trees Other		

Location #	1	2	3	4
Hwy (if different)				
Milepoint				
Direction of Travel (N-S/E-W)	N-S E-W	N-S E-W	N-S E-W	N-S E-W
Shoulder Width-Left (ft)				
Shoulder Width-Right (ft)				
Average Lane Width (ft)				
Posted Speed Limit (mph)	______ / Statutory	______ / Statutory	______ / Statutory	______ / Statutory
# of Access Points				
Pavement Condition	E / G / F / P	E / G / F / P	E / G / F / P	E / G / F / P
Sideslope Rating				
# Horizontal Curves				
Curve Advisory Signs				
Centerline Rumble Strips?	Y / N	Y / N	Y / N	Y / N
Edgeline Rumble Strips?	Y / N	Y / N	Y / N	Y / N
Lighting?	Y / N	Y / N	Y / N	Y / N
# Passing Lanes				

Figure 7. Copy of Site Characteristics Worksheet for Field Study.

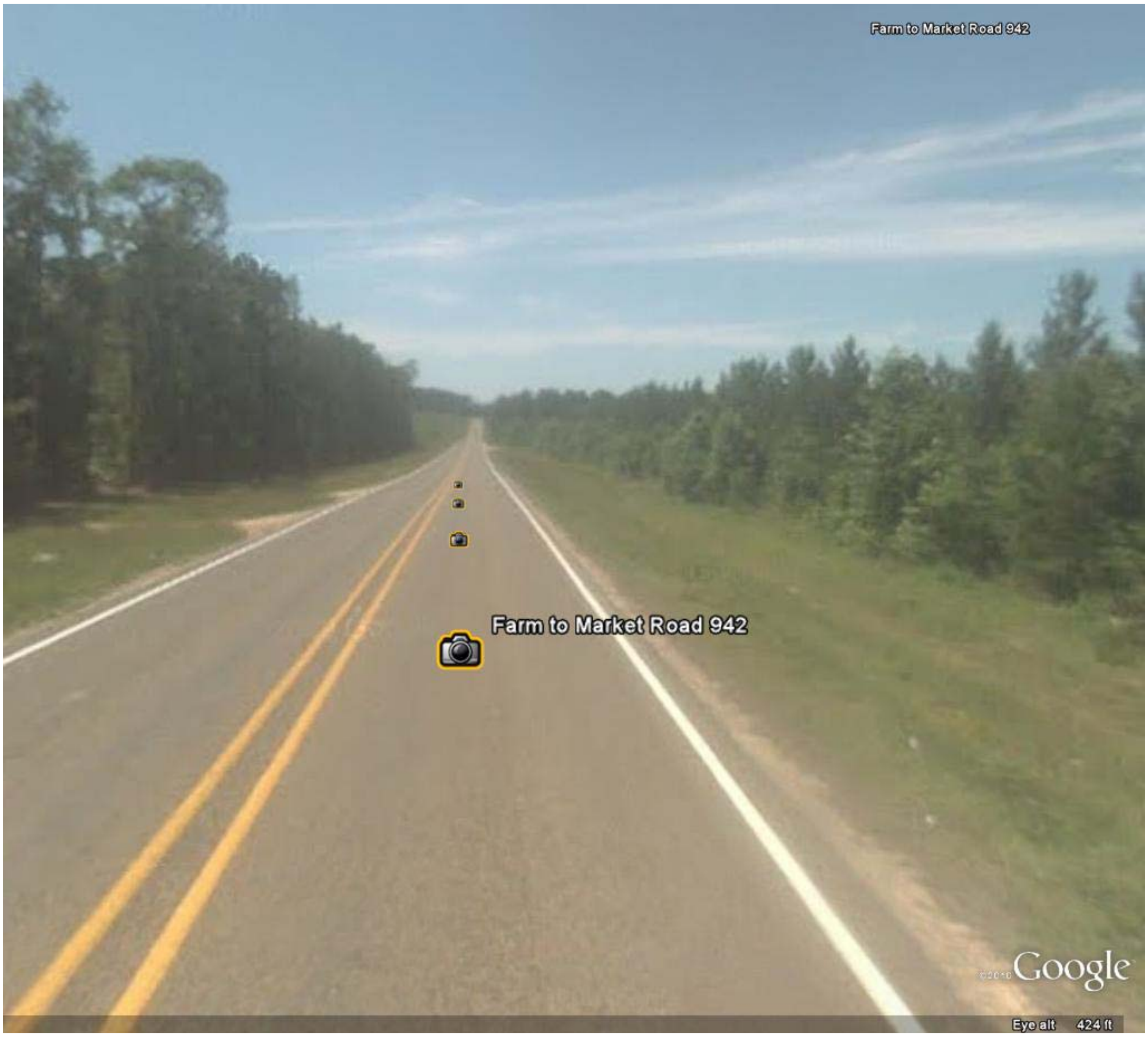


Figure 8. Example of Sideslope Rating 1.
(Image Credit: Google Earth™ Mapping Service, Street View)

Figure 9. Example of Sideslope Rating 2.
(Image Credit: Google Earth™ Mapping Service, Street View)

Figure 10. Example of Sideslope Rating 3.
(Image Credit: Google Earth™ Mapping Service, Street View)

Figure 11. Example of Sideslope Rating 4.
(Image Credit: Google Earth™ Mapping Service, Street View)

Figure 12. Example of Sideslope Rating 5.
(Image Credit: Google Earth™ Mapping Service, Street View)

Equipment Setup

The research team used minivans as study vehicles, which were more suitable for accommodating the three-person data collection team and the necessary equipment. The research team fitted the vehicle with a Dewetron data-collection system. This system includes unique synch-clock technology to combine data from many sources into one synchronized data file, which facilitates data analysis and processing. For this effort, the system employed two video cameras, a GPS receiver, and a lidar gun. One video camera was placed at the top center of the front windshield to record images from a driver's point of view and provided a permanent record of the alignment and profile of the road. A second camera was positioned on the rear window of the right side of the car to capture images of the roadside locations where lateral clearance and sideslope measurements were taken. The lidar gun was used to measure distances from the roadside to nearby obstructions and fixed objects, providing a record of lateral clearance. The Dewetron computer was set up in the back seat with the cameras and GPS connected to download their information directly to the computer, and lidar readings were input manually. The front passenger used a laptop computer to manually enter sideslope ratings, notes, and other important observations.

Roles

The data collection process required a team of three people in the vehicle: a driver, an observer/technician, and a Dewetron operator. Those roles are described in this section.

Driver

The driver's primary duty was to drive at a safe and appropriate speed at which the other two team members could record data. At key locations throughout each study site, the driver would stop the vehicle at the edge of the roadway so that a lateral clearance measurement could be taken. The driver also had the responsibility of measuring the lanes and shoulders in at least two locations on the control section. During these stops, the driver would take pictures of the road and surrounding area, providing a permanent record of the alignment and notable features.

Observer /Technician

The person in the passenger seat was in charge of navigating to each control section. For each study site, the passenger used the dataset stored on the laptop to identify the control section boundaries and confirm that the locations of curves and intersections agreed with the information from the RHiNo data. The trip odometer was zeroed out at the beginning of the control section so that the passenger could more easily track the team's relative location on the control section. On the first pass through the site, the observer noted and recorded the number of curves on the study site as well as the speed limits on any curve advisory signs. The observer also recorded certain characteristics of the road as noted in Figure 7. On the remaining passes through the site, the observer would rate the sideslope of the roadway for each segment for each side of the road.

Dewetron Operator

The person in the back seat was primarily in charge of monitoring the working status of the Dewetron system and measuring the lateral clearance with the lidar gun, making adjustments to the system in the event of technical issues such as loose cables or cameras out of focus. Prior to beginning the data collection passes, the Dewetron operator, along with the rest of the team, positioned and focused the two cameras inside the vehicle and attached the GPS receiver on the top of the vehicle. During data collection, the operator was in charge of counting the access points (e.g., intersections and driveways); the running count was kept on a clicker-counter and then recorded by the observer on the laptop. The more critical task of the operator, however, was measuring and recording lateral clearance values.

The analysis of lateral clearance data is based on segments divided by intersections, changes in cross-section, curves, and tangents. It was necessary to identify the location of curves and tangents at the start of data collection, which were generally identified by an initial pass through the study site. However, two control sections with a high density of horizontal curves had curve boundaries that were different from those listed in the GEO-HINI database; for those sites, the team drove through the site an additional time to manually record the locations of the start and end of each horizontal curve on the GPS profile of the roadway alignment before beginning the lateral clearance measurements.

As used in this analysis, lateral clearance is the lateral offset distance measured from the edge of the travel lane to the nearest fixed object or potential obstruction that a vehicle could collide with when leaving the roadway. This distance was measured by using a Kustom Pro-Laser III lidar gun in distance mode; after obtaining the measurement, the operator manually recorded that distance and the type of object into the Dewetron computer, creating a record of each lateral clearance reading relative to the GPS position of the roadway. The team's goal was to take a lateral clearance reading in each segment; however, characteristics of some sites necessitated more than one reading in a particular segment while other segments were not measured either because they had approximately the same clearance or because available sight distance and shoulder width precluded the possibility of safely stopping the vehicle to take a reading. The capability of the lidar gun prevented distance measurements less than 10 ft, so the distance to certain objects very near the edge of the travel lane, such as bridge guardrails, was estimated.

Figure 13 shows a screenshot of the Dewetron data collection. The lateral clearance measured by lidar is recorded into this system at the top right corner of the screen. The video signal recorded by the cameras is shown in the middle of the screen (forward camera on the left and side camera on the right), and the profile created by the GPS signal is shown at the bottom right. The lateral clearance and roadside rating of a given point on a study site can be evaluated by reviewing these three data sources.

Figure 13. Screenshot of Dewetron Software.

Safety Considerations

In addition to diligent assessment of visibility and available shoulder at the location of each reading, the team took other safety precautions during data collection. Team members wore reflective vests and hard hats, as well as protective footwear, while outside the vehicle for such activities as taking pictures and measuring the roadway width. The vehicle's hazard lights were activated at all times to alert drivers of the vehicle's reduced speed and frequent stops, and the driver turned into adjacent driveways to allow approaching traffic to pass when possible. Data were collected during daylight hours and generally under clear skies and dry pavement conditions.

COMPILATION OF MERGED DATABASE

The RHiNo, P-HINI, and GEO-HINI datasets each contain information about location. This information could be used to combine the three datasets into one. This is beneficial because it allows the research team to compile all the available variables for a given site into one record in the database, and it provides the information necessary to properly identify each of the roadway segments needed for analysis.

The research team desired to analyze the study sites on a segment-by-segment basis. The RHiNo database divides control sections into segments based on changes in variables in the database (e.g., roadway width, traffic volumes, etc.). A change in a variable creates a new segment at the location where the change occurs. However, the team also wanted to look at each site based on where intersections and horizontal curves were located. In addition, not all RHiNo segment changes were relevant to this analysis. Therefore, team members developed a method to identify all of the relevant segments at each site and merged the information from all databases into one file.

Beginning with the segments defined in the RHiNo file for each control section, team members reviewed those segments to determine which segments were defined by changes in the 30 variables deemed to be relevant to the analysis. Segment breaks generated by changes to other variables were removed, thus removing unnecessary segment breaks and simplifying the analysis.

Next, the team incorporated the P-HINI and GEO-HINI datasets to create segment breaks at intersections and horizontal curve boundaries. The variable used to link the information contained in the RHiNo dataset with the information contained in the P-HINI and GEO-HINI datasets is the common variable describing the location on the roadway. The BEGIN_CURVE and END_CURVE variables in GEO-HINI and the variable MPT in P-HINI were based on the control section milepoint and could be directly compared to the corresponding variable in RHiNo, allowing the research team to organize and sort the locations of segments, intersections, and curves spatially along the entire control section. This enabled the team to consider intersections and curve boundaries as segment break points in addition to the original segment divisions in RHiNo.

Using control section 2284-01 as an example, a screenshot of the final format of a merged dataset is shown in Figure 14. All of the relevant information contained in the three datasets for this control section was extracted using SAS. In the RHiNo dataset there are 12 original segments in this control section. The P-HINI and GEO-HINI datasets indicate that there are three major intersections and nine curves in this control section. Therefore, the milepoint of three intersections and beginning and ending milepoint of each curve were considered as segment break points in addition to the 12 original segments in RHiNo, resulting in 24 total segments in this control section.

In the file containing the merged dataset, each row represents a segment, and each column is a relevant variable from the RHiNo, P-HINI, and GEO-HINI datasets. This dataset was then combined with CRIS data by once again matching the location of crashes to the control section milepoints of the segments; this enabled the research team to determine the number of ROR KABC crashes that occurred in each segment.

Finally, other data collected in an office review using Google Earth, including the number of access points and initial estimate of sideslope rating, were added to the merged revised dataset. The highlighted areas of Figure 14 correspond to specific parts of the dataset and are described below:

- Part A: This is general information that describes the control section, including the control section number, rank of crash rate, district, highway number, and length of segment. This data comes from the RHiNo dataset.
- Part B: This column is input for use in the field study. It displays cumulative distance within the control section to help the technicians sequentially align the data in the spreadsheet with features found on the road.
- Part C: This portion of the spreadsheet describes each segment of the control section. It includes segment type (curve or tangent), the length, and the beginning and ending milepoints. This section also contains a place for comments made while inputting segment data. Segment breaks include not only those defined in RHiNo, but also the beginning and end of each horizontal curve and each intersection of two roads on the state highway system. These data are compiled from the data in sections A, D, and E.
- Part D: These data lists intersections that occur within each site. This data comes from the P-HINI dataset.
- Part E: These data describe the curves found in each control section. This data comes from the GEO-HINI dataset.
- Part F: These data describe characteristics of each segment such as number of lanes, speed limit, and shoulder width, as found in the RHiNo database.
- Part G: This portion of the spreadsheet consists of data collected in the field study and office review. Columns include number of access points (driveways and intersections counted from Google Earth), sideslope ratings from the field study and from Google Earth, and the number of single-vehicle ROR KABC crashes.

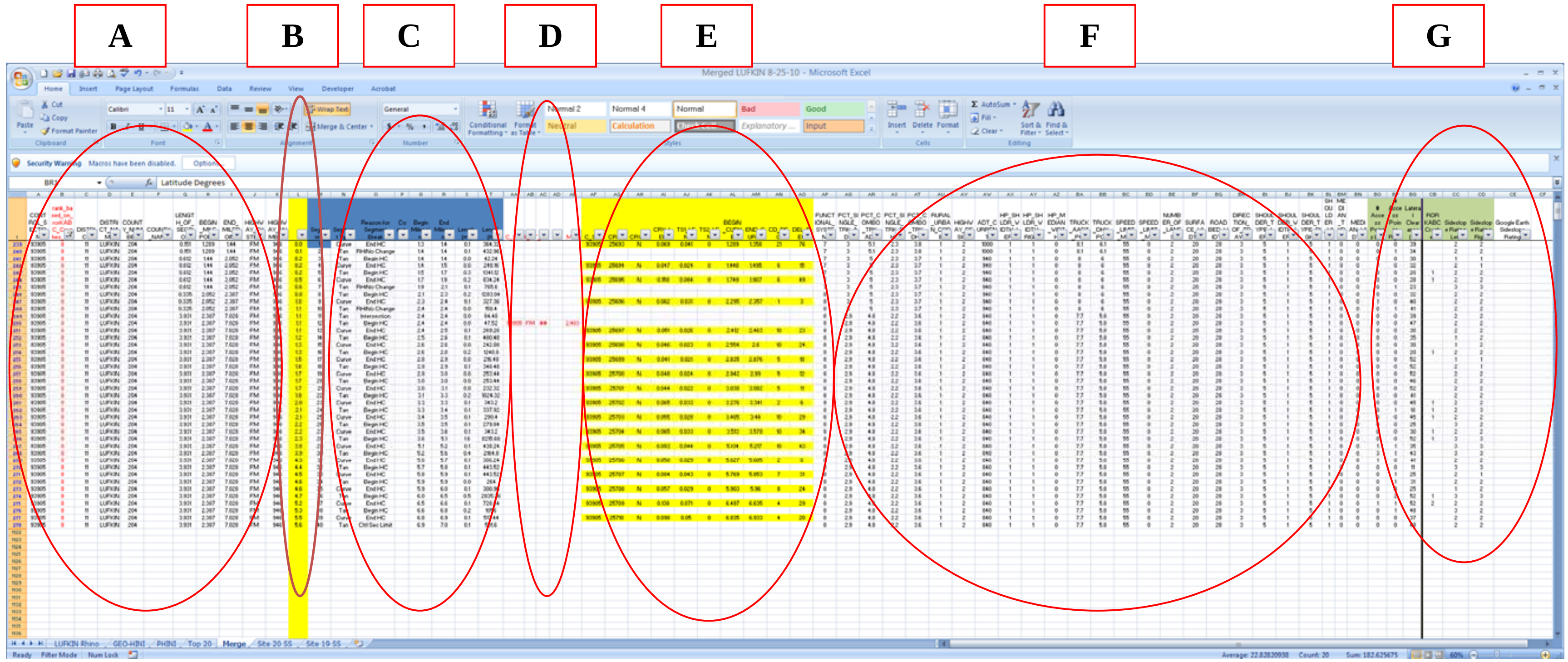


Figure 14. Merged Data File.

SUMMARY OF FINDINGS

Table 13 contains a summary of the roads that were chosen for data collection in this study. In total, the research team documented characteristics of 31 control sections, which included 1757 roadway segments and covered 340 miles. The remainder of this section provides discussion about the roads in each district and their characteristics.

Table 13. Summary of Field Data Collected.

DISTRICT NAME	COUNTY NAME	HIGHWAY SYSTEM	HIGHWAY NUMBER	CONTROL SECTION	BEGIN MILEPOINT	END MILEPOINT	def_1_2003_2008 total crash	ROR KABC average MVM 2003_2008	RANK	Length (Miles)	# Segments
ATLANTA	Upshur	FM	1404	1386-01	0	3.832	11	1.597783735	1	3.832	36
ATLANTA	Hartley	FM	3001	3041-03	0	1.709	5	1.307838682	2	1.709	8
ATLANTA	Upshur	FM	726	1895-01	0	3.828	9	0.91054335	6	3.828	36
ATLANTA	Hartley	FM	450	1382-03	0	4.53	7	0.889331196	7	4.53	58
ATLANTA	Hartley	FM	968	1575-02	0	18.5	45	0.810555538	9	18.352	156
ATLANTA	Upshur	FM	726	1896-01	0.807	3.657	4	0.748010904	10	2.85	27
ATLANTA	Panola	FM	699	0394-03	1.97	16.336	28	0.737612068	11	14.366	87
ATLANTA	Hartley	FM	449	0640-06	0	18.326	29	0.62749918	17	18.326	146
									Total	67.793	554
LUFKIN	San Jacinto	FM	2693	0756-04	0	3.884	5	1.988924189	2	3.884	16
LUFKIN	Angelina	FM	1669	1675-01	0	6.242	17	1.197507463	7	6.242	42
LUFKIN	San Jacinto	FM	946	0939-05	1.289	7.028	11	1.191792773	8	5.739	40
LUFKIN	Polk	FM	3277	3471-01	2.061	4.984	11	1.165884008	10	2.923	10
LUFKIN	Angelina	FM	843	1164-01	0.167	5.32	11	0.986232408	19	5.153	53
LUFKIN	Polk	FM	942	1193-01	0.004	20.194	21	0.974329731	20	20.19	16
									Total	44.131	177
ODESSA	Ward	FM	1927	1824-01	0	14.685	4	0.40676901	1	14.685	22
ODESSA	Reeves	US	285	0139-05	54.671	64.388	9	0.3447171	2	9.717	10
ODESSA	Reeves	SH	17	0103-01	13.034	25.35	4	0.321896324	3	3.994	6
ODESSA	Ward	BI	20	0004-01	10	15.204	5	0.309194588	4	5.204	24
ODESSA	Andrews	FM	1788	1718-04	0	13.728	6	0.236118272	5	13.728	10
ODESSA	Ward	SH	115	0354-02	0	8.675	4	0.227111173	6	8.675	13
ODESSA	Loving	SH	302	0479-03	3.127	19.787	6	0.205048887	9	16.66	22
ODESSA	Winkler	SH	302	0479-04	10	24.368	6	0.196147673	10	14.368	15
ODESSA	Martin	SH	349	0380-07	0	16.024	13	0.163660711	14	16.024	9
ODESSA	Andrews	FM	1788	1718-5	0	17.722			21+	17.722	10
									Total	120.777	141
SAN ANGELO	Real	RM	337	0792-02	21.032	32.987	40	2.708670081	1	11.955	210
SAN ANGELO	Real	RM	336	0554-01	0	26.384	23	2.202291697	2	25.07	279
SAN ANGELO	Real	RM	337	0792-01	0	21.032	22	0.802017834	3	21.032	168
SAN ANGELO	Kimble	US	377	0148-03	0	9.65	5	0.710744277	4	9.65	68
SAN ANGELO	Real	SH	41	0201-06	0	18.187	11	0.522723191	6	18.187	35
SAN ANGELO	Kimble	FM	2169	2007-01	1	15.143	5	0.353889472	9	14.143	68
SAN ANGELO	Real	FM	1120	0554-02	0	7.525	4	0.342139226	10	7.525	57
									Total	107.562	885
									Grand Total	340.263	1757

Lufkin District

The roads studied in the Lufkin District tended to vary in their horizontal and vertical alignment, as shown in Figure 15. Several of the control sections had more than seven horizontal curves, even though the sites tended to be less than 7 miles in length. The roadways had some slight vertical curves. Most of the roads were surrounded by dense growths of trees, and many were located in moderately residential areas. The tree line was often relatively close to the road and surrounded most of the roadway.

Figure 15. FM 2693 -- Typical Road Studied in Lufkin District.

Atlanta District

Most roadways in the Atlanta District were surrounded mainly by trees, as shown in Figure 16. The tree line was typically denser in comparison to that found in the Lufkin District. The tree line was close to the roadway, frequently at the edge of the clear zone. There was a noticeable amount of vertical alignment relief with small hills, though they were generally not steep. Control sections in this district averaged approximately 3.5 horizontal curves per mile. Compared to the other districts in this study, control sections in the Atlanta district had relatively steep sideslopes on both sides of the roadway.

Figure 16. FM 699 -- Typical Road Studied in Atlanta District.

San Angelo District

Most of the roads studied in this district had a high number of sharp horizontal curves (about 56 curves per control section) with small tangents in between. There was an average of about four horizontal curves per mile. The roadways also had constant changes in elevation as they traversed the hills. The sideslopes were very steep, as many roadside edges ended at the edge of a cliff or drop-off (frequently protected by a guardrail). Figure 17 provides one illustration. In addition, the horizontal and vertical curvature frequently limited the sight distance of the road ahead. Most of the roads studied had shoulder widths of 4 ft or less.

Figure 17. RM 337 -- Typical Road Studied in San Angelo District.

Odessa District

All of the roads in this district were very flat and straight with ample clear zone, as shown in Figure 18. The fixed objects that were on the edge of the road were usually small and not likely to cause substantial damage to a vehicle if struck during a departure from the roadway. Small brush and barb wire fences were the typical objects found in the roadside. In general, the few horizontal curves that existed were very gradual, with large radii. The roadways averaged about 0.4 horizontal curve per mile. Compared to the other districts in the study, the shoulders were generous, most being 7 ft or wider.

Figure 18. FM 1788 -- Typical Road Studied in Odessa District.

CHAPTER SUMMARY

This chapter has documented the data collection procedure. The procedure was divided into two components. In the first component, the research team assembled crash, roadway geometrics, and traffic flow data using the CRIS state database between 2003 and 2008. The data were assembled for roadway departure crashes that occurred on rural two-lane highways for the entire state of Texas. All the data were assembled in one common electronic database.

For the second component, the data were put together using a five-step process. First, the research team identified a sample of rural two-lane highways in four TxDOT districts, evenly split between eastern and western Texas. Then, the team obtained a copy of the original police report for all the crashes that occurred on the identified sections. Third, for each identified section, the team compiled data on crashes, geometric characteristics, bridges and curves, roadway segments, and traffic characteristics from the CRIS, RHiNo, P-HINI, and GEO-HINI databases. Fourth, the team visited all the sections to collect additional data using the Dewetron data collection system and to verify the data extracted from various databases. Like the first component, the data were assembled into one common electronic database. The databases in each component were established to be used in analyses of existing conditions and contributing factors to ROR crashes. The next chapter describes the analysis results for the data extracted from CRIS.

CHAPTER 4:
STATISTICAL ANALYSIS AND FINDINGS

INTRODUCTION

This chapter describes the analysis results for the crash data extracted from CRIS between 2003 and 2008. The chapter is divided into two sections. The first section summarizes the characteristics of the data. The second section covers the results for the regression analysis.

CRASH DATA CHARACTERISTICS

This section summarizes the characteristics of single-vehicle roadway departure crashes on two-lane rural roads.

In Texas, single-vehicle roadway departure crashes accounted for about 39 percent of all crashes occurring on two-lane rural roads between 2003 and 2008. Table 14 tabulates the total number of crashes and those associated with roadway departure by TxDOT district. In both cases, they include all severities (KABCO). The percentage of road departure crashes varied from about 25 percent to 52 percent. The lowest percentage was recorded in the Houston District, while the highest percentage was noted in the Laredo District.

Table 14. Roadway Departure Crashes by District (2003–2008).

ID	District	Total Number of Crashes	Road Departure Crashes	Percent of Road Departure Crashes
1	Paris	8,490	3,288	39%
2	Fort Worth	14,075	5,503	39%
3	Wichita Falls	3,869	1,773	46%
4	Amarillo	3,966	1,619	41%
5	Lubbock	3,521	1,352	38%
6	Odessa	2,358	1,116	47%
7	San Angelo	3,042	1,527	50%
8	Abilene	3,123	1,447	46%
9	Waco	9,040	3,759	42%
10	Tyler	18,586	7,903	43%
11	Lufkin	10,316	4,739	46%
12	Houston	15,390	3,903	25%
13	Yoakum	9,228	3,932	43%
14	Austin	9,915	4,192	42%
15	San Antonio	11,259	3,843	34%
16	Corpus Christi	5,085	2,107	41%
17	Bryan	11,056	5,382	49%
18	Dallas	13,484	4,397	33%
19	Atlanta	7,737	3,107	40%
20	Beaumont	9,704	3,619	37%
21	Pharr	7,907	2,080	26%
22	Laredo	1,517	787	52%
23	Brownwood	3,314	1,571	47%
24	El Paso	1,439	574	40%
25	Childress	1,345	520	39%
Total		188,766	74,040	39%

Figure 19 illustrates the annual trends for all (KABCO) and injury (KABC) crashes on two-lane rural roads in Texas. The trend lines show that the fluctuation is more pronounced for all crashes than for injury crashes. Overall, we can observe a small decrease in roadway departure crashes between 2003 and 2008.

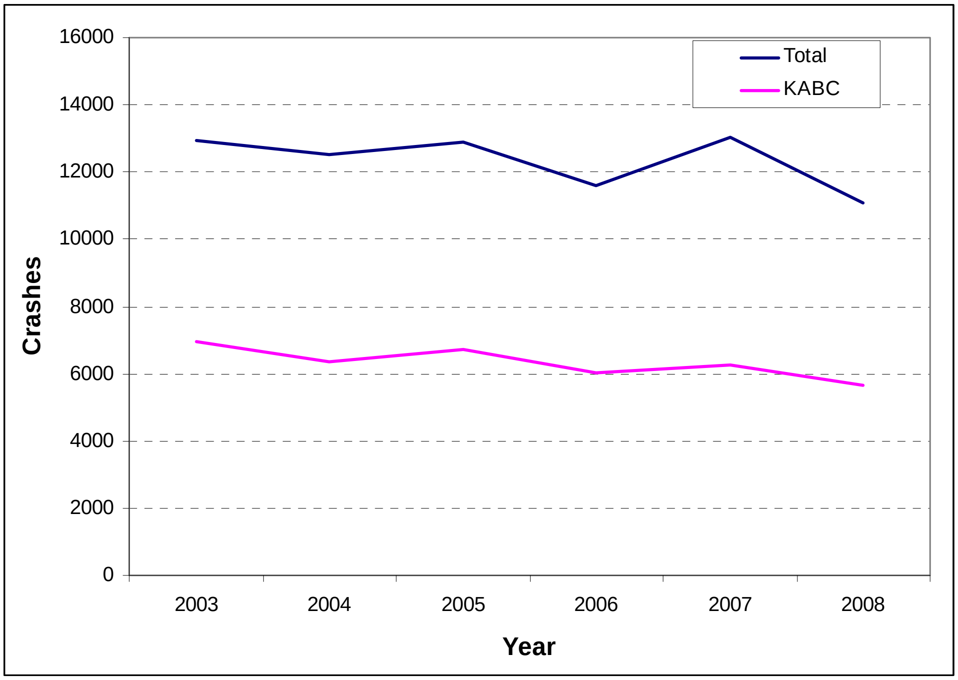


Figure 19. Roadway Departure Crashes in Texas.

Table 15 shows the number of roadway departure crashes by severity levels for all TxDOT districts. This table illustrates that approximately half of the crashes are non-injury crashes. Roadway departure fatal crashes accounted for about 3 percent in many districts. The Laredo District experienced the highest percentage of roadway departure fatal crashes when compared to other districts.

Table 15. Roadway Departure Crash Severity Analysis by District.

ID	District	K		A		B		C		O		Unknown		All	
		n	[a]	n	% [a]	n	% [a]	n	% [a]	n	% [a]	n	% [a]	n	% [b]
1	Paris	99	3%	340	10%	683	21%	584	18%	1,477	45%	105	3%	3,288	4%
2	Fort Worth	133	2%	425	8%	941	17%	867	16%	2,963	54%	174	3%	5,503	7%
3	Wichita Falls	52	3%	177	10%	358	20%	232	13%	925	52%	29	2%	1,773	2%
4	Amarillo	61	4%	127	8%	335	21%	229	14%	832	51%	35	2%	1,619	2%
5	Lubbock	48	4%	101	7%	315	23%	218	16%	636	47%	34	3%	1,352	2%
6	Odessa	48	4%	77	7%	219	20%	183	16%	557	50%	32	3%	1,116	2%
7	San Angelo	55	4%	207	14%	367	24%	182	12%	693	45%	23	2%	1,527	2%
8	Abilene	51	4%	162	11%	316	22%	194	13%	707	49%	17	1%	1,447	2%
9	Waco	99	3%	281	7%	794	21%	664	18%	1,833	49%	88	2%	3,759	5%
10	Tyler	198	3%	494	6%	1,508	19%	1,483	19%	3,932	50%	288	4%	7,903	11%
11	Lufkin	134	3%	468	10%	986	21%	835	18%	2,088	44%	228	5%	4,739	6%
12	Houston	90	2%	297	8%	716	18%	649	17%	1,934	50%	217	6%	3,903	5%
13	Yoakum	118	3%	284	7%	801	20%	696	18%	1,888	48%	145	4%	3,932	5%
14	Austin	116	3%	371	9%	850	20%	616	15%	2,061	49%	178	4%	4,192	6%
15	San Antonio	84	2%	333	9%	733	19%	578	15%	1,933	50%	182	5%	3,843	5%
16	Corpus Christi	64	3%	147	7%	370	18%	394	19%	1,031	49%	101	5%	2,107	3%
17	Bryan	148	3%	425	8%	1,194	22%	817	15%	2,665	50%	133	2%	5,382	7%
18	Dallas	95	2%	378	9%	799	18%	724	16%	2,225	51%	176	4%	4,397	6%
19	Atlanta	96	3%	307	10%	717	23%	555	18%	1,338	43%	94	3%	3,107	4%
20	Beaumont	106	3%	263	7%	698	19%	596	16%	1,840	51%	116	3%	3,619	5%
21	Pharr	60	3%	122	6%	349	17%	398	19%	950	46%	201	10%	2,080	3%
22	Laredo	45	6%	82	10%	156	20%	145	18%	326	41%	33	4%	787	1%
23	Brownwood	52	3%	160	10%	320	20%	259	16%	757	48%	23	1%	1,571	2%
24	El Paso	30	5%	66	11%	117	20%	100	17%	240	42%	21	4%	574	1%
25	Childress	19	4%	67	13%	111	21%	68	13%	248	48%	7	1%	520	1%
Total		2,101	3%	6,161	8%	14,753	20%	12,266	17%	36,079	49%	2,680	4%	74,040	100%

Note: Crashes are from 2003 to 2008
[a] percentage of each row
[b] percentage of column

Table 16 presents the number of roadway departure crashes by weather conditions. A greater share of severe crashes occurred during clear/cloudy conditions than in other weather conditions; approximately 88 percent of KAB crashes occurred in clear/cloudy conditions, compared to 80 percent of crashes with possible injury or property damage only. It is possible that during adverse weather conditions, drivers lower their speed, which results in less severe crashes.

Table 16. Roadway Departure Crash Severity Analysis by Weather Conditions.

Weather Condition	K		A		B		C		O		All	
	n	% [a]	n	% [a]	n	% [a]	n	% [a]	n	% [a]	n	% [b]
Clear/ Cloudy	1,910	3%	5,468	9%	12,602	22%	10,128	18%	27,907	48%	58,015	83%
Rain	126	1%	439	5%	1,440	15%	1,477	16%	5,854	63%	9,336	13%
Sleet/Hail	4	1%	23	4%	64	11%	83	14%	408	70%	582	1%
Snow	2	0%	13	3%	45	10%	56	12%	342	75%	458	1%
Fog	46	3%	98	6%	280	18%	270	17%	878	56%	1,572	2%
Other/ unknown	7	2%	58	18%	21	6%	67	21%	174	53%	327	0%
Total	2,095	3%	6,099	9%	14,452	21%	12,081	17%	35,563	51%	70,290	100%

Note: Crashes are from 2003 to 2008
[a] percentage of each row
[b] percentage of column

Table 17 summarizes the number of roadway departure crashes by the light condition. Roadway departure crashes that occurred during daylight or dark-lighted conditions were less likely to be fatal. In other words, good lighting conditions are associated with less severe crashes.

Table 17. Roadway Departure Crash Severity Analysis by Light Conditions.

Light Condition	K		A		B		C		O		All	
	n	% [a]	n	% [a]	n	% [a]	n	% [a]	n	% [a]	n	% [b]
Daylight	952	2%	3,323	9%	8,144	21%	6,914	18%	19,752	51%	39,085	56%
Dawn	57	4%	109	7%	294	18%	327	21%	812	51%	1,599	2%
Dark (Not lighted)	964	4%	2,388	9%	5,437	21%	4199	16%	12,931	50%	25,919	37%
Dark (lighted)	59	3%	137	7%	356	17%	361	17%	1,199	57%	2,112	3%
Dusk	31	3%	85	9%	195	21%	161	18%	444	49%	916	1%
Other/unknown	17	5%	22	6%	62	17%	68	18%	203	55%	372	1%
Total	2,080	3%	6,064	9%	14,488	21%	12,030	17%	35,341	50%	70,003	100%

Note: Crashes are from 2003 to 2008
[a] percentage of each row
[b] percentage of column

Table 18 summarizes the number of roadway departure crashes by the day of the week. This table shows that approximately half of crashes occurred between Friday and Sunday.

Table 18. Roadway Departure Crash Severity Analysis by Day of Week.

Day of Week	K		A		B		C		O		All	
	n	% [a]	n	% [a]	n	% [a]	n	% [a]	n	% [a]	n	% [b]
Sunday	427	3%	1,268	10%	2,680	22%	2,087	17%	5,933	48%	12,395	17%
Monday	256	3%	746	8%	1,928	21%	1,598	17%	4,795	51%	9,323	13%
Tuesday	230	3%	676	8%	1,725	20%	1,532	18%	4,454	52%	8,617	12%
Wednesday	227	3%	672	8%	1,750	19%	1,596	18%	4,771	53%	9,016	13%
Thursday	226	3%	685	8%	1,784	20%	1,573	18%	4,721	53%	8,989	13%
Friday	313	3%	838	8%	2,208	21%	1,784	17%	5,229	50%	10,372	15%
Saturday	426	3%	1,280	10%	2,696	21%	2,099	17%	6,191	49%	12,692	18%
Total	2,105	3%	6,165	9%	14,771	21%	12,269	17%	36,094	51%	71,404	100%

Note: Crashes are from 2003 to 2008
[a] percentage of each row
[b] percentage of column

Table 19 tabulates the number of roadway departure crashes by time of day. This table shows that crashes happening at night are slightly more severe than those occurring during the day (the proportion of KABC crashes at night is 34 percent versus 32 percent for crashes occurring during the daytime). Alcohol may be a factor for observing more severe crashes at night (e.g., it is estimated that between 55 and 75 percent of drunk drivers who are fatally injured do not wear their seat belt - see Transport Canada, 2008, etc.).

Table 19. Roadway Departure Crash Severity Analysis by Time of Day.

Time of Day	K		A		B		C		O		All	
	n	% [a]	n	% [a]	n	% [a]	n	% [a]	n	% [a]	n	% [b]
9PM-6AM	745	4%	1,841	9%	4,275	21%	3,338	16%	10,227	50%	20,426	29%
6AM-9PM	1,353	3%	4,320	9%	10,477	21%	8,897	18%	25,785	51%	50,832	71%
Total	2,098	3%	6,161	9%	14,752	21%	12,235	17%	36,012	51%	71,258	100%

Note: Crashes are from 2003 to 2008
[a] percentage of each row
[b] percentage of column

Table 20 summarizes the number of roadway departure crashes by right shoulder type. This table shows that about 52 percent of all roadway departure crashes occurred on surfaced shoulders, although that category accounts for about 43 percent of the total mileage of roads analyzed. This is the only shoulder type that is over-represented on a per-mile basis. However, it is anticipated that surfaced shoulders may be located on roads with large traffic flows.

Table 20. Roadway Departure Crash Severity Analysis by Right Shoulder Type.

Right Shoulder Type	Sites	Miles	K		A		B		C		O		All	
			n	% [a]	n	%	n	%	n	%	n	%	n	% [b]
None	5,134	7,520	211	3%	708	10%	1,546	21%	1,266	17%	3,702	50%	7,433	10%
Surfaced	19,332	24,048	1,034	3%	2,937	8%	7,446	20%	6,337	17%	19,260	52%	37,014	52%
Stabilized-Surfaced with Flex	5,869	9,140	371	3%	1,135	10%	2,464	21%	1,825	16%	5,834	50%	11,629	16%
Combination-Surface/ Stabilized	358	662	11	5%	24	11%	41	18%	45	20%	108	47%	229	0%
Earth-with or without turf	9,951	14,020	478	3%	1,361	9%	3,274	22%	2,796	19%	7,190	48%	15,099	21%
Total	40,644	55,390	2,105	3%	6,165	9%	14,771	21%	12,269	17%	36,094	51%	71,404	100%

Note: Crashes are from 2003 to 2008
[a] percentage of each row
[b] percentage of column

Table 21 presents the rollover crash rate by shoulder type. The "earth-with or without turf" shoulder type was associated with more rollover crashes per 100 million-vehicle-miles (MVM), followed by "stabilized-surfaced with flex" shoulder type. It should be pointed out that the manner in which the type of shoulder is defined varies for different TxDOT databases (i.e., TRM, RhiNo, etc.). Thus, the results shown in Table 21 should be interpreted with caution.

Table 21. Rollover Crash Rate by Right Shoulder Type.

Right Shoulder Type*	Injury and Fatal (KABC) rate per 100 MVM
None	0.29
Surfaced	0.29
Stabilized-Surfaced with Flex	0.47
Combination-Surface/Stabilized	0.02
Earth-with or without turf	0.65
*The manner in which the type of shoulder is defined varies for different TxDOT databases (i.e., TRM, RhiNo, etc.). Thus, the results shown should be interpreted with caution.	

Table 22 presents the injury (KABC) rates for roadway departure crashes per 100 MVM for all TxDOT districts. The rate was calculated for all segments, straight sections only, and horizontal curves only. Separating the road segments into straight and curved sections could help some districts determine whether the horizontal curves in their area may be more problematic than the state average.

Table 22. Roadway Departure Crash Rate by District.

ID	District	Injury and Fatal (KABC) rate per 100 MVM		
		All Segments	Straight Sections	Horizontal Curves
1	Paris	30.20	15.95	41.34
2	Fort Worth	36.95	19.28	50.42
3	Wichita Falls	27.02	23.62	33.20
4	Amarillo	17.91	12.59	57.61
5	Lubbock	19.94	17.88	21.11
6	Odessa	27.42	26.46	28.63
7	San Angelo	27.65	15.02	42.07
8	Abilene	23.69	22.72	39.15
9	Waco	27.19	17.21	39.45
10	Tyler	34.31	23.42	51.35
11	Lufkin	46.71	33.81	61.43
12	Houston	23.81	14.80	49.16
13	Yoakum	25.29	22.14	33.89
14	Austin	26.46	14.12	37.03
15	San Antonio	31.23	30.51	50.44
16	Corpus Christi	21.78	15.30	36.04
17	Bryan	32.11	21.01	47.72
18	Dallas	29.14	22.58	42.82
19	Atlanta	30.35	21.24	43.48
20	Beaumont	23.34	13.96	32.24
21	Pharr	26.11	14.57	41.07
22	Laredo	14.77	12.46	51.10
23	Brownwood	30.84	15.31	45.05
24	El Paso	18.20	20.07	48.87
25	Childress	15.84	15.52	30.54
State Average		**26.73**	**19.26**	**42.21**

As seen in Table 22, the average rate on horizontal curves is more than double that of the average rate on tangent sections, as expected. The Lufkin District experienced the highest rate per 100 MVM, irrespective of whether the road sections are straight or curved. Table 22 also shows that a district experiencing a low or medium crash rate on straight sections may experience a high rate on horizontal curves.

Based on the KABC roadway departure crash rates, the TxDOT districts were categorized into three different “rate groups”: High (top 8), Medium (middle 9), and Low (low 8). Table 23, which uses the data discussed in Table 22, shows the classification of districts into three rate groups for all segments, straight sections, and horizontal curves. This table also includes the results for KAB crashes from a previous TxDOT study on two-lane rural highways (TxDOT Report 4048-2). The ranking for each district is very similar between both this and the previous study.

Table 23. Crash Rate Groups by TxDOT Districts.

ID	District	KAB all crash rate*	KABC SV roadway departure crash rate		
			All Segments	Straight Sections	Horizontal Curves
1	Paris	Medium	High	Medium	Medium
2	Fort Worth	High	High	Medium	High
3	Wichita Falls	Medium	Medium	High	Low
4	Amarillo	Low	Low	Low	High
5	Lubbock	Low	Low	Medium	Low
6	Odessa	Low	Medium	High	Low
7	San Angelo	Low	Medium	Low	Medium
8	Abilene	Low	Low	High	Medium
9	Waco	Medium	Medium	Medium	Medium
10	Tyler	High	High	High	High
11	Lufkin	High	High	High	High
12	Houston	High	Medium	Low	High
13	Yoakum	Medium	Medium	High	Low
14	Austin	High	Medium	Low	Low
15	San Antonio	Medium	High	High	High
16	Corpus Christi	Medium	Low	Low	Low
17	Bryan	High	High	Medium	Medium
18	Dallas	High	Medium	High	Medium
19	Atlanta	High	High	Medium	Medium
20	Beaumont	Medium	Low	Low	Low
21	Pharr	Medium	Medium	Low	Medium
22	Laredo	Low	Low	Low	High
23	Brownwood	Medium	High	Medium	Medium
24	El Paso	Low	Low	Medium	High
25	Childress	Low	low	Medium	Low
* Classification for all types of crashes on two-lane rural roads from TxDOT Research Report 4048-2. This report used KAB crashes.					

Figure 20 shows the location of the rate groups for all types of segments in Texas. This figure shows that 5 of the 8 districts with high crash rates for all segments are located in east Texas. This is expected given the roadside conditions (i.e., trees, rolling terrain, etc.) in this part of Texas.

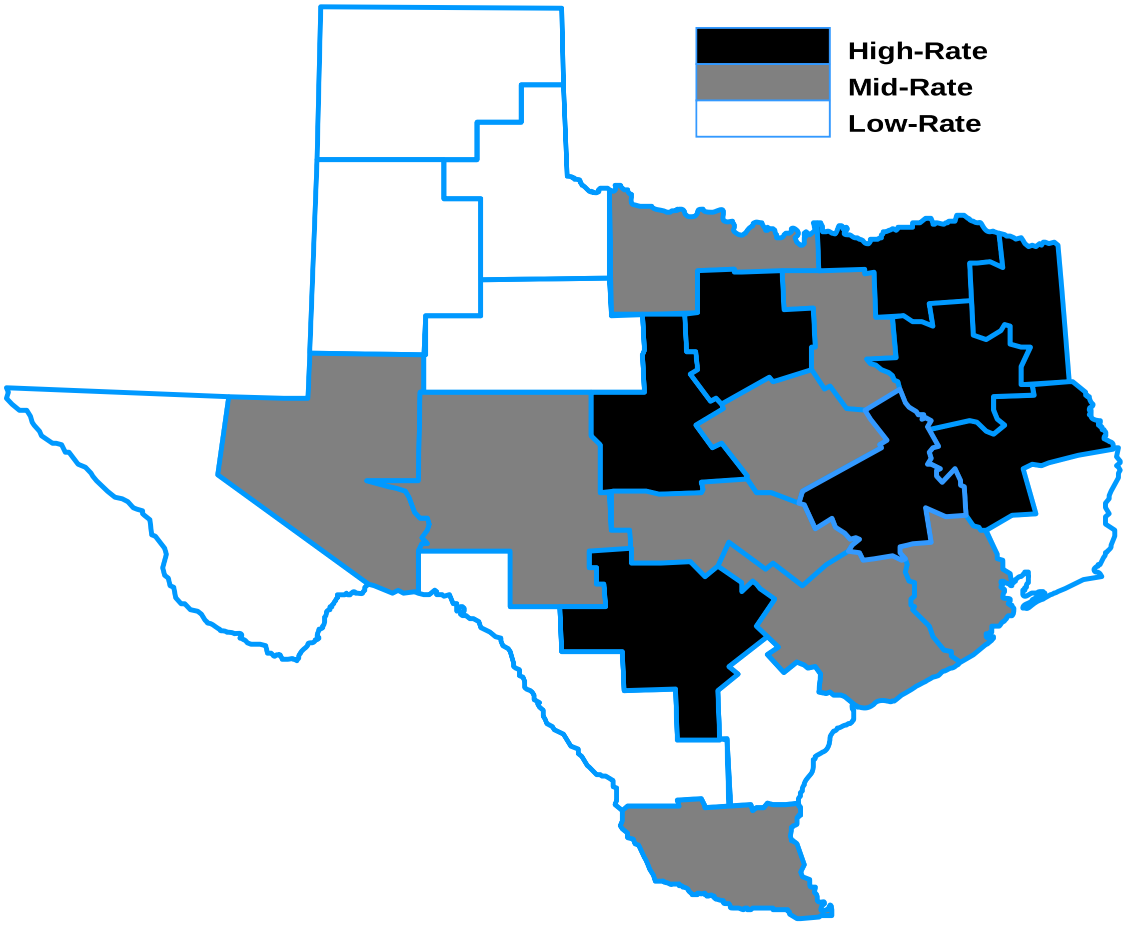


Figure 20. Location of Crash Rate Groups for Single Vehicle Roadway Departure KABC Crashes for All Segments in Texas.

Figure 21 illustrates the location of the rate groups for horizontal curves in the state. As opposed to Figure 20, the districts classified under the high crash rate group can also be found in West Texas and the Panhandle. Chapter 6 covers this aspect in greater detail.

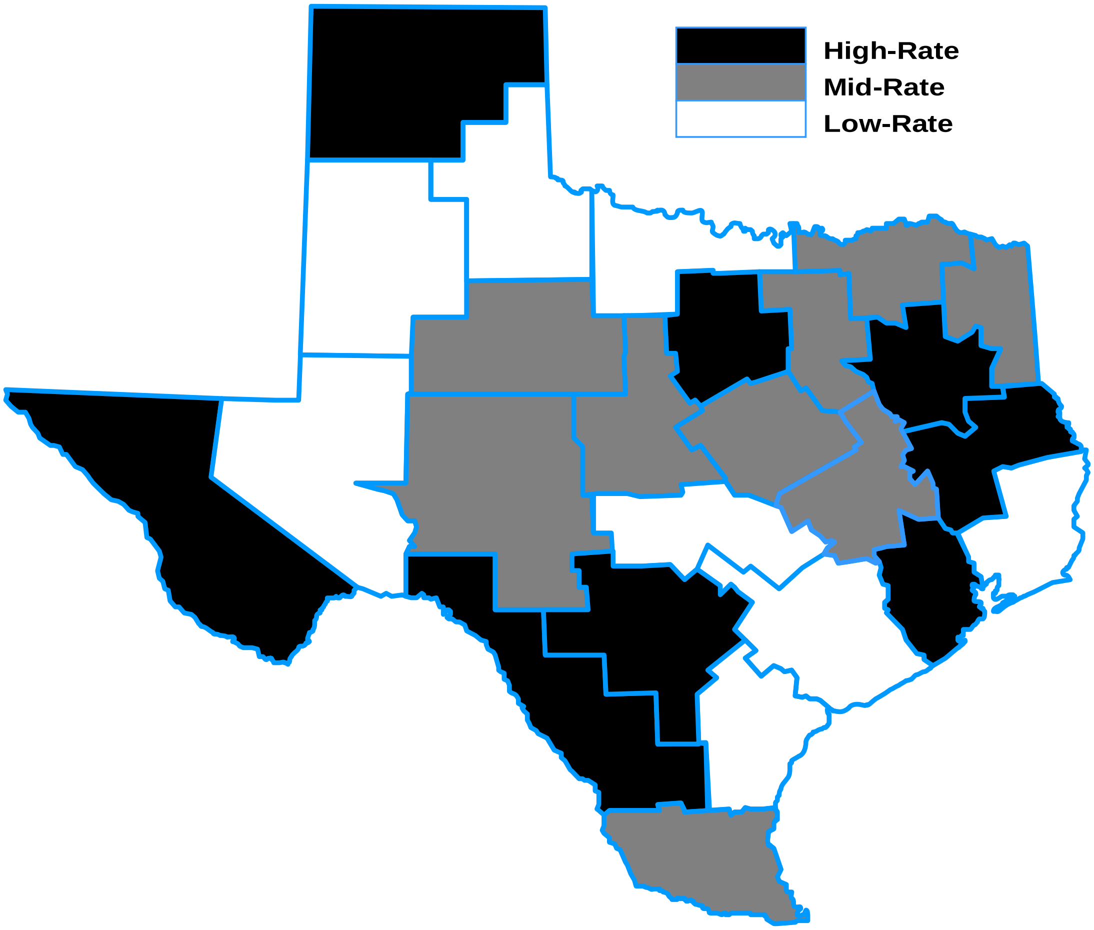


Figure 21. Location of Crash Rate Groups for Single Vehicle Roadway Departure KABC Crashes for Horizontal Curves in Texas.

REGRESSION ANALYSIS

This section briefly outlines the model characteristics, data characteristics, and modeling results.

Model Characteristics

The probabilistic structure used for developing the models is as follows: the number of crashes at the *i*th segment, Y_i, when conditional on its mean μ_i, is assumed to be Poisson distributed and independent over all segments as (Miaou and Lord, 2003):

$$Y_i \mid \mu_i \sim Po(\mu_i) \quad \text{i} = 1, 2, \ldots, \text{I} \tag{3}$$

The mean of the Poisson is structured as:

$$\mu_i = f(X;\beta)\exp(e_i) \tag{4}$$

Where,

$f(.)$ is a function of the covariates (*X*).

β is a vector of unknown coefficients.

e_i is a the model error independent of all the covariates.

It is usually assumed that exp(e_i) is independent and Gamma distributed with a mean equal to 1 and a variance $1/\phi$ for all *i* (with $\phi > 0$). With this characteristic, it can be shown that Y_i, conditional on $f(.)$ and ϕ, is distributed as a Negative Binomial (or Poisson-gamma) random variable with a mean $f(.)$ and a variance $f(.)(1+f(.)/\phi)$, respectively. The term ϕ is usually defined as the "inverse dispersion parameter" for the NB distribution.

Usually the dispersion parameter ($\alpha = 1/\phi$) or its inverse (ϕ) is assumed to be fixed, but recent research in highway safety has shown that the inverse dispersion parameter could potentially be dependent on the covariates (Hauer, 2001; Heydecker and Wu, 2001; Miaou and Lord, 2003). For simplifying the model development, the models were estimated using a fixed dispersion parameter.

An important characteristic associated with the development of statistical relationships is the choice of the functional form linking crashes to the covariates. For this work, the functional form is as follows:

$$\mu_i = \beta_0 \times L_i \times y \times F_i^{\beta_1} \times e^{\sum_{j=2}^{n} x_{ij}\beta_j} \tag{5}$$

Where,

μ_i = the estimated number of crashes per year for site i.

F_i = vehicles per day (ADT) for segment i.

L_i = length of segment i in miles.

y = number of years of crash data.

x_{ij} = a series of covariates (e.g., lane width, shoulder width, etc.) for site i.

n = number of covariates.

$\beta_0, \beta_1, \ldots, \beta_n$ = estimated coefficients.

The coefficients of the regression models were estimated with SAS (SAS, 2002). Because of the low sample size issue, for some models, the dispersion parameter was estimated using a weighted regression method (Lord, 2006). The residual deviance statistics were used to assess the model goodness-of-fit. Only variables that had the large influence on the predicted values were included in the models.

Data Characteristics

This sub-section briefly explains the data collection activities undertaken to assemble a database suitable for developing regression models for road departure crashes. It is then followed by the summary statistics of the data used for model development.

Several variables were considered in the regression models that may influence the number and severity of road departure crashes. The data collected included Annual Daily Traffic (ADT), lane width, shoulder width, shoulder type, horizontal curve density, and driveway density. The ADT, surface width, right and left shoulder widths, and shoulder type information were extracted from TxDOT's RHiNo database for 2003 to 2007. Since the RHiNo data for 2008 were not available at the time of this analysis, all road-related variables were assumed to be the same as that of 2007 except the ADT, which was estimated by applying the same percent change that occurred from 2006 to 2007. The lane width was calculated by dividing the surface width with total number of lanes. The average of right and left shoulder widths was considered for the shoulder width variable. The final database contained all road segments that meet the following criteria:

- Number_of_lanes = 2.
- Rural_Urban = 1 (this code refers to rural roads).
- Record_type = 1 (this code refers to main lanes only).
- Length_of_section ≥ 0.1 mi.
- Median_width = 0.
- Surface_width ≤ 26 ft.

The horizontal curve information was extracted from the GEO-HINI database. The GEO-HINI database contains geometrics for all curves on all highways in the state. Each curve is given a unique curve identifier number, and the beginning and ending milepoints of each curve are located through a given reference marker and curve length from that marker. Only normal curves (i.e. the curves that change at a constant rate) were considered in this study. The variables such as curve length, degree of curvature (CD), delta degree (change in direction at the point of intersection), and tangent lengths were extracted from the GEO-HINI database.

The driveway information was extracted from P-HINI database. The P-HINI database contains attributes about point-specific features of the roadway. The database does not have any information regarding the commercial and private roadway features. Only the features that meet the following criteria were considered in this study:

- *Int_type* ≠ B and *RFG* ≠ D & U (these codes refer to the features that are not grade-separated).
- *RFC* = 31, 32, or 33 (these codes refer to the features that are connector, ramp, or intersections).
- *INT_FTYP* = 11, 21, 31, 41, 51, 65, 66, or 67 (these codes refer to the features that are on-system main lanes, on-system frontage, federal and state lands, crossover, turnarounds, and local roads).

Once the crash and the road-related data were collected for each two-lane rural road segment, the data were combined using control section number and milepoints. Two separate databases, one for all segments and another for horizontal curves, were developed. Table 24 presents the summary statistics of all segments on two-lane rural roads in Texas that are used for model development. The final database contains 55,332 miles of roadway divided into 40,644 road sections. The segment length varied from 0.1 to 30 miles. The average traffic is from 10 to 40,000 vehicles per day. The average lane width and shoulder width is 11.1 ft and 4.7 ft, respectively. As discussed above, nearly 50 percent of the segments have 'surfaced' shoulders. The average curve and driveways densities were around 2 per mile each.

Table 24. Summary Statistics for Texas Dataset.

Variable	Minimum	Maximum	Mean (Std. Dev.)	Total
Segment Length (Miles)	0.1	30.1	1.36 (1.64)	55,331.8
ADT (Vehicles/day)	10	39,998	2,093 (2579.6)	--
Lane Width [a] (ft)	6	13	11.1 (1.2)	--
Shoulder Width [b] (ft)	0	30	4.7 (3.3)	--
Shoulder Type 1 (None)	--	--	--	5,134
Shoulder Type 2 (Surfaced)	--	--	--	19,332
Shoulder Type 3 (Stabilized-Surfaced with Flex)	--	--	--	5,869
Shoulder Type 4 (Combination-Surface/Stabilized)	--	--	--	358
Shoulder Type 5 (Earth-with or without turf)	--	--	--	9,951
Curve Density (curves/mile)	0	34.2	1.9 (2.6)	--
Driveway Density (driveways/mile)	0	44.8	2.4 (4.0)	--
Roadway Departure KABC Crashes (6 years)	0	35	0.79 (1.76)	32,242

[a] Lane Width= Surface Width /2;
[b] Shoulder Width= (Left Shoulder Width + Right Shoulder Width) / 2

Table 25 summarizes the distribution by segments and number of miles for two-lane rural highways in Texas used in this study.

Table 25. Distribution by Segments and Number of Miles for Texas Dataset.

	Range*	Segments	Miles		Range*	Segments	Miles
Segment Length (mi)	0-1	23,928	9,713	**Shoulder Width (ft)**	0-1	4,815	7,095
	1-2	7,260	10,473		1-2	3,145	4,937
	2-3	4,138	10,128		2-3	3,795	5,777
	3-4	2,442	8,412		3-4	4,038	5,772
	4-5	1,285	5,677		4-5	7,839	11,966
	5-6	692	3,765		5-6	1,603	2,262
	≥6	899	7,222		6-7	2,732	3,792
	TOTAL	40,644	55,390		7-8	1,005	1,051
					≥8	11,672	12,737
					TOTAL	40,644	55,390
ADT (veh/day)	≤100	1,500	3,393	**Curve Density (Curves/mi)**	0-1	19,873	29,197
	100-500	9,975	18,301		1-2	6,143	12,441
	500-1000	7,158	10,310		2-3	4,875	6,808
	1000-2000	8,157	10,135		3-4	3,228	3,393
	2000-5000	9,355	9,580		4-5	2,196	1,622
	>5000	4,499	3,671		5-6	1,420	863
	TOTAL	40,644	55,390		≥6	2,909	1,066
					TOTAL	40,644	55,390
Lane Width (ft)	<8	7	5	**Driveway Density (Driveways/mi)**	0-1	20,066	31,239
	8-9	24	33		1-2	7,818	15,653
	9-10	2,879	4,897		2-3	3,766	4,437
	10-11	13,496	20,972		3-4	2,073	1,562
	11-12	4,915	6,356		4-5	1,391	750
	≥12	19,323	23,127		5-6	970	413
	TOTAL	40,644	55,390		≥6	4,560	1,337
					TOTAL	40,644	55,390

* Ranges of variables are listed as x-y with x being inclusive and y being exclusive.

Modeling Results

Table 26 summarizes the parameter estimates associated with the calibrated models. Predictive models were developed separately for all type of crashes and roadway departure crashes to examine the influence of each variable on the two types of crashes. Separate models were also developed for three different rate groups mentioned above for road departure crashes on all segments. With the Texas data, the variables that are significant for all types of crashes were also significant at the 5 percent level for roadway departure crashes. The negative coefficients associated with the lane width and shoulder width variables indicate that an increase in these variables is associated with a decrease in the number of crashes. As expected, increases in traffic volume and curve density are associated with an increase in the number of crashes. Shoulders that are either surfaced or combination-surface/stabilized are associated with a decrease for all crash types. However, the driveway density has a mixed effect on different crash types, as seen below. For roadway departure crashes, the number of driveways had little effect (i.e., the curve in Figure 24 is almost flat), while the number of crashes goes up as driveway density increases for all crashes. Also, the shoulder type was not found to be significant at the 5-percent level for the three crash rate groups, probably because of the small sample size.

Table 26. Parameter Estimates on All Segments.

Variable	All Crashes	Roadway Departure Crashes			
	Texas	**Texas**	**Low-Rate Districts**	**Mid-Rate Districts**	**High-Rate Districts**
Intercept ($\ln \beta_0$)	−7.559 (0.04) [a]	−6.894 (0.09)	−7.822 (0.18)	−6.29 (0.15)	−6.383 (0.13)
ADT (F) (β_1)	1.0456 (0.003)	0.8035 (0.01)	0.8911 (0.02)	0.7351 (0.01)	0.7161 (0.01)
Lane Width (LW) (β_2)	−0.0632 (0.004)	−0.084 (0.01)	−0.085 (0.02)	−0.098 (0.02)	−0.054 (0.01)
Shoulder Width (SW) (β_3)	−0.0362 (0.001)	−0.058 (0.004)	−0.047 (0.01)	−0.056 (0.004)	−0.061 (0.005)
Presence of Shoulder Type 2 (ST2) (β_4)	−0.0746 (0.01)	−0.048 (0.02)	--	--	--
Presence of Shoulder Type 4 (ST4) (β_5)	−0.3856 (0.05)	−0.285 (0.10)	--	--	--
Curve Density (CDens) (β_6)	0.0710 (0.002)	0.1118 (0.00)	0.1133 (0.01)	0.1032 (0.01)	0.0884 (0.005)
Driveway Density (DDens) (β_7)	0.0447 (0.001)	−0.019 (0.00)	−0.016 (0.01)	−0.013 (0.005)	−0.019 (0.005)
Dispersion Parameter (α)	0.6753 (0.01)	0.556 (0.01)	0.5203 (0.04)	0.5135 (0.02)	0.5313 (0.02)
[a] Estimate (Standard error of the estimate)					

The annual roadway departure crash frequency per mile can be estimated by the following equations:

For Texas:

$$\mu = e^{-6.894} \times F^{0.8035} \times e^{(-0.084\times LW - 0.058\times SW - 0.048\times ST2 - 0.285\times ST4 + 0.1118\times CDens - 0.019\times DDens)} \quad (5)$$

For Low-Rate Districts:

$$\mu = e^{-7.822} \times F^{0.8911} \times e^{(-0.085\times LW - 0.047\times SW + 0.1133\times CDens - 0.016\times DDens)} \quad (6)$$

For Mid-Rate Districts:

$$\mu = e^{-6.29} \times F^{0.7351} \times e^{(-0.098\times LW - 0.056\times SW + 0.1032\times CDens - 0.013\times DDens)} \quad (7)$$

For High-Rate Districts:

$$\mu = e^{-6.383} \times F^{0.7161} \times e^{(-0.054\times LW - 0.061\times SW + 0.0884\times CDens - 0.019\times DDens)} \quad (8)$$

Where,

μ = the estimated number of crashes per year.

F = vehicles per day (ADT).

LW= lane width in feet.
SW= shoulder width in feet.
ST2= presence of shoulder type 2 (surfaced).
ST4= presence of shoulder type 4 (combination-surface/ stabilized).
CDens= curve density (curves per mile).
DDens= driveway density (driveways per mile).

Figure 22 shows the predicted number of crashes with the change in average shoulder width for different traffic flow levels. When traffic flow is very low, the effect of shoulder width on roadway departure crashes is negligible. However, with the increased flow, the increase in shoulder width has a great effect. For example, when the ADT is equal to 7000 vehicles per day, an increase in shoulder width from 0 to 10 ft could see a reduction in the number of crashes from 0.50 to 0.28 crashes per mile per year.

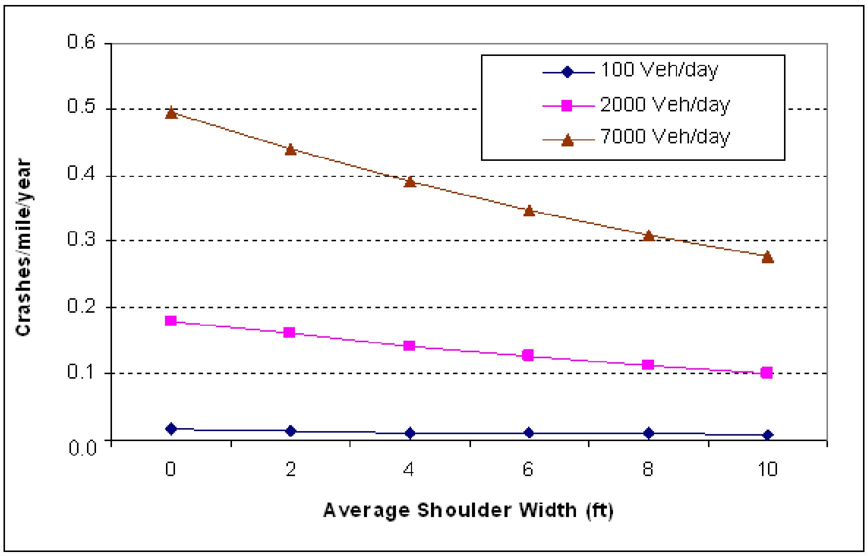


Figure 22. Change in Roadway Departure Crashes with Average Shoulder Width on All Segments in Texas.

Figure 23 presents the predicted number of roadway departure crashes as a function of the average shoulder width for the three crash groups. This figure shows that the rate of decrease in the number of crashes is almost the same for all rate groups.

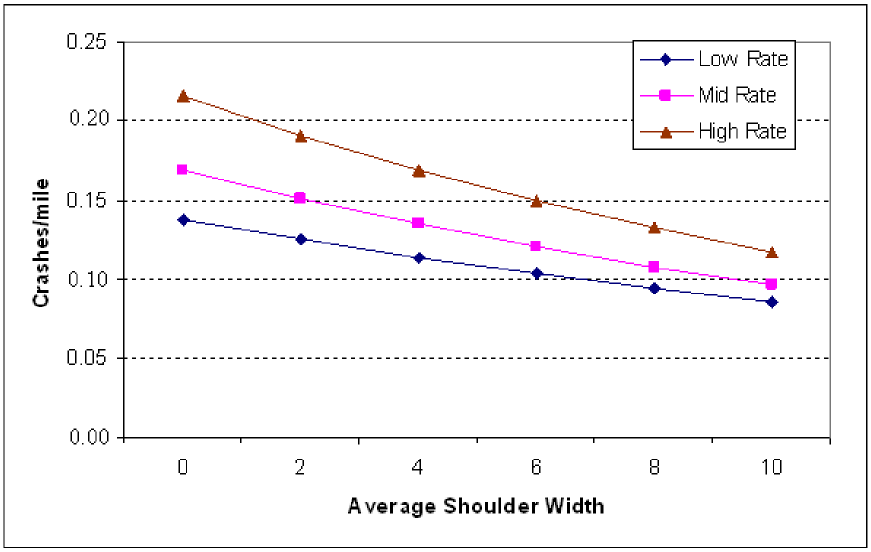


Figure 23. Change in Roadway Departure Crashes with Average Shoulder Width for Different Crash Rate Groups on All Segments.

Figure 24 shows the effects of driveway density on all type of crashes and road departure crashes. This figure suggests that an increase in driveway density is associated with an increase in the overall number of crashes, but it has almost no effect (slight decrease) on the number of roadway departure crashes. This is attributed to the assumption that increasing the number of driveways per unit of length increases the number of rear-end and sideswipe crashes, which reduces the likelihood of a single-vehicle roadway departure crash.

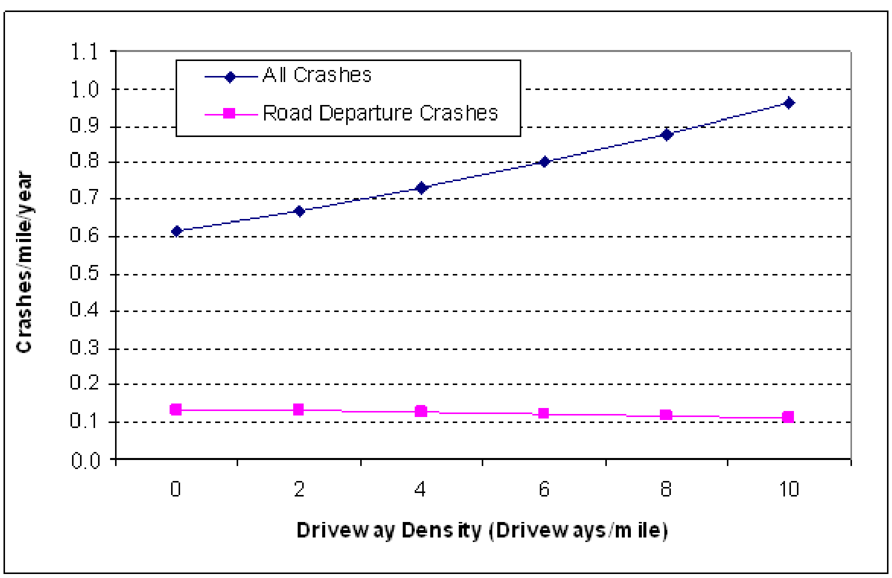


Figure 24. Change in Crashes with Driveway Density in Texas.

The coefficient values in Table 27 indicate the nature of the correlation between the road departure crashes and various covariates on horizontal curves. Due to the low sample mean values and small sample size, the few variables that were found to be significant at the 5 percent level for all segments were found to be insignificant at the 5 percent level for horizontal curves. As expected, the degree of curvature is positively associated with the number of roadway departure crashes.

Table 27. Parameter Estimates for Roadway Departure Crashes on Horizontal Curves.

Variable	Texas	Low-Rate	Mid-Rate	High-Rate
Intercept (ln β_0)	−6.448 (0.20) [a]	−7.4052 (0.25)	−7.1842 (0.22)	−6.5599 (0.19)
ADT (F) (β_1)	0.7657 (0.02)	0.7616 (0.04)	0.7382 (0.03)	0.7011 (0.03)
Lane Width (LW) (β_2)	−0.076 (0.02)	--	--	--
Shoulder Width (SW) (β_3)	−0.062 (0.01)	−0.0679 (0.02)	−0.0598 (0.01)	−0.0885 (0.01)
Degree of Curvature (CD) (β_4)	0.075 (0.01)	0.0586 (0.02)	0.08 (0.01)	0.0903 (0.01)
Dispersion Parameter (α)	1.4573 (0.09)	1.1683 (0.18)	1.6040 (0.16)	1.3801 (0.12)
[a] Estimate (Standard error of the estimate)				

The annual roadway departure crash frequency per mile on horizontal curves can be estimated by the following equations:

For Texas:

$$\mu = e^{-6.448} \times F^{0.7657} \times e^{(-0.076 \times LW - 0.062 \times SW + 0.075 \times CD)} \tag{9}$$

For Low-Rate Districts:

$$\mu = e^{-7.4052} \times F^{0.7616} \times e^{(-0.0679 \times SW + 0.0586 CD)} \tag{10}$$

For Mid-Rate Districts:

$$\mu = e^{-7.1842} \times F^{0.7382} \times e^{(-0.0598 \times SW + 0.08 CD)} \tag{11}$$

For High-Rate Districts:

$$\mu = e^{-6.5599} \times F^{0.7011} \times e^{(-0.0885 \times SW + 0.0903 CD)} \tag{12}$$

Where,

μ = the estimated number of crashes per year.
F = vehicles per day (ADT).
LW= lane width (ft).
SW= shoulder width (ft).
CD= degree of curvature.

Figure 25 shows the decrease in roadway departure crashes with the increase in shoulder width for different degrees of curvature. As the degree of curvature goes up, the influence of shoulder width becomes more important in reducing the number of crashes.

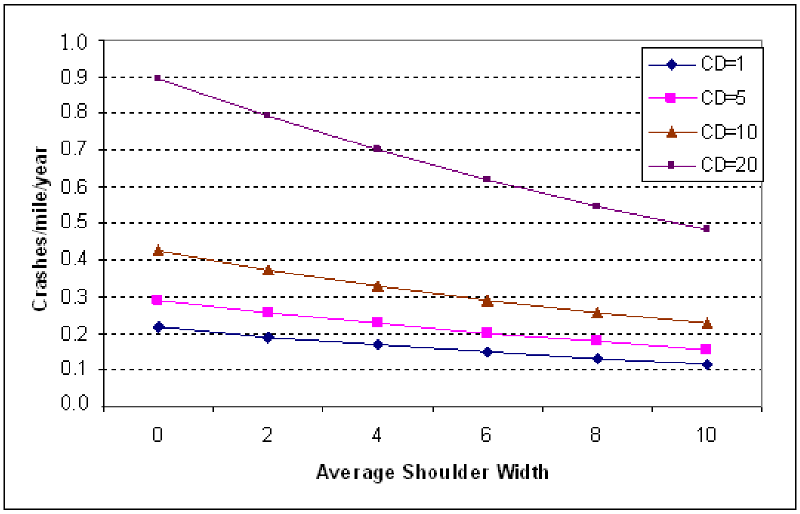


Figure 25. Roadway Departure Crashes as a Function of Shoulder Width.

Figure 26 illustrates the relationship between the number of roadway departure crashes occurring on horizontal curves and the average shoulder width for the three crash rate groups. This figure shows that the rate of decrease in the number of crashes is more significant for the high crash rate group. This means that the high crash rate group is expected to have greater benefits by widening the shoulders on horizontal curves than for the two lower crash rate groups.

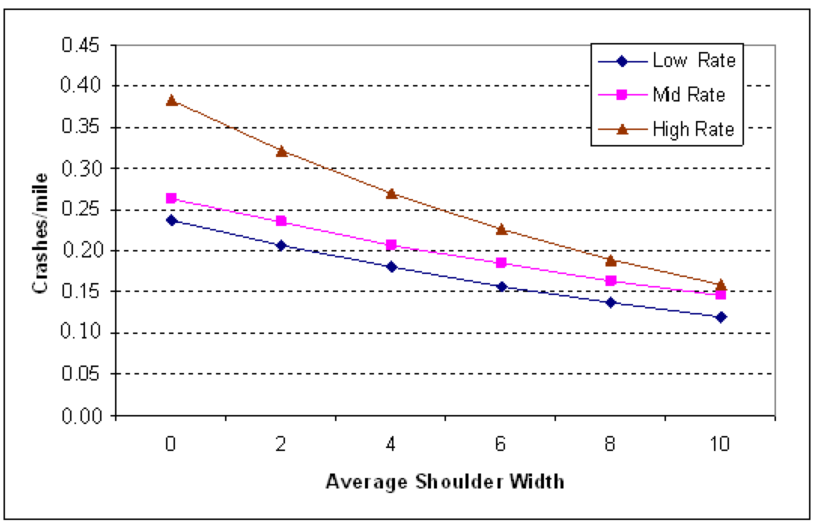


Figure 26. Change in Roadway Departure Crashes with Average Shoulder Width for Different Crash Rate Groups on Horizontal Curves.

Table 28 tabulates the coefficient estimates for the high crash rate districts for roadway departure crashes occurring on horizontal curves. Researchers developed models for only four districts (Fort Worth, Lufkin, San Antonio, and Tyler) due to sample size availability. Table 28 shows that sharper curves (high degree of curve) have a greater effect on the likelihood of a roadway departure in Tyler than the other three districts examined.

Table 28. Parameter Estimates for High Crash Rate Districts on Horizontal Curves.

Variable	Lufkin	Tyler	San Antonio	Fort Worth
Intercept ($\ln \beta_0$)	−6.9937 (0.52) [a]	−7.7236 (0.48)	−6.0476 (0.51)	−5.5231 (0.45)
F (β_1)	0.8185 (0.08)	0.8643 (0.06)	0.5893 (0.07)	0.5237 (0.06)
SW (β_3)	−0.1143 (0.03)	−0.1096 (0.02)	−0.0738 (0.03)	--
CD (β_4)	0.0525 (0.02)	0.1587 (0.02)	0.094 (0.03)	0.0735 (0.02)
Dispersion Parameter (α)	1.1629 (0.28)	1.0378 (0.20)	1.7717 (0.37)	1.1915 (0.23)
Note: Although Amarillo and Laredo Districts are in the high rate group, models could not be estimated. There were not enough data to estimate reliable models. [a] Estimate (Standard error of the estimate)				

CHAPTER SUMMARY

This chapter has presented the results of the statistical analyses conducted on the crash data that occurred on all two-lane rural highways between 2003 and 2008. The primary objective of these analyses was to provide key characteristics, patterns, and trends associated with roadway departure crashes on the identified network. Various types of statistical analyses were conducted on the data and were performed for the entire state, by region and on a per district basis.
The results of the analyses are as follows:

- The proportion of roadway departure crashes for the districts vary between 25 percent and 52 percent of all crashes that occurred on the two-lane rural network in Texas.
- The number of roadway departure injury crashes (KABC) has slightly diminished between 2003 and 2008.
- Wider shoulders on horizontal curves have a greater positive impact on safety compared to tangent sections for districts categorized as having a high crash rate.
- Wider shoulders on horizontal curves with a larger degree of curve have a greater positive impact on safety compared to tangent sections.
- More fatal crashes occur during nighttime conditions than during daytime.
- The regression models showed that driveway density had little influence on roadway departure crashes; however, the number of driveways per mile is associated with the increase of all crashes (mainly multi-vehicle crashes).
- As expected, more drivers are involved in roadway departure crashes between Friday and Sunday, which may be partly attributed to people driving under the influence of alcohol on weekends (NHTSA, 2008).
- There are more drivers leaving the traveled way in East Texas districts (Lufkin, Fort Worth, Tyler, Bryan, San Antonio) per 100 MVM than in West Texas. However, districts that experience a large number of roadway departures per 100 MVM are not limited to a single region in Texas.

CHAPTER 5:
CRASH REPORT ANALYSIS AND FINDINGS

INTRODUCTION

This chapter describes the analysis of crash record narratives and safety analysis related to the operational and design features associated with sites in the four districts. Based on the crash records listed in the CRIS database, the research team obtained electronic versions of the Peace Officer's Accident Report for each of the "Top 20" sites identified in Chapter 4, which contained the officers' narratives and diagrams in addition to the codes provided in the database. Using the information obtained from these reports, the research team then analyzed the data to look for trends and patterns that would suggest causes for, and corresponding countermeasures to, roadway departure crashes on rural two-lane highways in Texas.

IDENTIFYING RELEVANT CRASHES

The research team identified the 20 control sections with the highest run-off-road injury (KABC) crash rate in each of the four districts under consideration (Atlanta, Lufkin, Odessa, and San Angelo). The crash rate was defined in terms of crashes per million-vehicle- miles traveled during the 2003–2008 time period. The research team calculated these crash rates through the use of the CRIS and RHiNo databases to identify the number of crashes on each control section and the corresponding ADT for each year. In addition to the 20 control sections in each district with the highest crash rates, an additional site was submitted by the Project Monitoring Committee, resulting in 81 total sites for consideration. Of those 81 sites, 31 were selected for further study. A summary of these sites is shown in Table 29 and Figure 27, and further characteristics of these sites and their selection process are described in greater detail in Chapter 3.

Table 29. Summary of Sites Visited for Field Study.

District	Sites Visited	Total Miles	Total Segments
ATL	8	67.8	554
LFK	6	44.1	177
ODA	10	120.8	141
SJT	7	107.6	885

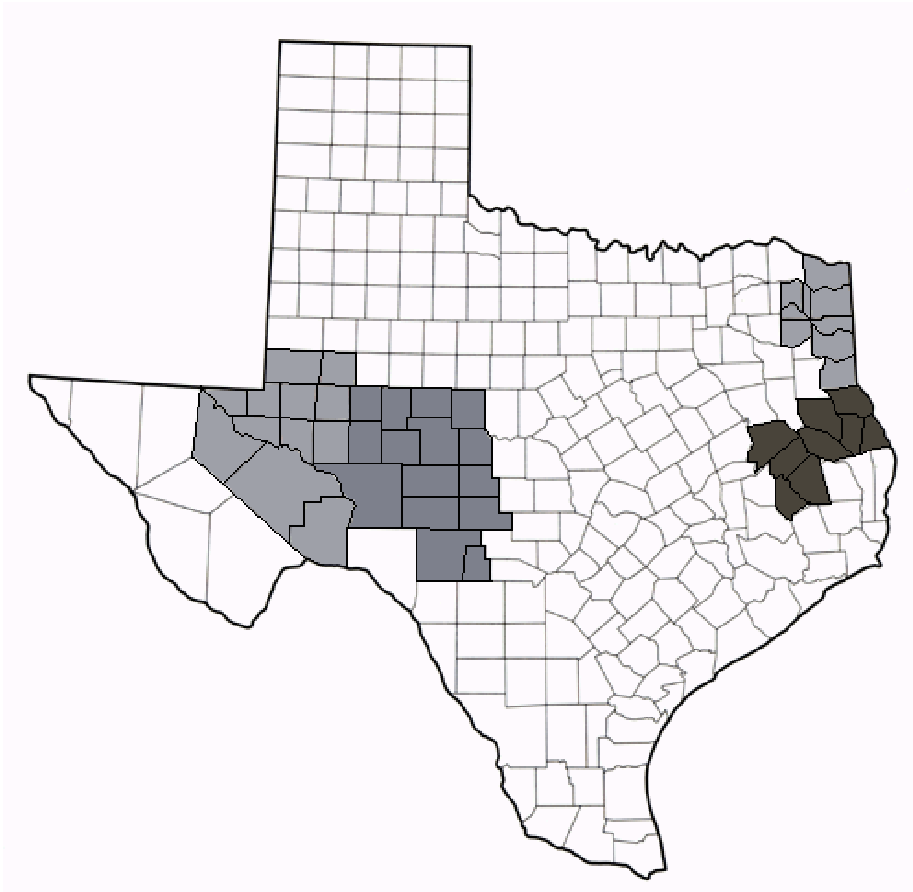


Figure 27. TxDOT Districts Visited for Field Study.

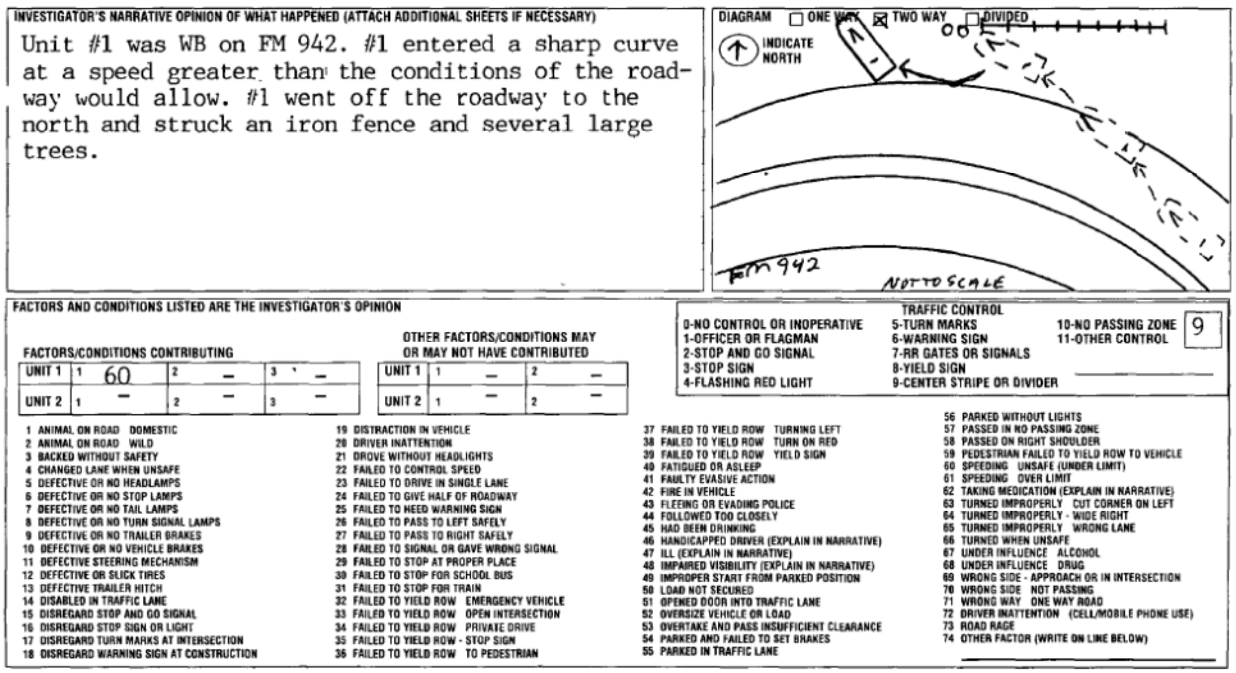
The research team identified 865 crashes at the 81 sites during the six-year study period, of which 394 occurred on the 31 control sections that were reviewed during the field studies. The research team requested electronic copies of the Peace Officer's Accident Report for each of those 394 crashes from TxDOT to conduct the analysis of narratives and diagrams.

ANALYSIS OF CONTRIBUTING FACTORS

The Texas Peace Officer's Accident Report contains sections on the location, date and time, vehicles involved, drivers and passengers involved, roadway conditions, injuries and property damage, charges filed, officer's narrative, and officer's diagram. The sections containing the officer's narrative and the diagram provide a great deal of insight into what occurred during a crash event. It is these two sections that are the primary difference between the full report and the crash codes in CRIS, and these two sections were the focus of this analysis.

The narrative describes in the officer's own words what happened during the crash event, based on the officer's observations supplemented by interviews with available witnesses, drivers, and passengers. The narrative section of the report also includes a summary of the factors and conditions that, in the opinion of the officer, contributed to the crash. The diagram, drawn or generated by the officer, is a pictorial representation of the events described in the narrative. An example of a narrative and diagram is shown in Figure 28.

A review of the narrative text, the diagram, and the contributing factors and conditions provide a great deal of information in determining the circumstances surrounding a crash, revealing specific effects of driver distractions or impairment, roadway conditions, and traffic conditions. The research team reviewed these three components of the accident report for the 394 crashes that occurred on the 31 study sites, to identify common causes of crashes and determine possible relationships between those causes and other characteristics. Initially, the research team reviewed each report to evaluate the frequency of specific contributing factors, events, and driver actions. Findings from that review are presented in the remainder of this section.



INVESTIGATOR'S NARRATIVE OPINION OF WHAT HAPPENED (ATTACH ADDITIONAL SHEETS IF NECESSARY)

Unit #1 was WB on FM 942. #1 entered a sharp curve at a speed greater than the conditions of the roadway would allow. #1 went off the roadway to the north and struck an iron fence and several large trees.

DIAGRAM ☐ ONE WAY ☒ TWO WAY ☐ DIVIDED

INDICATE NORTH

FM 942

NOT TO SCALE

FACTORS AND CONDITIONS LISTED ARE THE INVESTIGATOR'S OPINION

FACTORS/CONDITIONS CONTRIBUTING

UNIT 1	1 60	2 –	3 –
UNIT 2	1 –	2 –	3 –

OTHER FACTORS/CONDITIONS MAY OR MAY NOT HAVE CONTRIBUTED

UNIT 1	1 –	2 –
UNIT 2	1 –	2 –

TRAFFIC CONTROL

0-NO CONTROL OR INOPERATIVE
1-OFFICER OR FLAGMAN
2-STOP AND GO SIGNAL
3-STOP SIGN
4-FLASHING RED LIGHT
5-TURN MARKS
6-WARNING SIGN
7-RR GATES OR SIGNALS
8-YIELD SIGN
9-CENTER STRIPE OR DIVIDER
10-NO PASSING ZONE
11-OTHER CONTROL

9

1 ANIMAL ON ROAD DOMESTIC
2 ANIMAL ON ROAD WILD
3 BACKED WITHOUT SAFETY
4 CHANGED LANE WHEN UNSAFE
5 DEFECTIVE OR NO HEADLAMPS
6 DEFECTIVE OR NO STOP LAMPS
7 DEFECTIVE OR NO TAIL LAMPS
8 DEFECTIVE OR NO TURN SIGNAL LAMPS
9 DEFECTIVE OR NO TRAILER BRAKES
10 DEFECTIVE OR NO VEHICLE BRAKES
11 DEFECTIVE STEERING MECHANISM
12 DEFECTIVE OR SLICK TIRES
13 DEFECTIVE TRAILER HITCH
14 DISABLED IN TRAFFIC LANE
15 DISREGARD STOP AND GO SIGNAL
16 DISREGARD STOP SIGN OR LIGHT
17 DISREGARD TURN MARKS AT INTERSECTION
18 DISREGARD WARNING SIGN AT CONSTRUCTION
19 DISTRACTION IN VEHICLE
20 DRIVER INATTENTION
21 DROVE WITHOUT HEADLIGHTS
22 FAILED TO CONTROL SPEED
23 FAILED TO DRIVE IN SINGLE LANE
24 FAILED TO GIVE HALF OF ROADWAY
25 FAILED TO HEED WARNING SIGN
26 FAILED TO PASS TO LEFT SAFELY
27 FAILED TO PASS TO RIGHT SAFELY
28 FAILED TO SIGNAL OR GAVE WRONG SIGNAL
29 FAILED TO STOP AT PROPER PLACE
30 FAILED TO STOP FOR SCHOOL BUS
31 FAILED TO STOP FOR TRAIN
32 FAILED TO YIELD ROW EMERGENCY VEHICLE
33 FAILED TO YIELD ROW OPEN INTERSECTION
34 FAILED TO YIELD ROW PRIVATE DRIVE
35 FAILED TO YIELD ROW - STOP SIGN
36 FAILED TO YIELD ROW TO PEDESTRIAN
37 FAILED TO YIELD ROW TURNING LEFT
38 FAILED TO YIELD ROW TURN ON RED
39 FAILED TO YIELD ROW YIELD SIGN
40 FATIGUED OR ASLEEP
41 FAULTY EVASIVE ACTION
42 FIRE IN VEHICLE
43 FLEEING OR EVADING POLICE
44 FOLLOWED TOO CLOSELY
45 HAD BEEN DRINKING
46 HANDICAPPED DRIVER (EXPLAIN IN NARRATIVE)
47 ILL (EXPLAIN IN NARRATIVE)
48 IMPAIRED VISIBILITY (EXPLAIN IN NARRATIVE)
49 IMPROPER START FROM PARKED POSITION
50 LOAD NOT SECURED
51 OPENED DOOR INTO TRAFFIC LANE
52 OVERSIZE VEHICLE OR LOAD
53 OVERTAKE AND PASS INSUFFICIENT CLEARANCE
54 PARKED AND FAILED TO SET BRAKES
55 PARKED IN TRAFFIC LANE
56 PARKED WITHOUT LIGHTS
57 PASSED IN NO PASSING ZONE
58 PASSED ON RIGHT SHOULDER
59 PEDESTRIAN FAILED TO YIELD ROW TO VEHICLE
60 SPEEDING UNSAFE (UNDER LIMIT)
61 SPEEDING OVER LIMIT
62 TAKING MEDICATION (EXPLAIN IN NARRATIVE)
63 TURNED IMPROPERLY CUT CORNER ON LEFT
64 TURNED IMPROPERLY - WIDE RIGHT
65 TURNED IMPROPERLY WRONG LANE
66 TURNED WHEN UNSAFE
67 UNDER INFLUENCE ALCOHOL
68 UNDER INFLUENCE DRUG
69 WRONG SIDE - APPROACH OR IN INTERSECTION
70 WRONG SIDE NOT PASSING
71 WRONG WAY ONE WAY ROAD
72 DRIVER INATTENTION (CELL/MOBILE PHONE USE)
73 ROAD RAGE
74 OTHER FACTOR (WRITE ON LINE BELOW)

Figure 28. Example of Narrative and Diagram in Peace Officer's Accident Report.

Crash and Driver Characteristics

The research team wanted to determine what events and characteristics were common in the 394 study-site crashes, and what roadside features were commonly struck when impact was made. A review of the narratives, diagrams, contributing factors, and other details produced a distribution of these events and features for further analysis. A summary of key crash characteristics is provided in Table 30.

Table 30. Summary of Study-Site Crash Characteristics.

Characteristic	Number of Crashes	Percent of Crashes
On a horizontal curve	261	66.1
Overturned vehicle	163	41.3
At night	136	34.4
Involved a motorcycle	92	23.3
Fatality	35	8.9
At an intersection	16	4.1
Vehicle with trailer	11	2.8
NOTE: Many crashes had multiple characteristics, and all characteristics are shown. Therefore, the sum of the percent of crashes is greater than 100.		

The number of crashes occurring on a horizontal curve was nearly two-thirds of all of the ROR KABC crashes at the study sites. The vast majority of these crashes were a result of a vehicle attempting to negotiate the curve at a speed that was too fast for the curve or too fast for the weather or roadway conditions present at the time of the curve (e.g., wet pavement, loose gravel, etc.). This suggests that either the drivers involved in these crashes did not sufficiently consider the warnings, advisories, or regulations described by adjacent traffic control devices, or there is a need for additional devices to provide more information to drivers.

In a related finding, nearly a quarter of the observed crashes involved a motorcycle. In many cases, the motorcycle was approaching or traveling through a curve at the time of the crash. The relationship between crashes and motorcycles will be explored in more detail in the following section. Also potentially related to curve crashes is that more than a third of the observed crashes occurred at night, which could help to obscure the alignment of a curve for an approaching driver.

Over 40 percent of observed crashes resulted in an overturned vehicle, typically caused by the vehicle striking an embankment, culvert, or ditch at a low angle and/or high speed shortly after departing the roadway. As the summary of events will show, a sizeable proportion of crashes involved vehicles that departed the roadway on the far side or on both sides, which is frequently preceded by overcorrecting steering maneuvers; at high speeds, those maneuvers also increase the likelihood of overturning a vehicle.

Almost 9 percent of the observed crashes resulted in a fatality; this compares to approximately 6 percent of all KABC roadway departure crashes in Texas over the same period, as calculated from Table 30.

Table 31 shows a summary of driver demographic information. This information shows that 70 percent (277) of the drivers in study-site crashes were male, and the share of total crashes in each age group declined as age increased. Of the 394 drivers involved in a study-site crash, 138 (35 percent) were 25 years of age or younger; 77 drivers (19.5 percent) were aged 16 to 20.

Table 31. Summary of Study-Site Crash Driver Demographics.

Driver Demographic	Number of Crashes	Percent of Crashes
Gender		
Male	277	70.4
Female	117	29.6
Age		
16–25	138	35.0
26–35	72	18.3
36–45	70	17.8
46–55	58	14.7
56–65	37	9.4
>65	17	4.3
Unknown	2	0.5

Contributing Factors

Table 32 shows the distribution of selected contributing factors for the 394 study-site crashes, as listed by the reporting officer in the contributing factors codes. Just over half of the crashes (205) were due in some part to a vehicle traveling at a speed unsafe for conditions. In addition, another 21 crashes were affected by a driver exceeding the speed limit. This is consistent with the high number of crashes on curves shown in Table 32, in that vehicles traveling under the speed limit were still traveling too fast to negotiate the curve when the crash took place.

Almost a fourth of the crashes involved a driver that was inattentive; common distractions cited in the narratives included reaching for a cellular phone and adjusting the audio system. Other related factors included:

- A driver who was fatigued or asleep (49 crashes).
- A driver under the influence of alcohol or who had been drinking (71 crashes).
- A driver under the influence of other drugs (11 crashes).

Table 32. Summary of Contributing Factors.

Factor	Number of Crashes	Percent of Crashes
Speeding - unsafe (under limit)	205	52.0
Driver inattention	95	24.1
Faulty evasive action	78	19.8
Failed to heed warning sign	54	13.7
Fatigued or asleep	49	12.4
Failed to drive in single lane	48	12.2
Under influence - alcohol	47	11.9
Had been drinking	24	6.1
Animal on road - wild	22	5.6
Speeding - over limit	21	5.3
Under influence - drug	11	2.8
Defective or slick tires	10	2.5
Other factors	80	20.3
NOTE: Many crashes had multiple contributing factors, and all factors are shown. Therefore, the sum of the percent of crashes is greater than 100.		

Table 33 shows the distribution of key events that took place during the 394 study-site crashes, as described in the reporting officers' narratives and accompanying diagrams. Nearly 80 percent of the crashes (313) resulted in the vehicle departing the traveled-way on the right side of the road; this is not an unexpected result for a sample of single-vehicle run-off-road crashes. However, nearly half of the crashes (187) involved a vehicle that crossed the centerline, and most of those crashes (164) resulted in the vehicle leaving the road on the left side. As a result, there were 83 crashes (21 percent) of the 394 in which a vehicle actually left the roadway on both the left and right sides. This was typically accomplished by the vehicle initially departing the right shoulder, after which the driver overcorrected and crossed the centerline to exit the roadway on the far side. Given the high proportion of crashes on curves, this scenario was not uncommon, particularly at locations with curves that turned to the left (from the driver's view).

Table 33. Summary of Events in Study-Site Crashes.

Factor	Number of Crashes	Percent of Crashes
Ran off road on near (right) side	313	79.2
Crossed centerline	187	47.3
Ran off road on far (left) side	164	41.5
Ran off road on both sides	83	21.0
Struck man-made fixed object	157	39.7
Struck natural fixed object	137	34.7
Struck animal	2	0.5
Avoided animal	24	6.1
No object struck	109	27.6
Vehicle overturned	163	41.3
NOTE: Many crashes had multiple contributing factors, and all factors are shown. Therefore, the sum of the percent of crashes is greater than 100.		

Nearly 40 percent (157) of involved vehicles struck a man-made fixed object (e.g., sign, fence, etc.) during a crash, while over one-third (137) struck a natural fixed object, typically a tree. There were 19 crashes in which a vehicle struck both types of fixed objects and two crashes where an animal was struck. Six percent of the crashes (24) were initiated or exacerbated by the driver's maneuvers to avoid an animal. A little more than one-fourth of the crashes (109) resulted in no fixed object being struck; this usually meant that the vehicle drove into a culvert or onto an embankment, or it skidded out of control while on the roadway. These crashes frequently resulted in the vehicle overturning, occurring in 77 of the 109 crashes.

Overall, overturned vehicles occurred in 163 of the 394 study-site crashes, or 41.3 percent of the total. The nature of these crashes (e.g., higher speeds, roadway departure, overcorrecting and severe evasive maneuvers, etc.) contributes to a higher frequency of overturned vehicles than in the entire population of statewide crashes.

CHARACTERISTICS OF CRASHES BY DISTRICT

After reviewing the individual characteristics of ROR crashes at the study sites, the research team analyzed the crashes according to the district in which they occurred, using several events and features as criteria. The Atlanta (ATL) and San Angelo (SJT) Districts recorded the most crashes, with 137 and 109, respectively. The Lufkin (LFK) and Odessa (ODA) Districts had crash totals similar to each other, with 76 and 71, respectively. These results indicate that there was not a noticeable difference based solely on geographical (i.e., "east vs. west") location. However, 85 of the 109 crashes in San Angelo occurred on three control sections on RM 336 and RM 337 (i.e., the top three crashes by ROR crash rate), resulting in a low crash frequency at the other study sites. Table 34 shows the distribution of crashes by vehicle type (e.g., motorcycle, vehicle with trailer), roadway location (e.g., on a curve, at an intersection), and nighttime conditions.

Table 34. Summary of District Crashes by Vehicle Type, Roadway Location, and Nighttime.

District	Total Crashes	Vehicle Type		Roadway Location		
		% Motorcycle	% Trailer	% Curve	% Intersection	% Nighttime
ATL	137	10.2	2.2	67.9	5.8	43.8
LFK	76	6.6	2.6	71.1	5.3	42.1
ODA	71	0.0	7.0	14.1	4.2	42.3
SJT	109	67.0	0.9	94.5	0.9	12.8

The San Angelo District recorded by far the highest number and proportion of motorcycle crashes, which is consistent with the higher share of motorcycle traffic on the study sites in that district. A full two-thirds of the SVROR crashes in San Angelo involved a motorcycle. In addition, nearly 95 percent of the crashes there took place on a curve, which is also a function of the alignment of the roadways on the study sites there. The two findings are related, because the study sites near Leakey are noted as being popular among the motorcyclist community because of the varying horizontal and vertical alignment. The changes in alignment that make the roadway a popular location to drive, however, also increase the likelihood of an ROR crash.

Because of the high number of motorcycle and curve crashes, the share of trailer-related crashes and intersection-related crashes were nearly zero.

The Atlanta and Lufkin Districts also saw a high proportion of crashes on curves, at approximately 70 percent. The high frequency of curves on these study sites is typical of rural two-lane roads in these districts. Other similarities between these districts were a crash rate of 5 to 6 percent at intersections, 2 to 3 percent involving trailers, and 6 to 10 percent involving motorcycles.

The Odessa District had the fewest number of crashes, as well as the lowest percentages of any district in all but one category. A full 7 percent (i.e., five) of Odessa's crashes involved vehicles with trailers; one driver stated that high winds made his trailer unstable, two drivers were fatigued and fell asleep before leaving the roadway, and one cited defective steering. The fifth trailer crash was attributed to unsafe speed and faulty evasive action. The Odessa District had no motorcycle crashes, three intersection crashes, and ten curve crashes. Of the curve-related crashes, six were due at least in part to driver fatigue and/or intoxication.

Three districts had a proportion of nighttime crashes of approximately 43 percent; however, the San Angelo District's share of nighttime crashes was about one in eight, indicating that the common motorcycle crash on a curve was not typically due to lack of visibility.

Table 35 shows the distribution of crashes by events during the crash. The numbers from the Atlanta and Lufkin Districts are very similar for each category: three-fourths of vehicles left the roadway on the right side, half crossed the centerline and departed the roadway on the left side, about one-fourth of vehicles left the roadway on both sides, and nearly 40 percent overturned.

Table 35. Summary of District Crashes by Event.

District	Total Crashes	% Left Road Near Side	% Crossed CL	% Left Road Far Side	% Left Road Both Sides	% Overturned
ATL	137	75.2	53.3	49.6	24.8	39.4
LFK	76	77.6	50.0	43.4	21.1	38.2
ODA	71	81.7	59.2	47.9	29.6	81.7
SJT	109	84.4	30.3	26.6	11.0	19.3

The Odessa District has similar, but higher, numbers for most categories except for overturned; over 80 percent of the 71 ROR vehicles overturned. This combination of characteristics suggests driver inattention/fatigue and overcorrection (i.e., faulty evasive/corrective maneuver) as the common causes of crashes at study sites in the Odessa District, which is supported by the information in the officers' narratives and diagrams. In their review of the crash reports, the research team was unable to identify roadway features that would induce an ROR vehicle to overturn; however, potential tripping mechanisms (such as the boundary between the edge of the shoulder and the foreslope) should be examined in greater detail to investigate causes for the proportionally high number overturned vehicles in Odessa compared to crashes in other districts.

The San Angelo District had the highest proportion of vehicles that departed the roadway on the right side, at almost 85 percent, but it also had the lowest percentage of the other categories shown in Table 35. Most of the crashes that occurred in San Angelo were such that the drivers could not recover after leaving the roadway on the near side. Given the high proportion of motorcycle crashes, it is more likely that such a vehicle, upon leaving the road at high speed, would not have the stability to allow the driver to correct the trajectory enough to return to the roadway, let alone cross the centerline and depart the roadway again on the far side.

Table 36 shows the distribution of crashes by object struck. Between 35 and 50 percent of crashes involved a vehicle striking a man-made fixed object in each district, with similar numbers for natural fixed objects in each district except for Odessa, where study sites had few natural fixed objects with which to collide. Mirroring those results, nearly half of Odessa crashes resulted in no object being struck, compared to approximately 20 percent in the other districts. For these crashes, vehicles typically came to rest in a ditch or overturned without striking another object first. Only two crashes involved a vehicle striking an animal (one in Atlanta and one in Lufkin) but there were multiple crashes in each district that were initiated by the driver avoiding an animal.

Table 36. Summary of District Crashes by Object Struck.

District	Total Crashes	% Man-Made Object	% Natural Object	% Struck Animal	% Avoided Animal	% No Object
ATL	137	37.2	39.4	0.7	6.6	24.8
LFK	76	46.1	46.1	1.3	10.5	18.4
ODA	71	43.7	2.8	0.0	7.0	50.7
SJT	109	36.7	42.2	0.0	1.8	22.0

Table 37 contains a summary of crashes in each district by selected driver characteristics. While the sites in the Odessa District had the most forgiving roadside of the four districts in terms of fixed objects, Odessa also had the highest share of fatalities, which is likely related to the high proportion of overturned vehicles shown in Table 35, and the highest shares of fatigued/asleep drivers and distracted drivers. The other three districts had similar proportions of fatalities (6 to 9 percent), fatigued/asleep drivers (4 to 10 percent), and distracted drivers (7 to 10 percent). The Atlanta District had the highest share of impaired drivers, accounting for approximately one-fourth of crashes as compared to 7 to 15 percent elsewhere. Over half of the crashes in Atlanta and San Angelo were at least partially attributed to speeding over the posted limit or unsafe speed.

Table 37. Summary of District Crashes by Driver-Related Factors.

District	Total Crashes	% Fatality	% Fatigued/ Asleep	% Speeding/ Unsafe Speed	% Impaired	% Distracted
ATL	137	8.8	10.2	65.7	25.5	8.8
LFK	76	9.2	6.6	42.1	11.8	10.5
ODA	71	12.7	26.8	33.8	15.5	23.9
SJT	109	6.4	4.6	57.8	7.3	7.3

The distribution of crashes by driver age is shown in Table 38. Crashes in the Atlanta, Lufkin, and Odessa Districts follow the same general trend of declining frequency with increasing age. In San Angelo, however, the number of crashes by age group is relatively constant from age 16 to age 65, even increasing slightly as age increases. This suggests that there was no measurable relationship between the SVROR crashes in the San Angelo District and the drivers' ability or experience level. Because motorcycle and curve crashes were such a high proportion of the crashes in San Angelo, it is reasonable to assume that these two characteristics would be well-represented among all age groups. While younger, inexperienced drivers may have a more difficult time than older drivers judging the severity of a curve, motorcycle riders can be found in any age group, thus minimizing the effect of age on crash distribution for that segment of the driving population. Outside of motorcycle crashes on curves, however, the results in Table 38 suggest that driver age (and, by implication, experience) has an effect on roadway departure crashes.

Table 38. Summary of District Crashes by Driver Age.

District	Total Crashes	Number of Crashes in Age Group						
		16–25	26–35	36–45	46–55	56–65	>65	Unknown
ATL	137	50	27	32	20	6	2	1
LFK	76	35	13	10	8	4	6	0
ODA	71	33	15	7	7	5	3	1
SJT	109	20	17	21	23	22	6	0

RELATIONSHIPS BETWEEN CONTRIBUTING FACTORS

Previous analyses examined specific characteristics and factors, which provided insight on common causes and suggested potential targets for countermeasures. However, a more thorough analysis requires examining the interactions and relationships between factors, offering a better explanation of the conditions that are more likely for crashes to occur and the countermeasures to mitigate the effects of those conditions. This section contains a discussion and findings from those analyses.

Motorcycles

The research team first reviewed the characteristics of motorcycle crashes, looking for patterns and trends in commonly occurring causes or contributing factors. Table 39 contains a summary of selected characteristics of motorcycle crashes at the study sites.

Table 39. Summary of Characteristics of Motorcycle Crashes.

	District	Total Crashes	Curve	Speeding/ Unsafe	Impaired Driver	Distracted Driver	Weather	Nighttime
Motorcycle		**92**	**87**	**64**	**3**	**46**	**1**	**4**
	ATL	14	12	13	3	0	0	2
	LFK	5	5	3	0	1	0	1
	ODA	0	0	0	0	0	0	0
	SJT	73	70	48	0	45	1	1
Not Motorcycle		**302**	**174**	**146**	**60**	**46**	**14**	**132**
	ATL	124	82	78	32	12	7	58
	LFK	71	49	29	9	7	1	31
	ODA	71	10	24	11	17	6	30
	SJT	36	33	15	8	10	0	13

As discussed previously, only about one-fourth (92) of the 394 study-site crashes involved a motorcycle, but 73 of those crashes were in the San Angelo District, including 70 on curves. The 70 motorcycle crashes on curves in the San Angelo District represented:

- 76 percent of all motorcycle crashes in the four districts.
- 64 percent of all San Angelo study-site crashes.
- 96 percent of motorcycle crashes on study sites in San Angelo.

A more detailed review of the 73 motorcycle crashes in San Angelo revealed that all 48 of the speeding/unsafe speed crashes were on curves, and 44 of the 45 distracted-driver crashes were on curves. No motorcycle crashes on curves were weather-related, and one was at night. This suggests that there is a particular problem with either speeding or unsafe speed under the speed limit that is common at study sites in the San Angelo District, specifically on RM 336 and RM 337. Similarly, motorcycle drivers appear to be disproportionately distracted on those roadways, with almost as many distracted drivers in the 73 motorcycle crashes on curves in San Angelo as there were in all of the remaining study-site crashes in all four districts.

Motorcycle crash distributions in the other three districts were generally unremarkable, representing no more than 10 percent of the SVROR study-site crashes in those districts.

However, 12 of the 14 motorcycle crashes in Atlanta and all five motorcycle crashes in Lufkin occurred on curves, with 13 and three, respectively, due to speeding/unsafe speeds. This suggests that the problem of motorcycles speeding on curves may be applicable to an area of the state that is larger than just the San Angelo District.

Curves

Based on the findings from motorcycle crashes, the research team examined crashes on curves, a summary of which is displayed in Table 40. There were approximately twice as many crashes on curves as on straight sections at the study sites.

Table 40. Summary of Characteristics of Curve Crashes.

	District	Total Crashes	Fatigued/ Asleep	Speeding/ Unsafe	Impaired Driver	Distracted Driver	Weather	Nighttime
Curve		**261**	**16**	**168**	**42**	**65**	**6**	**81**
	ATL	94	4	72	24	7	5	41
	LFK	54	3	29	8	4	0	20
	ODA	10	5	4	2	1	1	7
	SJT	103	4	63	8	53	0	13
Not Curve		**133**	**27**	**42**	**21**	**27**	**9**	**55**
	ATL	44	10	19	11	5	2	19
	LFK	22	2	3	1	4	1	12
	ODA	61	14	20	9	16	5	23
	SJT	6	1	0	0	2	1	1

The proportion of drivers who were fatigued or asleep was higher for straight sections (20.3 percent) than curves (6.1 percent). However, the proportion of drivers who were speeding or traveling at an unsafe speed was twice as high on curves (64.4 percent) than it was on tangents (31.6 percent). The share of distracted drivers was somewhat higher on curves, and there were no substantial differences in proportions of impaired drivers, weather-related crashes, or nighttime crashes.

The high percentages of speeding/unsafe speed factors on curve crashes across all four districts suggest that drivers are not properly recognizing the presence of a curve that requires a speed change to negotiate the curve safely. Whether this means that drivers are overconfident in their driving ability or their vehicle's performance, or whether drivers are simply traveling too fast to react to an upcoming curve, the relationship between speed and curve crashes is worthy of further attention. Improved roadway surfaces, signing, markings, delineation, or lighting may be countermeasures that would improve performance at these locations.

Overturned

The research team reviewed conditions associated with crashes resulting in an overturned vehicle; results are shown in Table 41. Approximately 41 percent of the study-site crashes involved an overturned vehicle.

Table 41. Summary of Characteristics of Crashes with Overturned Vehicles.

	District	Total Crashes	Curve	Fatal	Fatigued/ Asleep	Speeding/ Unsafe	Impaired Driver	Distracted Driver	Nighttime
Overturned		**163**	**85**	**19**	**28**	**85**	**37**	**28**	**74**
	ATL	55	38	5	6	41	17	6	26
	LFK	29	20	3	3	12	6	2	16
	ODA	58	9	8	15	23	9	15	24
	SJT	21	18	3	4	9	5	5	8
Not Overturned		**231**	**176**	**16**	**15**	**125**	**26**	**64**	**62**
	ATL	83	56	7	8	50	18	6	34
	LFK	47	34	4	2	20	3	6	16
	ODA	13	1	1	4	1	2	2	6
	SJT	88	85	4	1	54	3	50	6

About half of overturned crashes occurred on a curve, compared to nearly three-fourths of crashes with no overturned vehicle. There were 19 overturned crashes (11.7 percent) that resulted in a fatality, almost twice the share of fatalities in non-overturned crashes (16 crashes for 6.9 percent). A larger discrepancy occurred for crashes involving a driver who was fatigued or asleep, with 28 overturned crashes (17.2 percent) versus 15 non-overturned crashes (6.5 percent). Similarly, the proportion of impaired drivers in overturned crashes (22.7 percent) was twice that of non-overturned crashes (11.3 percent). There were proportionally more distracted drivers in non-overturned crashes (27.7 versus 17.2 percent), but nighttime crashes were more common where the vehicle overturned (45.4 to 26.8 percent). The share of drivers who were speeding varied little between overturned (54.1 percent) and non-overturned vehicles (52.1 percent).

These findings indicate that there were no particularly strong indicators of an ROR crash that results in an overturned vehicle, though the influences of nighttime crashes and possible correlation to fatigued drivers may provide some insight.

Fatalities

The finding that crashes with overturned vehicles were twice as likely to result in a fatality led the research team to review other characteristics of fatal ROR crashes; results are summarized in Table 42. There were approximately 10 times as many non-fatal crashes (i.e., crashes with severity rating of A, B, C, or O) as fatal crashes on the study sites. There were similar proportions for motorcycle and curve crashes. Speeding or unsafe speed contributed to over half of crashes in both categories. There was at least one occupant (i.e., driver or passenger) who was unrestrained (i.e., not wearing a seat belt) in 74 percent of fatal crashes, as compared to 36 percent of ABCO crashes.

Table 42. Summary of Characteristics of Crashes with Fatalities.

	District	Total Crashes	Motorcycle	Curve	No Restraint	Overturned	Nighttime
Fatal		**35**	**7**	**24**	**130**	**19**	**17**
	ATL	12	3	8	35	5	5
	LFK	7	1	6	13	3	4
	ODA	9	0	3	8	8	6
	SJT	7	3	7	74	3	2
Not Fatal		**359**	**85**	**237**	**26**	**144**	**119**
	ATL	126	11	86	8	50	55
	LFK	69	4	48	4	26	28
	ODA	62	0	7	9	50	24
	SJT	102	70	96	5	18	12

	District	Total Crashes	Fatigued/ Asleep	Speeding/ Unsafe	Impaired Driver	Distracted Driver
Fatal		**35**	**7**	**21**	**12**	**4**
	ATL	12	2	11	7	0
	LFK	7	0	2	2	1
	ODA	9	5	4	1	0
	SJT	7	0	4	2	3
Not Fatal		**359**	**36**	**189**	**51**	**88**
	ATL	126	12	80	28	12
	LFK	69	5	30	7	7
	ODA	62	14	20	10	17
	SJT	102	5	59	6	52

A little over half of ABCO crashes involved overturned vehicles, compared to 40 percent of fatalities. Fatigued/asleep drivers made up 20 percent of the fatal crashes, while they were only involved in 10 percent of non-fatalities. Similarly, impaired drivers contributed to more than a third of fatal crashes, compared to 14 percent of ABCO crashes. In a possible related finding, almost half (48.6 percent) of the fatal crashes at study sites occurred at night, in contrast to a third of non-fatal crashes. Distracted driving led to about 11 percent of fatal crashes, less than half the share of non-fatal crashes at 24.5 percent.

Fatigued/Asleep Drivers

The research team reviewed characteristics of crashes involving drivers who were deemed to be fatigued or asleep (F/A); Table 43 summarizes the findings. More than 60 percent of fatigued/asleep drivers crossed the centerline and left the road on the far side, compared to 46 and 39 percent, respectively, for alert drivers; this discrepancy emphasizes the difficulty for a fatigued driver to maintain position in the travel lane.

Table 43. Summary of Characteristics of Crashes with Fatigued/Asleep Drivers.

	District	Total Crashes	Crossed Centerline	Left Road on Far Side	Man-Made Object	Natural Object
F/A		**43**	**26**	**26**	**21**	**7**
	ATL	14	9	9	7	5
	LFK	5	3	3	2	2
	ODA	19	11	11	10	0
	SJT	5	3	3	2	0
Not F/A		**351**	**161**	**137**	**136**	**130**
	ATL	124	65	58	44	49
	LFK	71	35	30	33	33
	ODA	52	31	23	21	2
	SJT	104	30	26	38	46
	District	**Total Crashes**	**Overturned**	**Fatality**	**Speeding/ Unsafe**	**Nighttime**
F/A		**43**	**28**	**7**	**13**	**28**
	ATL	14	6	2	5	9
	LFK	5	3	0	2	4
	ODA	19	15	5	6	13
	SJT	5	4	0	0	2
Not F/A		**351**	**135**	**28**	**197**	**108**
	ATL	124	49	10	86	51
	LFK	71	26	7	30	28
	ODA	52	43	4	18	17
	SJT	104	17	7	63	12

Nearly half of F/A drivers who ran off the road struck a man-made fixed object, but only 16 percent collided with a natural fixed object; alert drivers collided with both types of objects at a rate of about 38 percent. This suggests a common scenario in which the drowsy driver cannot maintain position in the traveled lane and collides with objects such as signs and guardrails, then the vehicle stops (either under driver control or as a result of the collision) before colliding with a tree or other natural object at a greater distance from the roadway.

As one would expect, nearly two-thirds of F/A crashes occurred at night, compared to 31 percent of non-F/A crashes. Nearly two-thirds of F/A crashes resulted in an overturned vehicle, as opposed to 38.5 percent of non-F/A crashes. F/A drivers were twice as likely to be involved in a fatality (16 percent) as alert drivers (8 percent). Excessive speed was not as great an influence in F/A crashes, contributing to 30 percent of those collisions, as opposed to 56 percent of non-F/A crashes; this indicates that fatigued drivers are not necessarily traveling at an unsafe speed for conditions, but their lack of alertness impedes their ability to control their vehicles even at moderate speeds.

Speeding/Unsafe Speed

Table 44 shows a summary of selected characteristics of crashes in which speeding or unsafe speed (S/US) contributed to the crash. Excessive speed was cited as a factor in 53 percent of all ROR study-site crashes (210 of 394).

Table 44. Summary of Characteristics of Crashes with Speeding/Unsafe Speed.

	District	Total Crashes	Motorcycle	Curve	Overturned	Fatality	Impaired Driver	Distracted Driver
S/US		**210**	**64**	**168**	**85**	**21**	**40**	**39**
	ATL	91	13	72	41	11	26	6
	LFK	32	3	29	12	2	5	1
	ODA	24	0	4	23	4	2	5
	SJT	63	48	63	9	4	7	27
Not S/US		**184**	**28**	**93**	**78**	**14**	**23**	**53**
	ATL	47	1	22	14	1	9	6
	LFK	44	2	25	17	5	4	7
	ODA	47	0	6	35	5	9	12
	SJT	46	25	40	12	3	1	28

As discussed in a previous section, motorcycles were commonly involved in crashes with excessive speed, representing 30 percent of such crashes as opposed to 15 percent of non-S/US crashes. A full 80 percent of S/US crashes occurred on curves, which is an intuitive finding given the nature of traveling on curves, and it is consistent with other findings from the narrative analysis. In contrast, approximately half of crashes with no influence from speed occurred on curves. The proportions of overturned vehicles were similar between the two speed categories, just over 40 percent. Fatalities were more frequent with excessive speed, at exactly 10 percent, compared to 7.6 percent of non-S/US crashes. The proportion of impaired drivers who were speeding (19 percent) was higher than those who were not speeding (12.5 percent), but distracted drivers were more common among slower drivers (28.8 percent) than faster drivers (18.6 percent).

Impaired Drivers

Table 45 contains a summary of selected characteristics for ROR crashes by impaired drivers. Of the 394 study-site crashes, 16 percent involved an impaired driver. There was a large discrepancy in the proportion of impaired crashes by motorcycle drivers; only 5 percent of impaired crashes were on motorcycles, versus 27 percent of non-impaired crashes. Two-thirds of crashes by both impaired and non-impaired drivers occurred on curves. A greater proportion of impaired drivers crossed the centerline and left the roadway on the far side, approximately 67 and 62 percent, respectively, compared to 44 and 38 percent for non-impaired drivers. Impaired drivers also had a greater frequency of fatalities, accounting for 19 percent of all impaired crashes, as opposed to 7 percent for non-impaired drivers. Both impairment categories had high rates of excessive speed: 63.5 percent for impaired, 51.4 percent for non-impaired.

Given that impairment by alcohol or other drugs is a choice the driver makes and that it represents a low proportion of the crashes in the study, options for engineering countermeasures are limited, but the findings do provide insight into behaviors of impaired drivers.

Table 45. Summary of Characteristics of Crashes with Impaired Drivers.

	District	Total Crashes	Motorcycle	Curve	Crossed Centerline	Left Road on Far Side	Fatality	Speeding/ Unsafe Speed
Impaired		**63**	**3**	**42**	**42**	**39**	**12**	**40**
	ATL	35	3	24	24	24	7	26
	LFK	9	0	8	4	4	2	5
	ODA	11	0	2	8	6	1	2
	SJT	8	0	8	6	5	2	7
Not Impaired		**331**	**89**	**219**	**145**	**125**	**23**	**170**
	ATL	103	11	70	50	44	5	65
	LFK	67	5	46	34	29	5	27
	ODA	60	0	8	34	28	8	22
	SJT	101	73	95	27	24	5	56

Distracted Drivers

The research team also reviewed characteristics of distracted drivers; Table 46 contains a summary of selected characteristics. Of the 394 study-site crashes, 23 percent involved a distracted driver.

Table 46. Summary of Characteristics of Crashes with Distracted Drivers.

	District	Total Crashes	Motorcycle	Curve	Crossed Centerline	Left Road on Far Side	Fatality	Speeding/ Unsafe Speed
Distracted		**92**	**46**	**65**	**26**	**23**	**4**	**39**
	ATL	12	0	7	5	5	0	6
	LFK	8	1	4	2	1	1	1
	ODA	17	0	1	8	6	0	5
	SJT	55	45	53	11	11	3	27
Not Distracted		**302**	**46**	**196**	**161**	**141**	**31**	**171**
	ATL	126	14	87	69	63	12	85
	LFK	68	4	50	36	32	6	31
	ODA	54	0	9	34	28	9	19
	SJT	54	28	50	22	18	4	36

Half of the distracted-driver crashes occurred on motorcycles, versus 15 percent for undistracted drivers. As with impaired crashes, about two-thirds of crashes by both distracted and undistracted drivers occurred on curves. In contrast to impaired crashes, however, a greater proportion of undistracted drivers crossed the centerline and left the roadway on the far side, approximately 53 and 47 percent, respectively, compared to 28 and 23 percent for distracted drivers. Undistracted drivers also had a greater frequency of fatalities, accounting for 10 percent of all undistracted crashes, as opposed to 4 percent for distracted drivers. Speeding rates were also higher for undistracted drivers, at 56 percent compared to 42 percent for distracted drivers.

It is likely that drivers who are distracted are commonly traveling at lower speeds, because just as their attention is diverted from the driving task, it is also diverted from maintaining pressure on the accelerator, assuming that the cruise control is not in use. Determining the certainty of that scenario is not possible within the scope of this project, but it is consistent with anecdotal evidence that distracted drivers drive slower. The lower speeds can, in turn, reduce the severity of crashes, resulting in lower fatality rates. Similar to impaired driving, distracted driving is a choice the driver makes, representing a low proportion of the crashes in this study.

Nighttime Crashes

Table 47 contains a summary of characteristics from study-site nighttime crashes. Nearly 35 percent of the 394 study-site crashes occurred at night.

Very few nighttime crashes (3 percent) occurred on motorcycles, versus 34 percent for daytime crashes. Almost 60 percent of nighttime crashes took place on curves, less than the 70 percent of daytime crashes. Just over 10 percent of nighttime crashes were caused due to a driver attempting to avoid colliding with an animal in the roadway, almost three times the percentage of daytime crashes. Three of every 10 nighttime crashes (30.1 percent) were caused by an impaired driver, nearly four times the percentage of daytime crashes.

Over half of nighttime crashes (54 percent) resulted in an overturned vehicle, 20 percentage points higher than the share for daytime crashes. One of every eight nighttime crashes (12.5 percent) resulted in a fatality, as opposed to 7 percent of daytime crashes. Speeding rates were similar in daytime and nighttime conditions, 54.3 percent and 51.5 percent, respectively.

Table 47. Summary of Characteristics of Nighttime Crashes.

	District	Total Crashes	Motorcycle	Curve	Avoided Animal	Impaired Driver
Nighttime		**136**	**4**	**81**	**14**	**41**
	ATL	60	2	41	4	23
	LFK	32	1	20	4	7
	ODA	30	0	7	4	7
	SJT	14	1	13	2	4
Not Nighttime		**258**	**88**	**180**	**10**	**22**
	ATL	78	12	53	5	12
	LFK	44	4	34	4	2
	ODA	41	0	3	1	4
	SJT	95	72	90	0	4
	District	**Total Crashes**	**Overturned**	**Fatality**	**Fatigued/ Asleep**	**Speeding/ Unsafe**
Nighttime		**136**	**74**	**17**	**28**	**70**
	ATL	60	26	5	9	42
	LFK	32	16	4	4	9
	ODA	30	24	6	13	12
	SJT	14	8	2	2	7
Not Nighttime		**258**	**89**	**18**	**15**	**140**
	ATL	78	29	7	5	49
	LFK	44	13	3	1	23
	ODA	41	34	3	6	12
	SJT	95	13	5	3	56

CHAPTER SUMMARY

The research team reviewed Texas Peace Officer's Accident Reports for 394 single-vehicle run-off-road KABC crashes for 31 sites in four TxDOT districts. These crashes occurred between 2003 and 2008. The research team focused on the officers' written narratives and diagrams, in addition to the contributing factors noted by the officer as having an influence on the events during the crash. Some of the key findings are as follows:

- Nearly two-thirds (261) of all study-site crashes occurred on a horizontal curve.
- Almost one-fourth (93) of the crashes involved a motorcycle.
- More than one-third (136) of the crashes occurred at night.
- Over 40 percent (163) of observed crashes resulted in an overturned vehicle.
- Almost 9 percent (35) of the crashes resulted in a fatality.
- Approximately 70 percent (277) of the drivers in study-site crashes were male.

- The share of total crashes in each age group declined as age increased. Of the 394 drivers involved in a study-site crash, 138 (35 percent) were 25 years of age or younger; 77 drivers (19.5 percent) were aged 16 to 20.
- Just over half of the crashes (205) were due in some part to a vehicle traveling at a speed unsafe for conditions. In addition, another 21 crashes were affected by a driver exceeding the speed limit.
- Nearly 80 percent of the crashes (313) resulted in the vehicle departing the roadway on the right side of the road.
- Almost half of the crashes (187) involved a vehicle that crossed the centerline and most of those crashes (164) resulted in the vehicle leaving the road on the left side. As a result, there were 83 crashes (21 percent) of the 394 in which a vehicle actually left the roadway on both the left and right sides.
- Nearly 40 percent (157) of involved vehicles struck a man-made fixed object (e.g., sign, fence, etc.) during a crash, while over a third (137) struck a natural fixed object.

A review of crashes by TxDOT district revealed these findings:

- The Atlanta and San Angelo Districts recorded the most crashes, with 137 and 109, respectively. The Lufkin and Odessa Districts had crash totals similar to each other, with 76 and 71, respectively. These results indicate that there was not a noticeable difference based solely on geographical (i.e., "east vs. west") location.
- Of the 109 crashes in San Angelo, 85 occurred on three control sections on RM 336 and RM 337 (i.e., the top three crashes by ROR crash rate), resulting in a low crash frequency at the other study sites.
- Two-thirds of the SVROR crashes in San Angelo involved a motorcycle, which is consistent with the higher share of motorcycle traffic on the study sites in that district. In addition, nearly 95 percent of the crashes there took place on a curve, which is also a function of the alignment of the roadways on the study sites there.
- The Atlanta and Lufkin Districts also saw a high proportion of crashes on curves, at approximately 70 percent.
- Three districts (ATL, LFK, and ODA) had a proportion of nighttime crashes of approximately 43 percent.
- Over 80 percent of the 71 ROR vehicles in the Odessa District crashes overturned.
- The Odessa District had the highest fatality rate, at 12.7 percent. Rates in the other districts were between 6 and 10 percent.
- Over half of the crashes in Atlanta and San Angelo were at least partially attributed to speeding over the posted limit or unsafe speed.
- Crashes in the Atlanta, Lufkin, and Odessa districts follow the same general trend of declining frequency with increasing age. In San Angelo, however, the number of crashes by age group is relatively constant from age 16 to age 65, even increasing slightly as age increases.

A review of relationships between contributing factors revealed these findings:

- Only about one-fourth (92) of the 394 study-site crashes involved a motorcycle, but 73 of those crashes were in the San Angelo District, including 70 on curves.
- The 70 motorcycle crashes on curves in the San Angelo District represented:

  - 76 percent of all motorcycle crashes in the four districts.
  - 64 percent of all San Angelo study-site crashes.
  - 96 percent of motorcycle crashes on study sites in San Angelo.
- All 48 of the speeding/unsafe speed crashes in the San Angelo District were motorcycle crashes on curves, as were 44 of the 45 distracted-driver crashes.
- 12 of the 14 motorcycle crashes in Atlanta and all five motorcycle crashes in Lufkin occurred on curves, with 13 and three, respectively, due to speeding/unsafe speeds.
- There were approximately twice as many crashes on curves (261) as on straight sections (133) at the study sites.
- The proportion of drivers who were fatigued or asleep was higher for straight sections (20.3 percent) than curves (6.1 percent). However, the proportion of drivers who were speeding or traveling at an unsafe speed was twice as high on curves (64.4 percent) as it was on tangents (31.6 percent).
- About half of the 163 crashes involving an overturned vehicle occurred on a curve, compared to nearly three-fourths of the 231 crashes with no overturned vehicle.
- There were 19 overturned crashes (11.7 percent) that resulted in a fatality, almost twice the share of fatalities in non-overturned crashes (16 crashes for 6.9 percent). A larger discrepancy occurred for crashes involving a driver who was fatigued or asleep, with 28 overturned crashes (17.2 percent) versus 15 non-overturned crashes (6.5 percent). Similarly, the proportion of impaired drivers in overturned crashes (22.7 percent) was twice that of non-overturned crashes (11.3 percent).
- There were approximately 10 times as many non-fatal crashes (359) as fatal crashes (35) on the study sites.
- Impaired drivers contributed to more than a third of fatal crashes, compared to 14 percent of non-fatal crashes.
- More than 60 percent of the 43 fatigued/asleep drivers that crashed crossed the centerline and left the road on the far side, compared to 46 and 39 percent, respectively, for alert drivers.
- Nearly two-thirds of fatigued/asleep crashes occurred at night, compared to 31 percent of non-F/A crashes. Nearly two-thirds of F/A crashes resulted in an overturned vehicle, as opposed to 38.5 percent of non-F/A crashes. F/A drivers were twice as likely to be involved in a fatality (16 percent) as alert drivers (8 percent).
- Excessive speed was cited as a factor in 210 (53 percent) of all study-site crashes.
- Motorcycles were commonly involved in crashes attributed to speeding/unsafe speed, representing 30 percent of such crashes as opposed to 15 percent of non-S/US crashes. A full 80 percent of S/US crashes occurred on curves.
- About 16 percent of study-site crashes (63) involved an impaired driver.
- Only 5 percent of impaired crashes were on motorcycles, versus 27 percent of non-impaired crashes.
- A greater proportion of impaired drivers crossed the centerline and left the roadway on the far side, approximately 67 and 62 percent, respectively, compared to 44 and 38 percent for non-impaired drivers. Impaired drivers also had a greater frequency of fatalities, accounting for 19 percent of all impaired crashes, as opposed to 7 percent for non-impaired drivers.
- Of the 394 study-site crashes, 23 percent (92) involved a distracted driver.

- Half of the distracted-driver crashes occurred on motorcycles, versus 15 percent for undistracted drivers.
- Nearly 35 percent (136) of the 394 study-site crashes occurred at night.
- Very few nighttime crashes (3 percent) occurred on motorcycles, versus 34 percent for daytime crashes.
- Just over 10 percent of nighttime crashes were caused due to a driver attempting to avoid colliding with an animal in the roadway, almost three times the percentage of daytime crashes.
- Three of every ten nighttime crashes (30.1 percent) were caused by an impaired driver, nearly four times the percentage of daytime crashes.
- Over half of nighttime crashes (54 percent) resulted in an overturned vehicle, 20 percentage points higher than the share for daytime crashes.

The next chapter discusses the study results for the safety effects of operational and highway design features for the sample of sites identified in the four TxDOT districts.

CHAPTER 6: OPERATIONAL AND GEOMETRIC DESIGN FEATURES ANALYSIS AND FINDINGS

INTRODUCTION

This chapter describes the safety analysis related to the operational and design features collected in the field studies in the four districts. The analyses documented in this chapter used the same narratives to examine the relationships between the number and severity of roadway departure crashes and highway and operational design features. Additional characteristics of key highway and operational features for the four districts visited are presented in Appendix C.

DESIGN AND OPERATIONAL FEATURES

Table 48 provides the summary statistics for eight of the variables collected in the field. It should be pointed out that all of the sites visited did not have any rumble strips or street lighting. The pavement condition for most sites was considered as fair.

Table 48. Summary Statistics for Field Data Collected in Four Districts.

Variable	Min	Max	Mean	Standard Deviation
Posted speed limit (mph)	50	75	62.1	8.9
Curve density (per mile)	0.2	7.1	2.4	1.8
Advisory signs	0	50	6.7	10.1
Driveway density (per mile)	1.0	30.1	9.1	7.5
Shoulder width (ft)	0.5	9.8	3.7	2.9
Lane width (ft)	10	12.3	11.4	0.6
Lateral clearance (ft)	0	87.1	26.0	13.7
Sideslope rating	1	5	2.8	1

In the following sections, the distributions for each variable and their relationship with the average run-off-the-road injury crash rate in million vehicle-miles (MVM) and crashes per mile for six years (2003–2008) are presented. As indicated in previous documents, data were analyzed for KABC crashes in order to increase the sample size and the robustness of results.

Posted Speed Limit

Figure 29 shows the distribution for the posted speed limit variable. The dataset contained 31 sections. This figure shows that nearly half of all the segments have a speed limit equal to 55 mph. The lowest posted speed limit is 50 mph, while the highest speed limit is 75 mph.

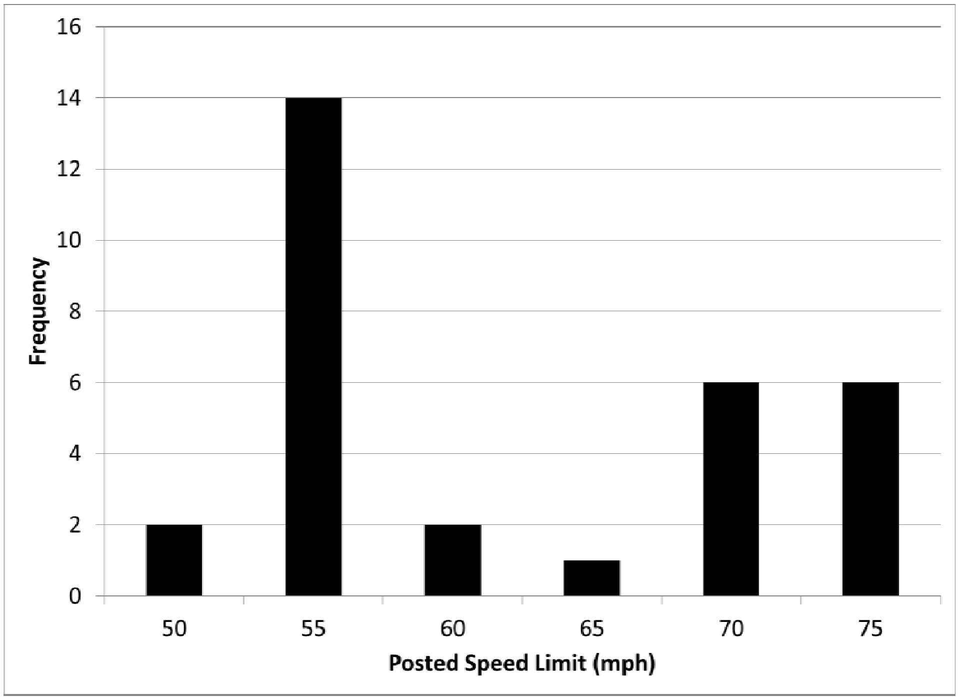
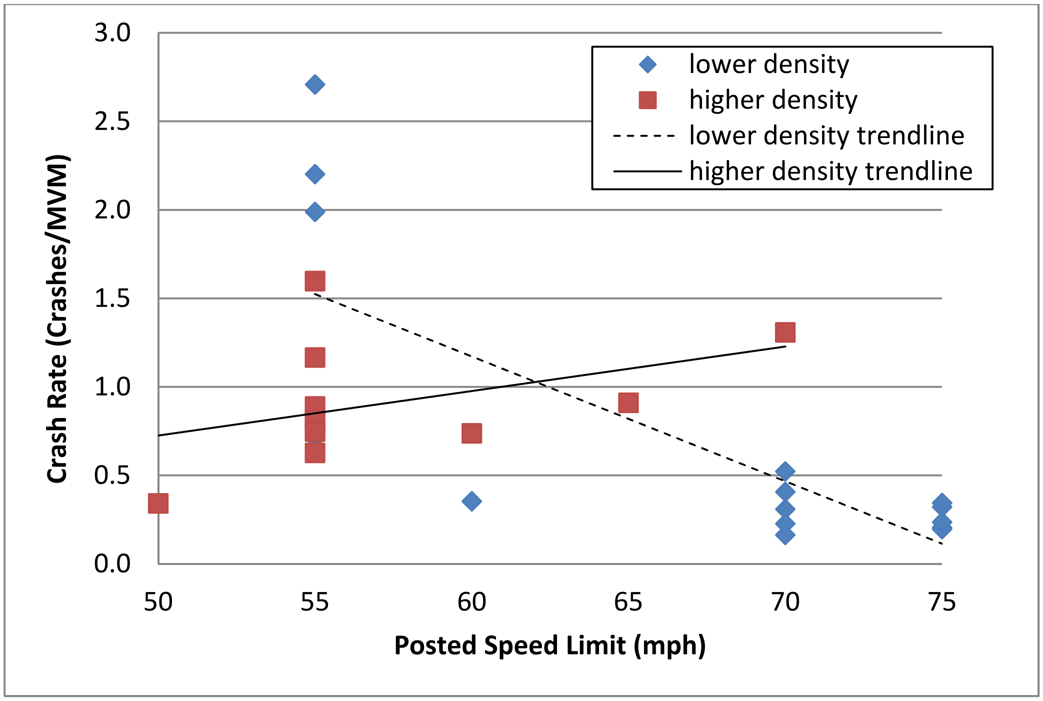
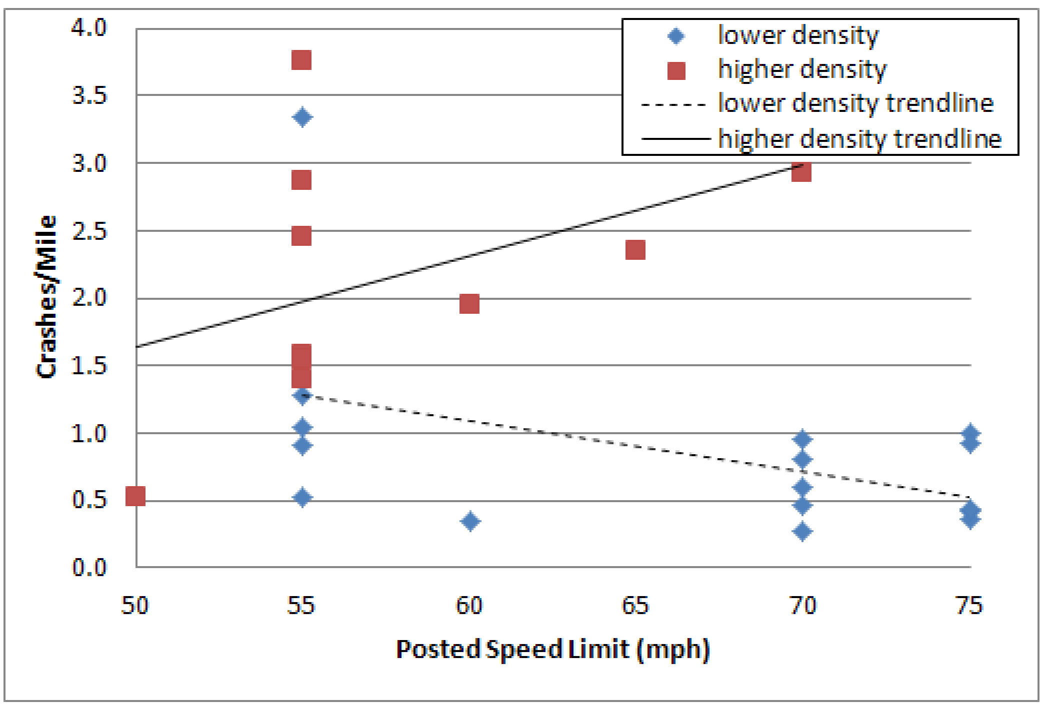


Figure 29. Distribution of Posted Speed Limit.

The relationships between posted speed limits and crash rate and the number of crashes per mile are shown in Figure 30. The data were subdivided by the driveway density (less or more than 10 driveways per mile). Two linear regression lines were fitted among the data points to better illustrate the trend of the relationships; this does not mean, however, that the actual relationships cannot be non-linear. Two important findings can be observed in Figure 30. First, the figure shows that ROR crashes seem to decrease as the posted speed limit increases. This general trend appears to be counterintuitive, but this can be attributed to the fact that two-lane highway segments with higher posted speed limits are designed to a higher standard. For instance, the horizontal curve density in curves per mile goes down as the posted speed limit goes up (see Figure 31); the next section discusses the safety effects of curve density in greater detail. For the second finding, by separating the data by driveway density, one can see that crashes tend to increase as the speed limit and driveway density both increase. This implies that driveways may play a more important role than originally anticipated. This is also further examined below.



(a) Crash Rate



(b) Number of Crashes per Mile

Figure 30. Relationship between ROR Crashes and Posted Speed Limit.

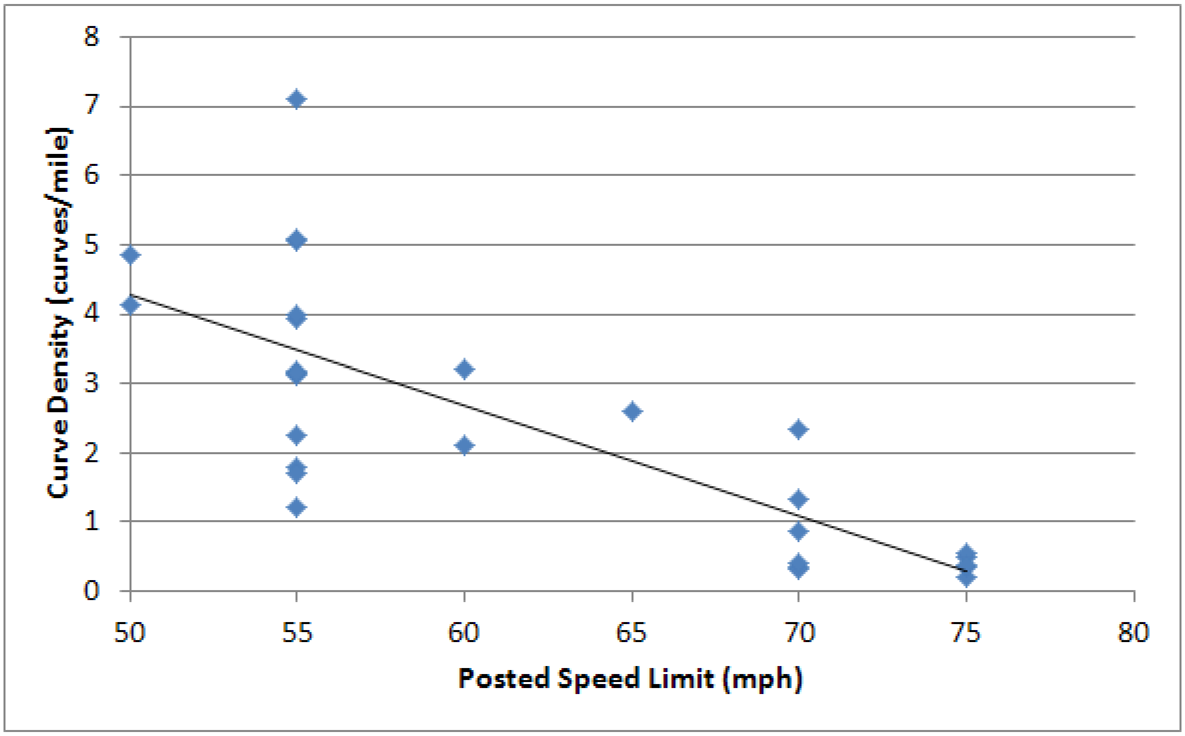


Figure 31. Relationship between Curve Density and Posted Speed Limit.

Curve Density

Researchers calculated the curve density based on the number of horizontal curves observed on each control section. The distribution of curve density is shown in Figure 32. The data included 31 segments and 736 curves. The lowest curve density is 0.2 per mile, while the highest is 7.1 per mile. The average curve density for these segments is about 2.4 per mile.

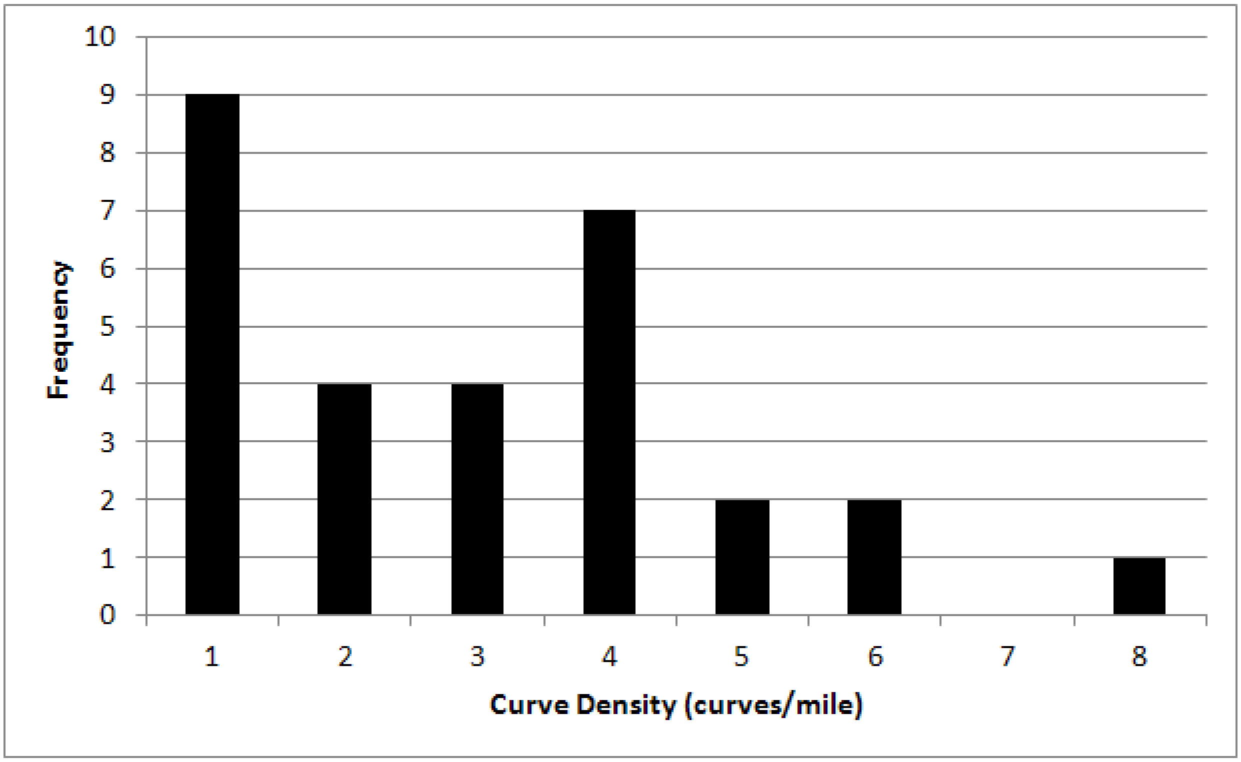
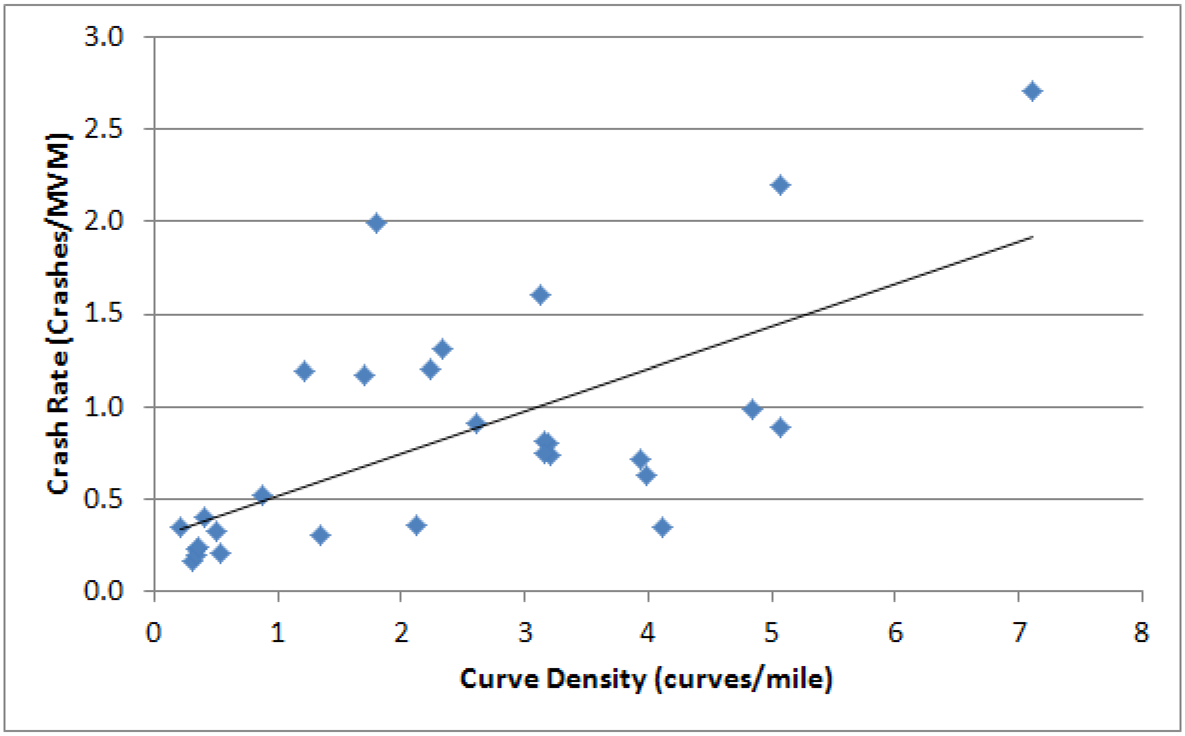
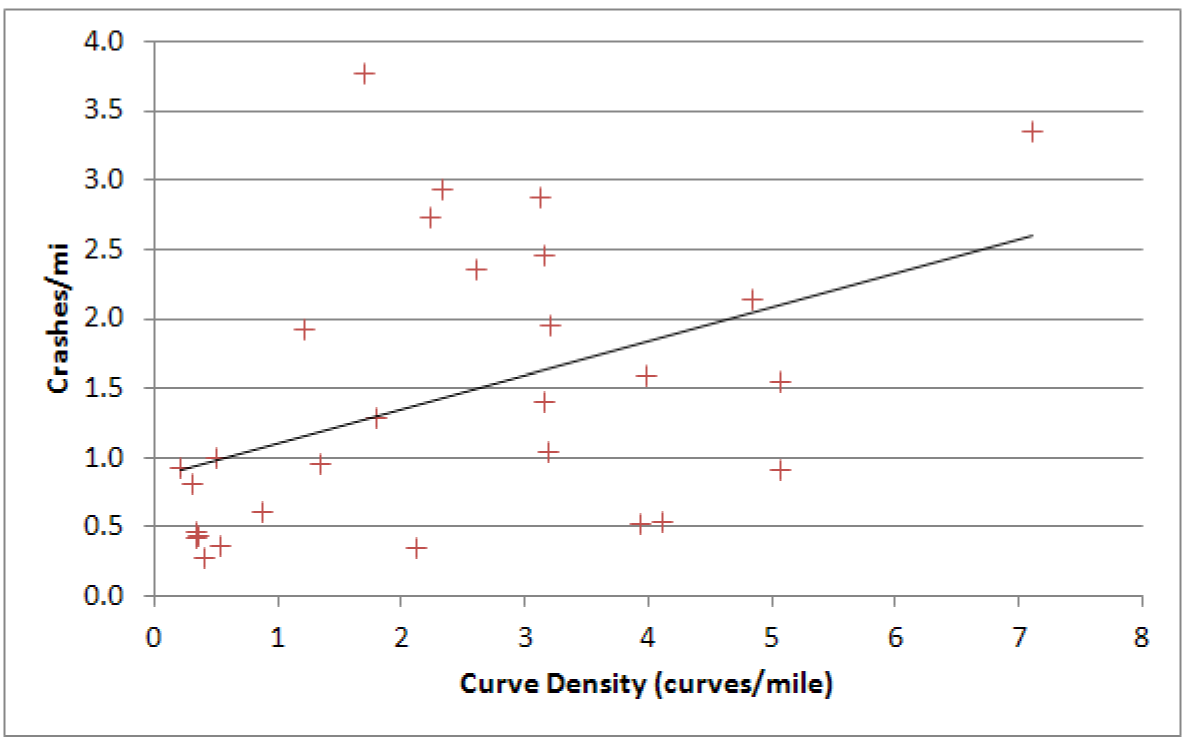


Figure 32. Distribution of Curve Density.

Figure 33 illustrates the relationship between curve density and ROR crashes. This figure clearly shows that the crash rate and the number of crashes per mile increase as the curve density increases. This relationship was also documented in the review of the crash report narratives in the previous chapter.



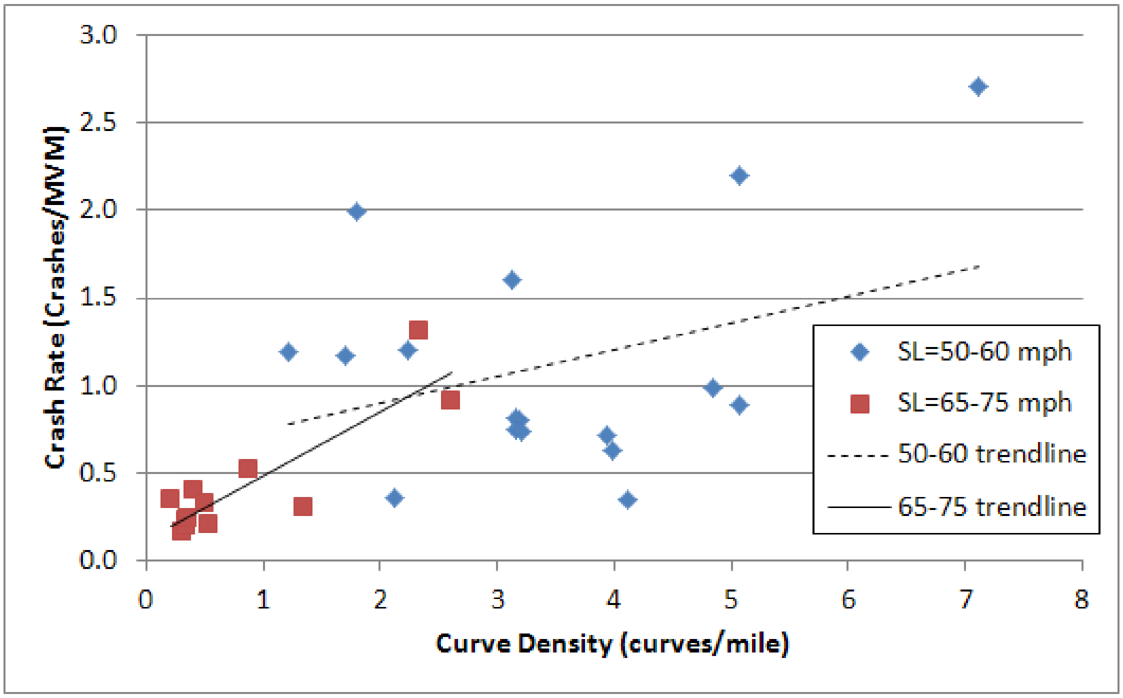
(a) Crash Rate



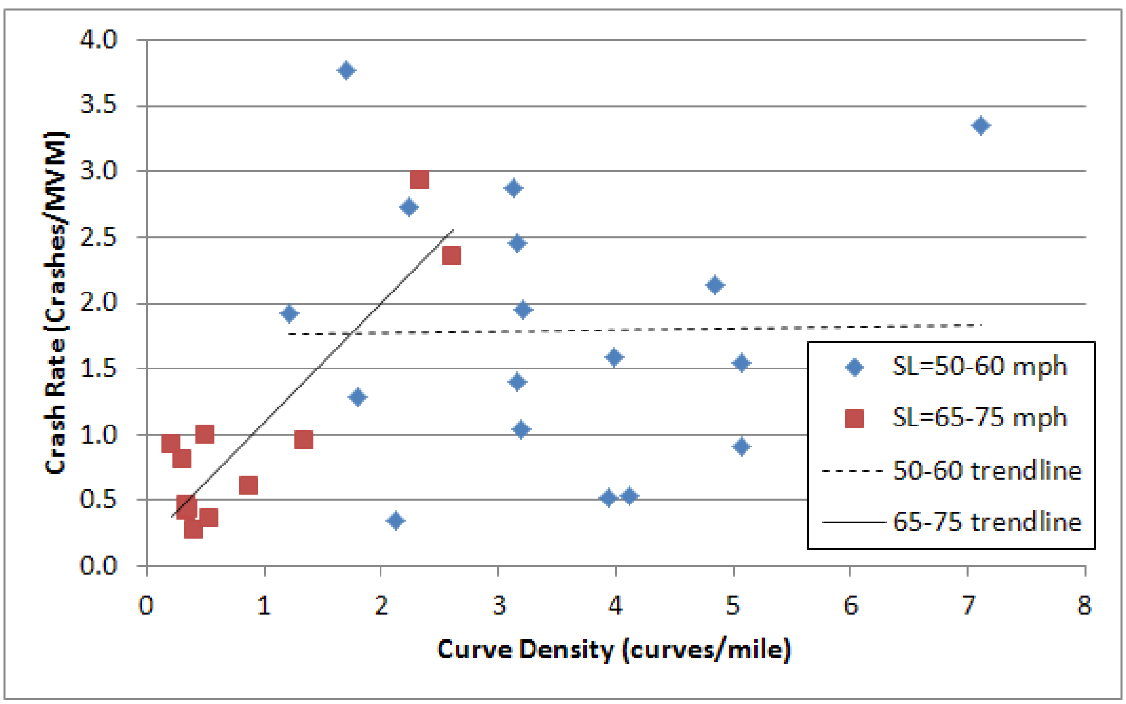
(b) Number of Crashes per Mile

Figure 33. Relationship between ROR Crashes and Curve Density.

Researchers subdivided the observations into two groups by posted speed limit to further examine the relationship between ROR crashes and curve density. Posted speed limits up to 60 mph were categorized as the lower group, while posted speed limits above 60 mph were classified as the higher group. Figure 34 shows that the ROR crash rate increases as the curve density increases for both groups. This trend is more significant for the higher posted speed limit group.



(a) Crash Rate



(b) Number of Crashes per Mile

Figure 34. Relationship between ROR Crashes and Curve Density by Speed Limit.

Driveway Density

The driveway density was calculated based on the number of access points counted on both sides for each control section. There were 1,978 access points and 1,757 segments in the data. The distribution of driveway density is shown in Figure 35. The lowest driveway density is 1.0 access point per mile, and the highest is approximately 30.1 access points per mile. The average driveway density for these segments is 9.1 access points per mile.

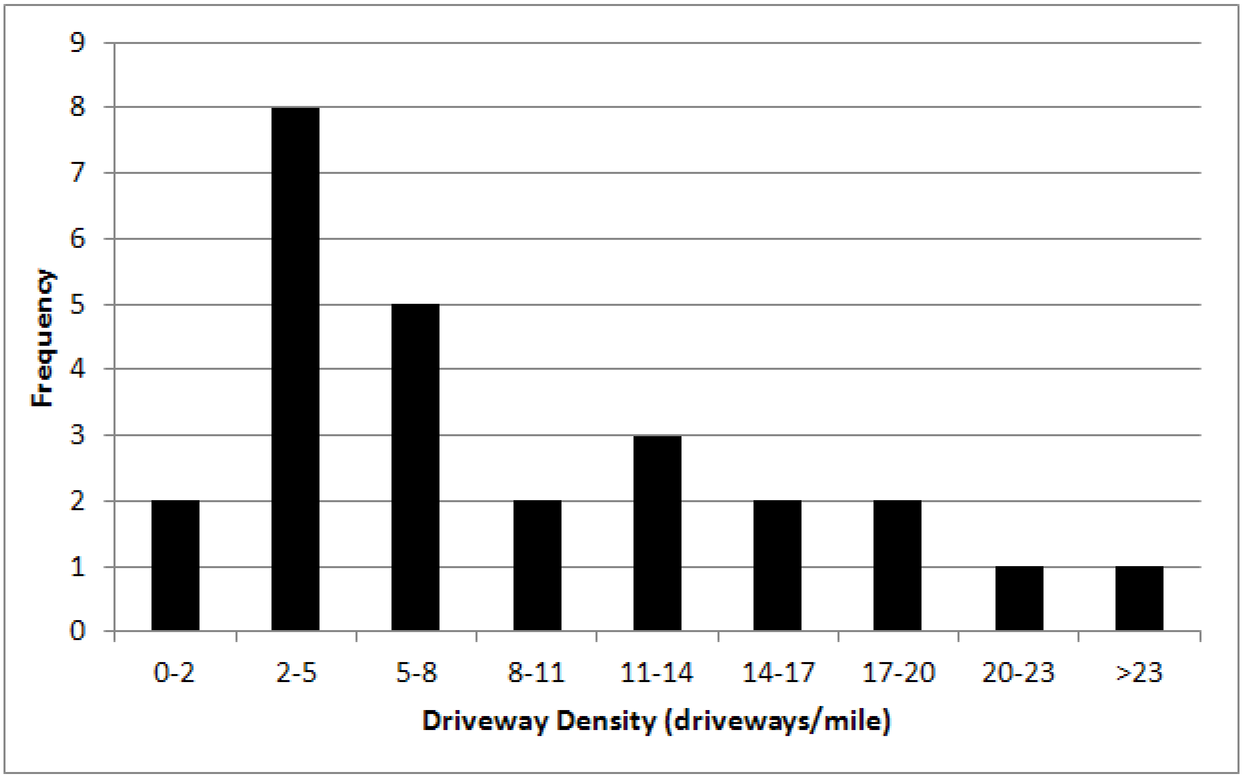
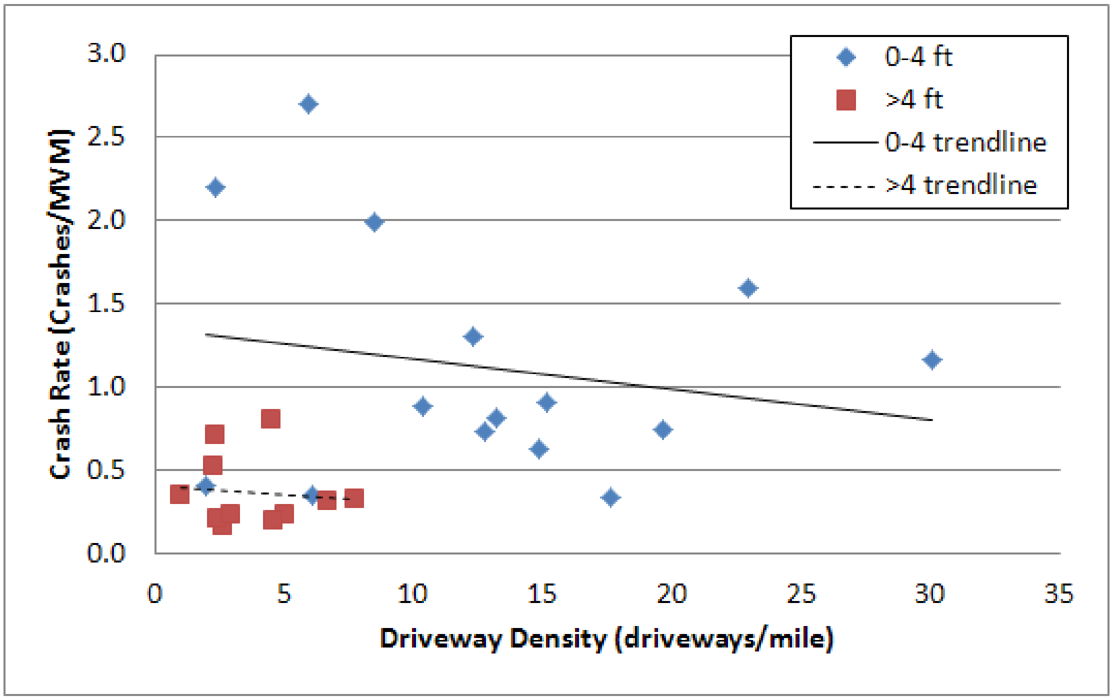
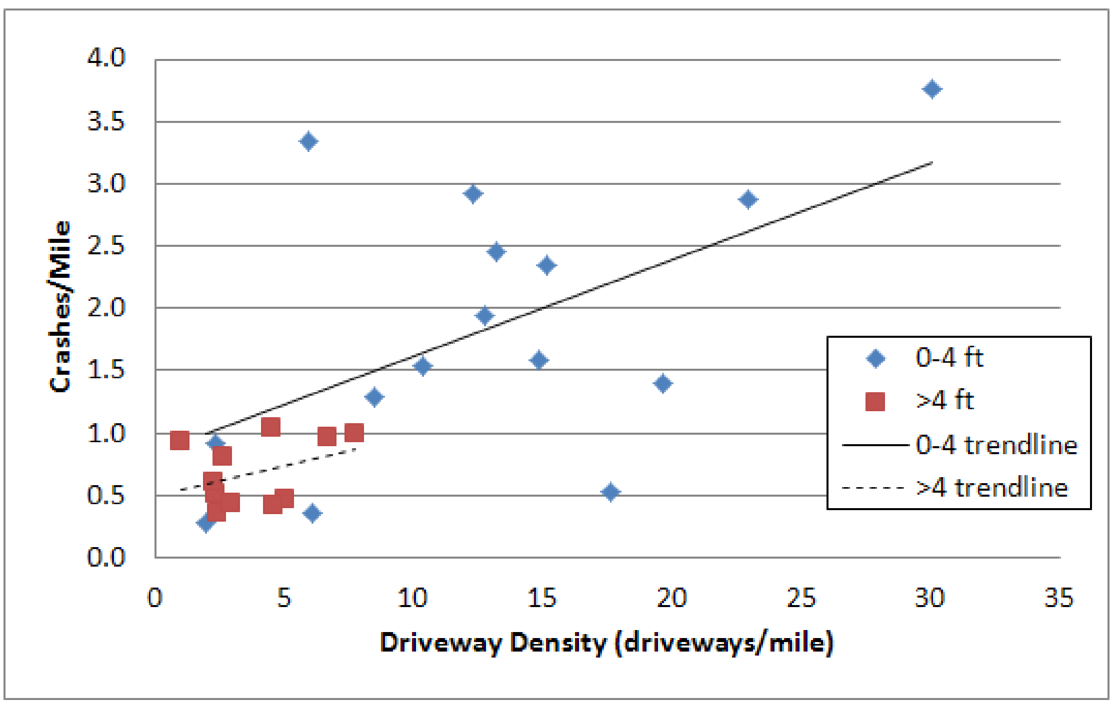


Figure 35. Distribution of Driveway Density.

The relationship between driveway density and ROR crashes is illustrated in Figure 36. In the figure, the data are separated into two shoulder width categories, greater than or less than 4 ft. Linear regression lines for both groups also calculated to better illustrate the relationship. Figure 36 suggests that the ROR crash rate and the number of crashes per mile slightly decrease or remains constant as the driveway density increases. However, the number of crashes per mile shows an opposite relationship where the number of ROR crashes increases as the driveway density increases. This may be explained by confounding factors, such as high driveway density segments that are linked to large traffic flows (which explains the characteristics observed in Figure 36a). The results illustrated in Figure 36 clearly show that narrower shoulders have more ROR crashes around driveways.



(a) Crash Rate



(b) Number of Crashes per Mile

Figure 36. Relationship between ROR Crashes and Driveway Density by Shoulder Width.

Shoulder Width

The shoulder width was measured at two or three points on each homogeneous segment. The distribution of shoulder widths is shown in Figure 37. This figure shows that the majority of the shoulder widths on these segments were less than 6 ft. The shoulder widths varied from 0.5 ft to 9.8 ft, and the average shoulder width was about 3.7 ft.

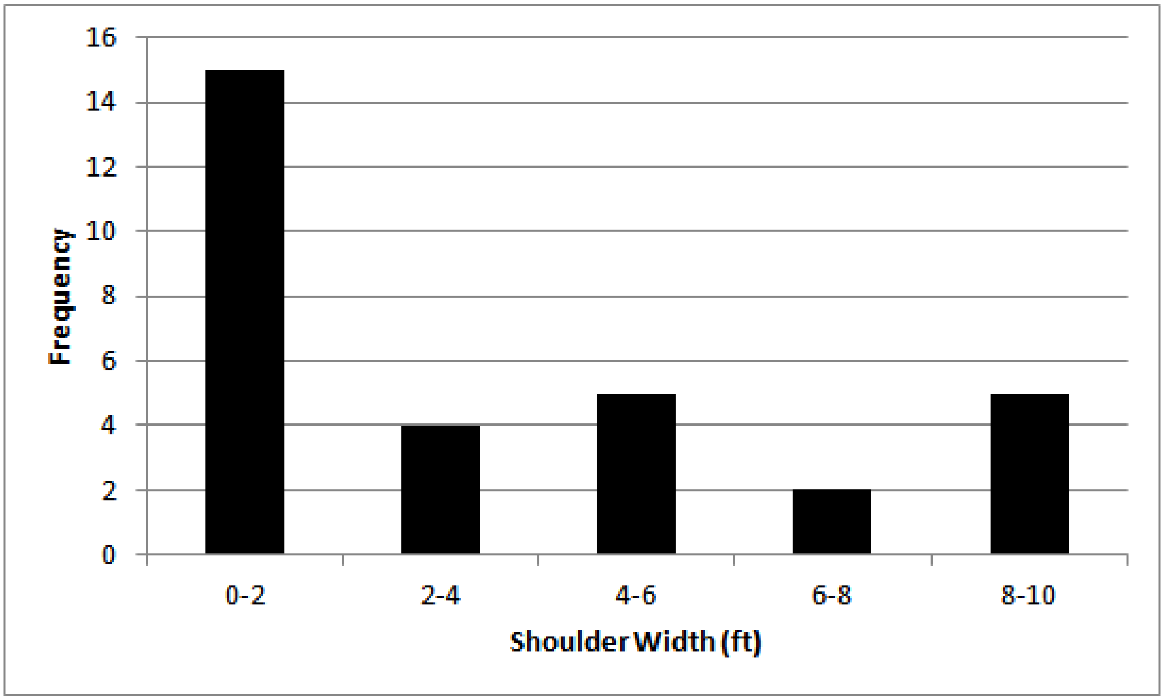
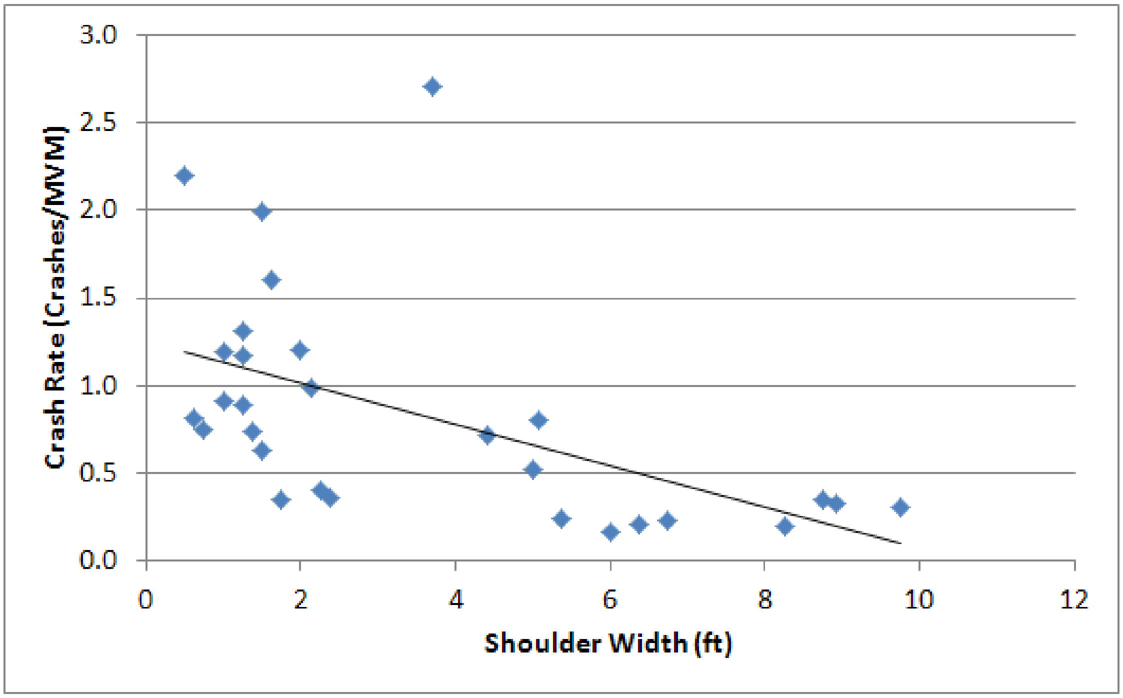
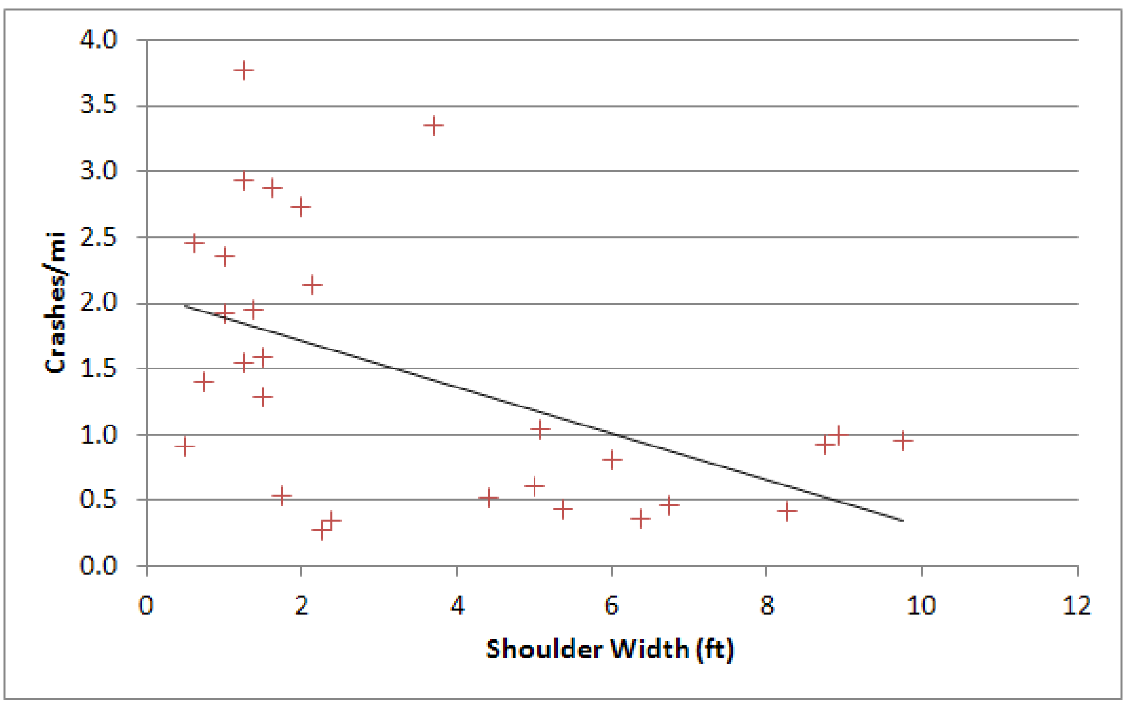


Figure 37. Distribution of Shoulder Width.

Figure 38 illustrates the relationship between shoulder width and ROR crashes. Similar to the analysis related to driveway density, a linear regression line was calculated to better illustrate the relationship. Figure 38 suggests that the ROR crash rate and the number of crashes per mile decrease as the shoulder width increases from 0.5 ft to around 10 ft. It can clearly be seen in this figure that the crash rate and crashes per mile are substantially lower for shoulder widths less than 5 ft.



(a) Crash Rate



(b) Number of Crashes per Mile

Figure 38. Relationship between ROR Crashes and Shoulder Width.

Lane Width

Similar to the shoulder width, the lane width was also measured at multiple points along the control section. The distribution of lane widths is illustrated in Figure 39. The smallest average lane width is 10 ft, and the largest is 12.3 ft. The sample average lane width for these control sections is 11.4 ft.

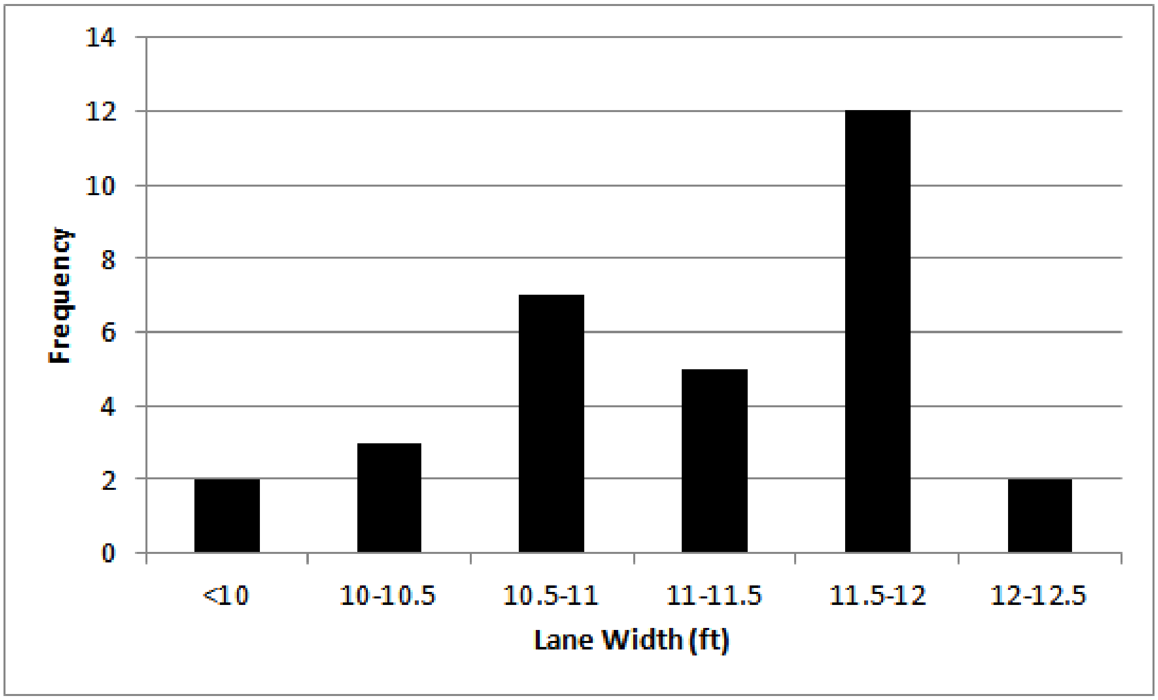
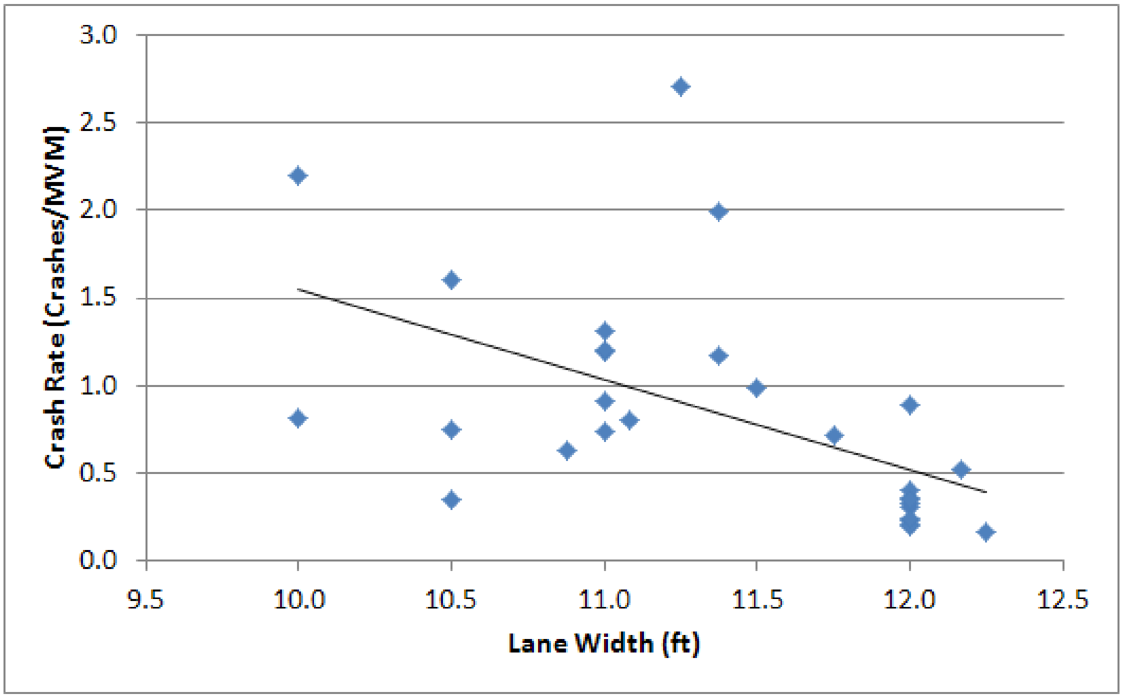
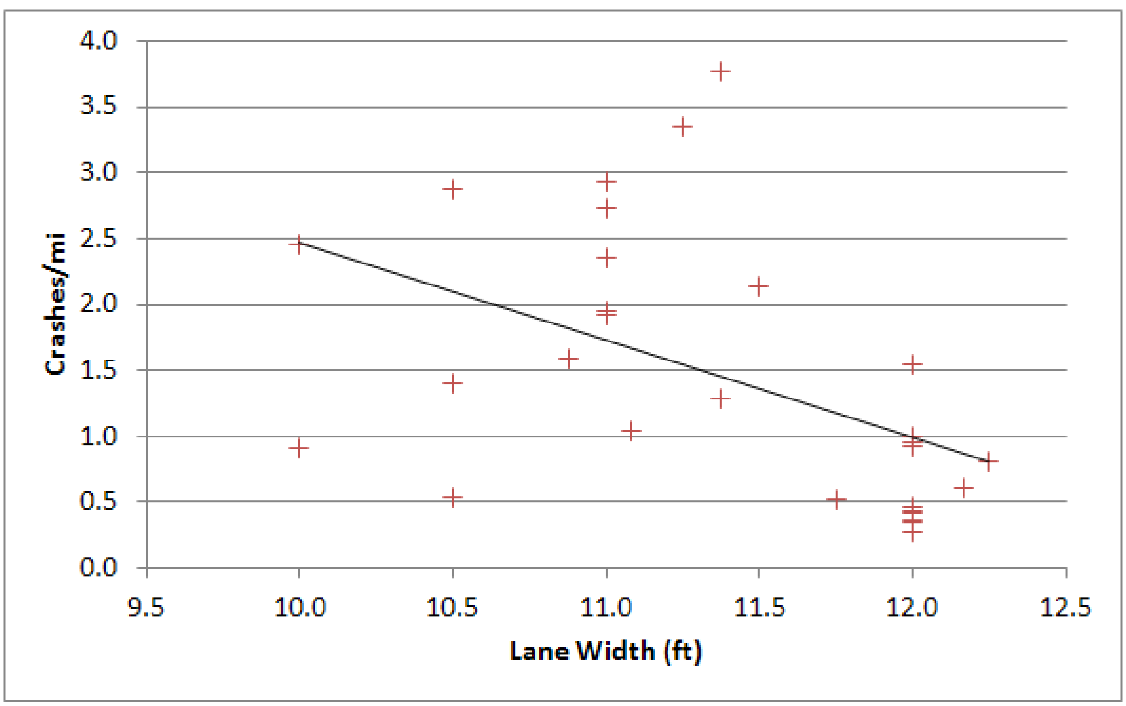


Figure 39. Distribution of Lane Width.

Figure 40 shows the relationship between lane width and ROR crashes. As expected, the figure suggests that the ROR crash rate decreases as the lane width increases. Previous research has shown similar relationships, as documented in Chapter 2 (see also AASHTO, 2010, and references herein).



(a) Crash Rate



(b) Number of Crashes per Mile

Figure 40. Relationship between ROR Crashes and Lane Width.

Lateral Clearance Distance

The lateral clearance distance was measured at several locations along each control section using the lidar gun. The measurements were performed on both sides of the traveled way, and the research team collected a total of 1,101 measurements. Figure 41 shows the distribution of the lateral clearance distances. The smallest clearance was 0 ft (or no clearance), which was always attributed to the location of a barrier or guardrail, while the largest clearance was measured at 87.1 ft. Most of the measurements were between 15 ft and 35 ft, and the average lateral clearance was about 26 ft.

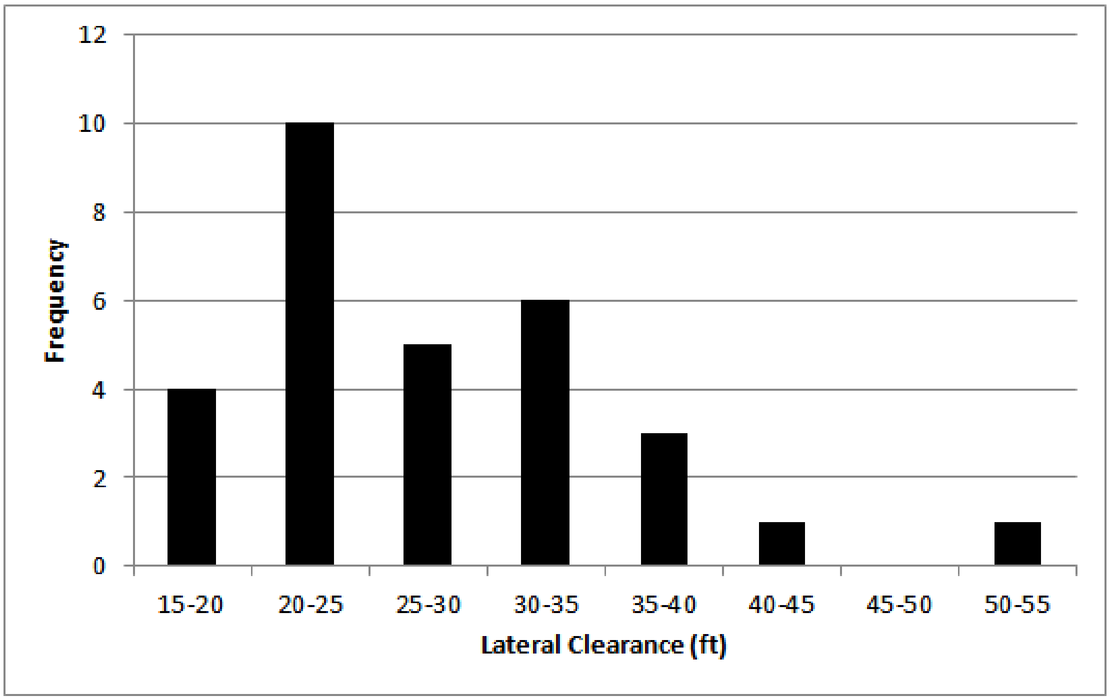
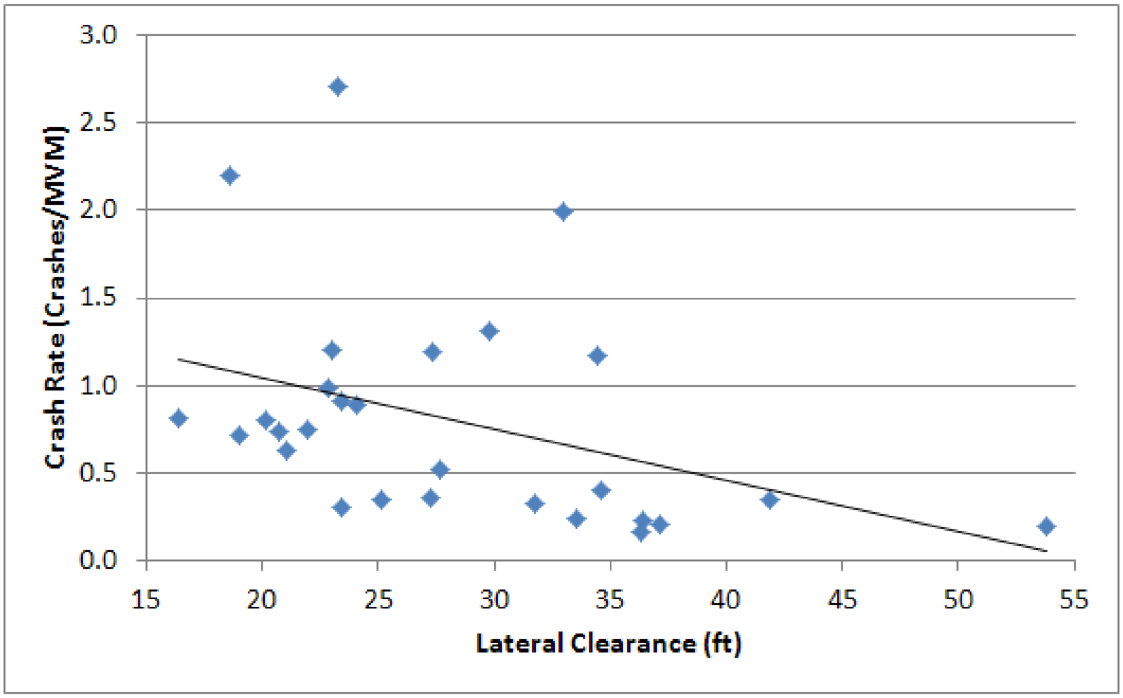
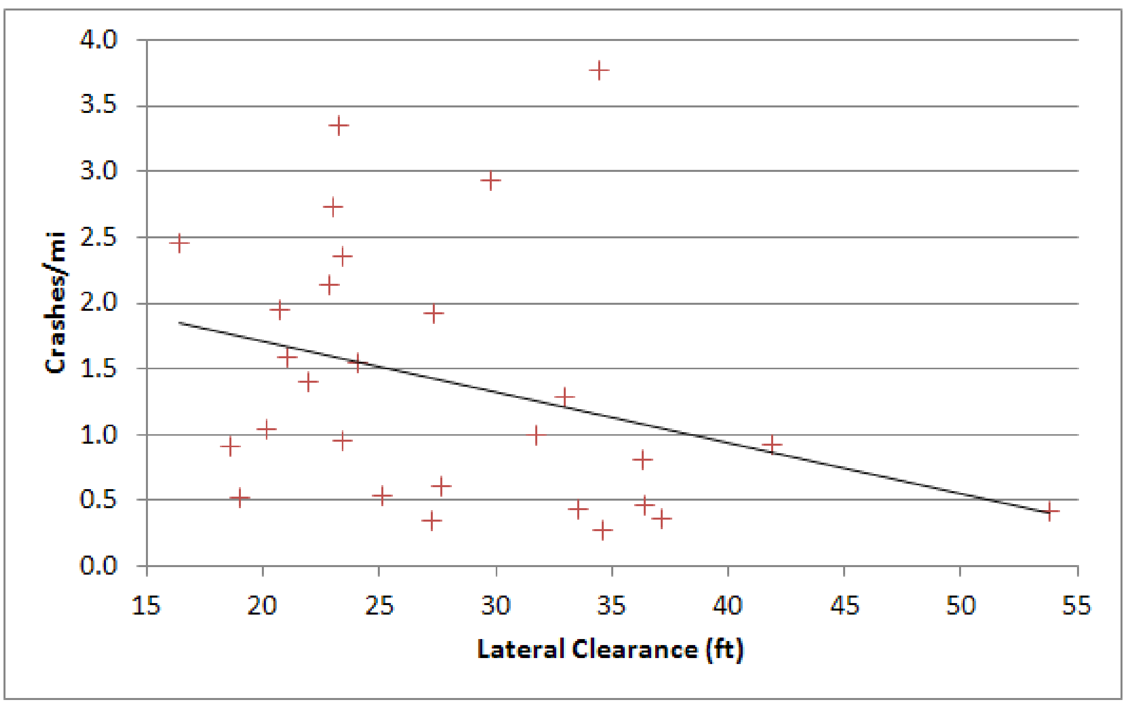


Figure 41. Distribution of Lateral Clearance Distances.

Figure 42 shows the relationship between ROR crashes and lateral clearance distance, which suggests that the ROR crash rate and number of crashes per mile decrease as the lateral clearance distance increases. The figure indicates a noticeable difference in the number of crashes for lateral clearances greater than 35 ft, with no more than 0.4 crash/MVM or 0.8 crash/mile.



(a) Crash Rate



(b) Number of Crashes per Mile

Figure 42. Relationship between ROR Crashes and Average Lateral Clearance Distance.

Figure 43 shows the cumulative distribution function of the lateral clearance distances for the segments where at least one crash occurred. For this figure, all 1,101 observations were used. Figure 43 shows that 90 percent of ROR crashes occurred at locations where lateral clearance is less than 40 ft, as discussed above.

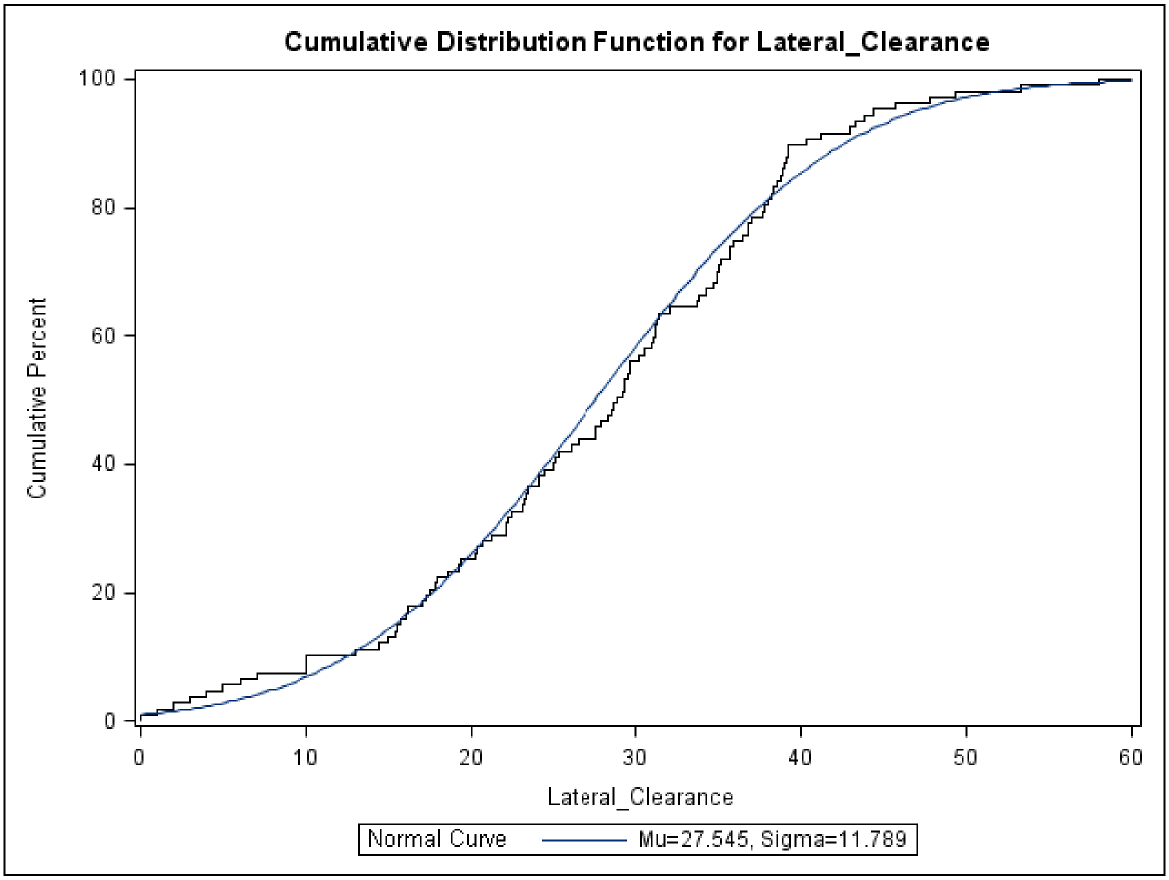


Figure 43. Cumulative Distribution Function of Lateral Clearance in Segments Where at Least One Crash Occurred.

Sideslope Ratings

As discussed previously, the sideslope conditions were also rated on both sides of the traveled way. Figure 44 illustrates the distribution of average sideslope ratings. There were a total of 1,639 sideslope ratings for all the sites. Ratings varied from 1 to 5 according to different roadside conditions, with 1 being the least severe and 5 being the most severe. The average rating for all these segments was 2.8.

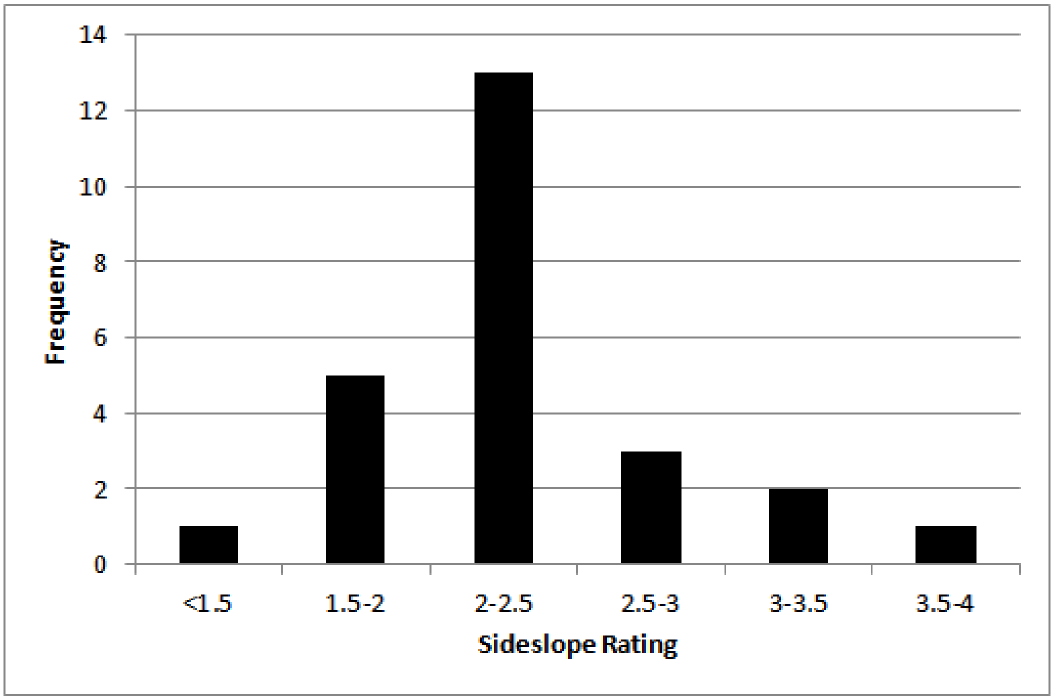
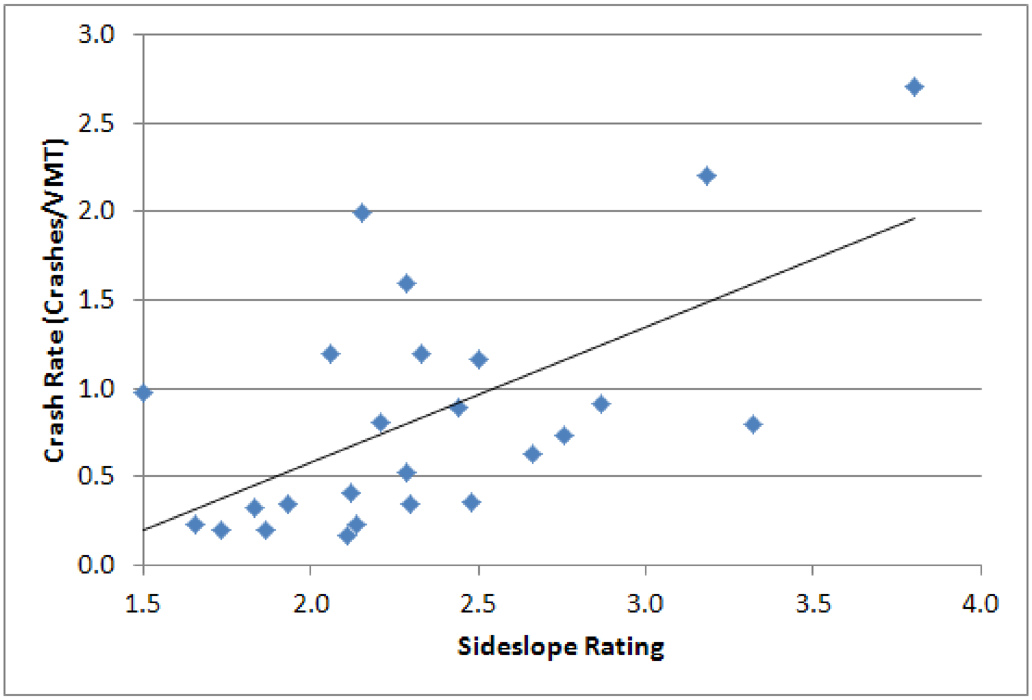
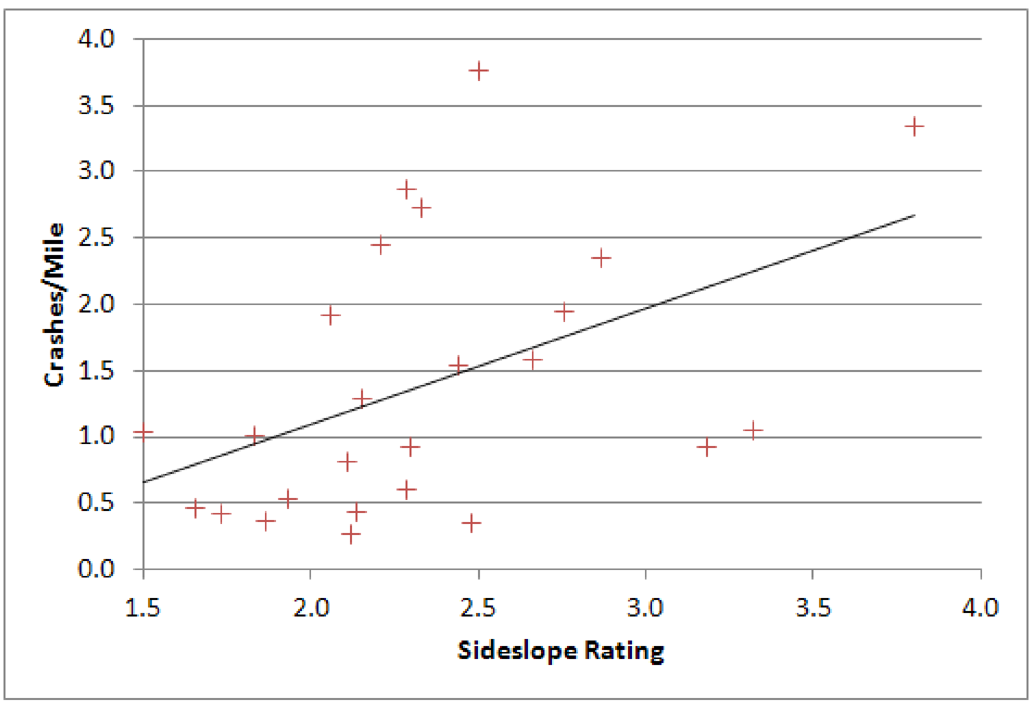


Figure 44. Distribution of Average Sideslope Ratings.

The relationship between average sideslope ratings and ROR crashes for each segment is shown in Figure 45. This figure shows that ROR crashes increase as the sideslope conditions become more severe. This relationship has also been observed in previous studies, as discussed in Chapter 2 (see also AASHTO, 2010).



(a) Crash Rate



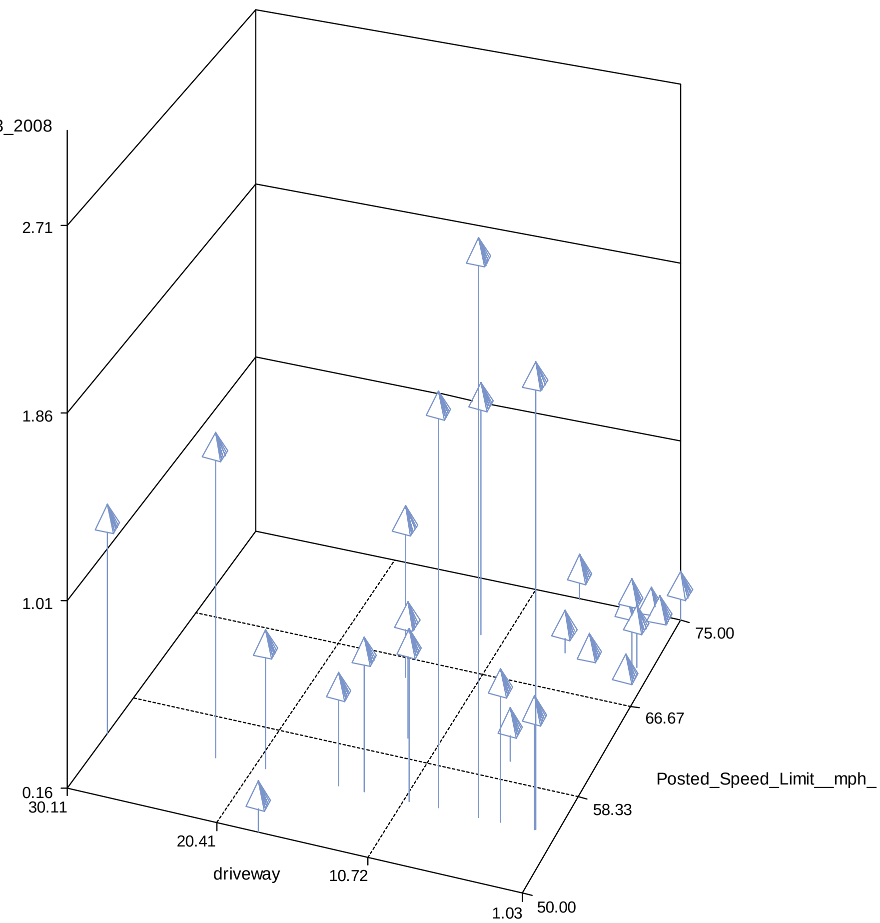
(b) Number of Crashes per Mile

Figure 45. Relationship between ROR Crashes and Average Sideslope Ratings.

The next few sections describe multilevel relationships between the variables described above. Three-dimensional (3-D) figures are used to better illustrate the variable interactions.

Driveway Density and Posted Speed Limit

Figure 46 shows the 3-D scatter plot between crash rate, posted speed limit, and driveway density. This figure shows that the crash rate decreases as the driveway density decreases and posted speed limit increases. Segments with higher posted speed limit are also characterized by a low driveway density. Therefore, the decrease in crash rate may be more attributed to the decrease of driveway density instead of the posted speed limit.



Driveway: driveway density(driveways/mile)
Posted_Speed_Limit__mph_: Posted Speed Limit(mph)
ROR_KABC_average_MVM_2003_2008: crash rate(Crashes/MVM)

Figure 46. Relationship between Crash Rate, Posted Speed Limit, and Driveway Density.

Posted Speed Limit and Curve Density

Figure 47 illustrates the relationship between crash rate, posted speed limit, and curve density. This figure shows that the crash rate decreases when the curve density decreases and posted speed limit increases. As discussed above, there is an inverse relationship between posted speed limit and curve density. This means that the decrease in crash rate should be attributed more to the decrease in curve density rather than the posted speed limit.

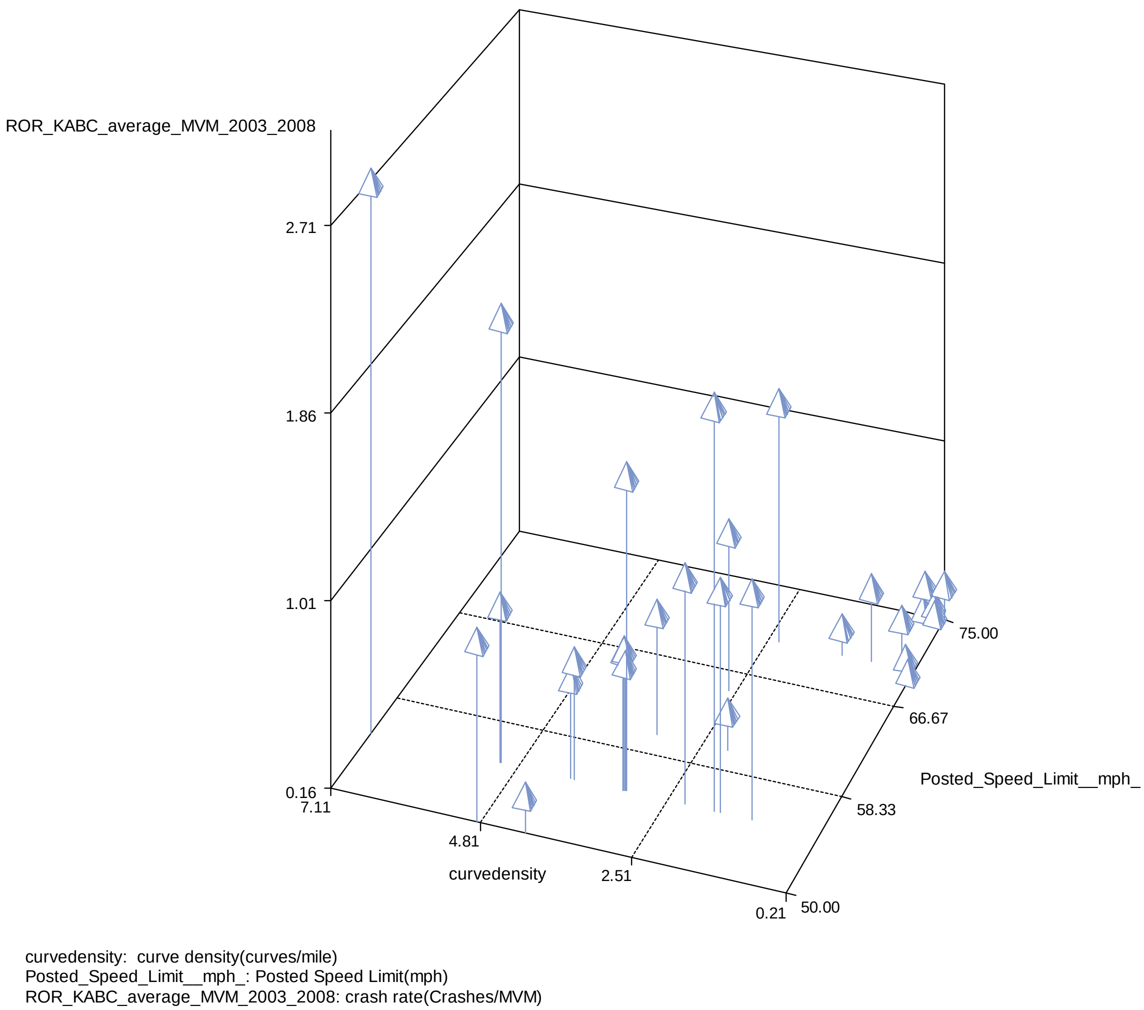
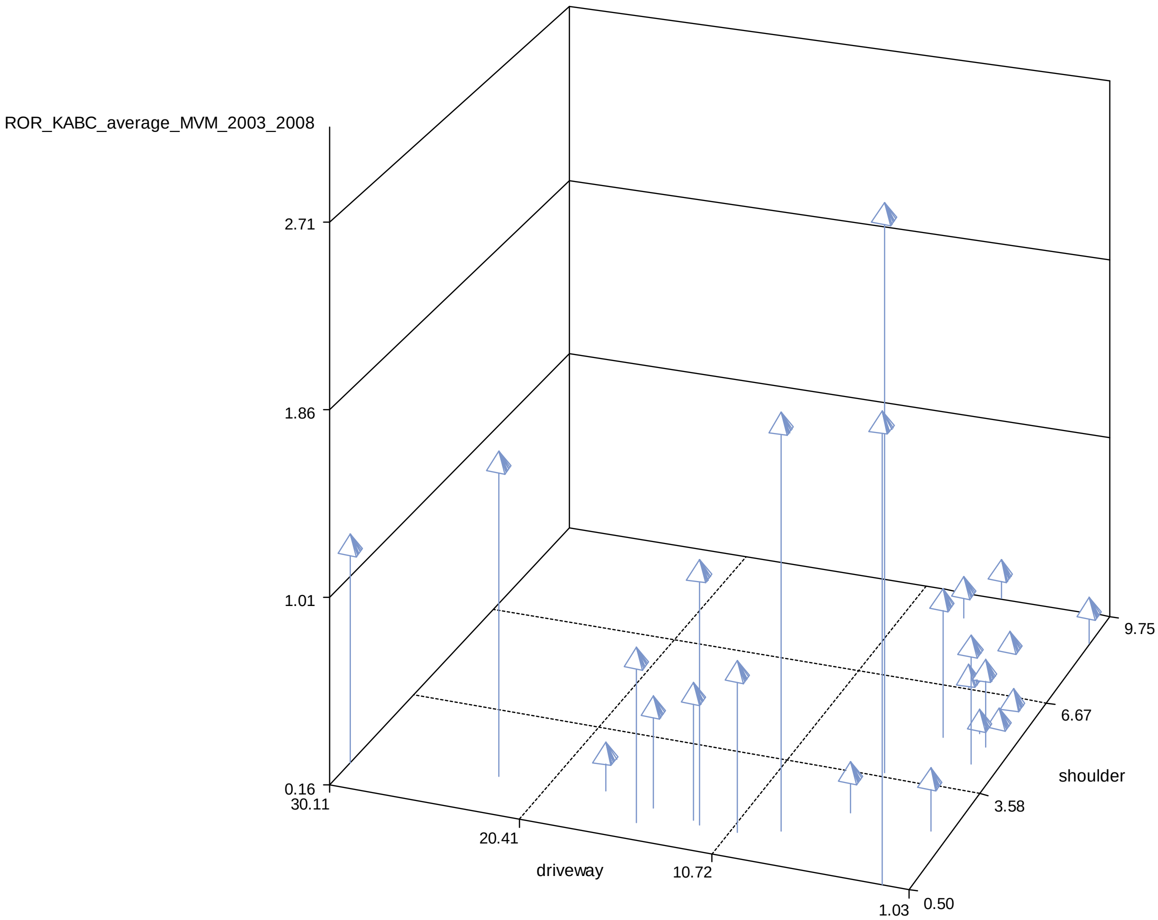


Figure 47. Relationship between Crash Rate, Posted Speed Limit, and Curve Density.

Shoulder Width and Driveway Density

Figure 48 illustrates the relationship between the crash rate, shoulder width and driveway density. This figure shows the crash rate decreases when the shoulder width increases and driveway density decreases. Narrow shoulder width combined with higher driveway density can significantly affect ROR crashes.



Driveway: driveway density(driveways/mile)
shoulder: shoulder width(ft)
ROR_KABC_average_MVM_2003_2008: crash rate(Crashes/MVM)

Figure 48. Relationship between Crash Rate, Shoulder Width, and Driveway Density.

Lateral Clearance and Sideslope Ratings

Figure 49 illustrates the relationship between crash rate, lateral clearance, and sideslope rating. This figure clearly shows that the crash rate decreases as the lateral clearance increases and sideslope rating decreases (or gets worse).

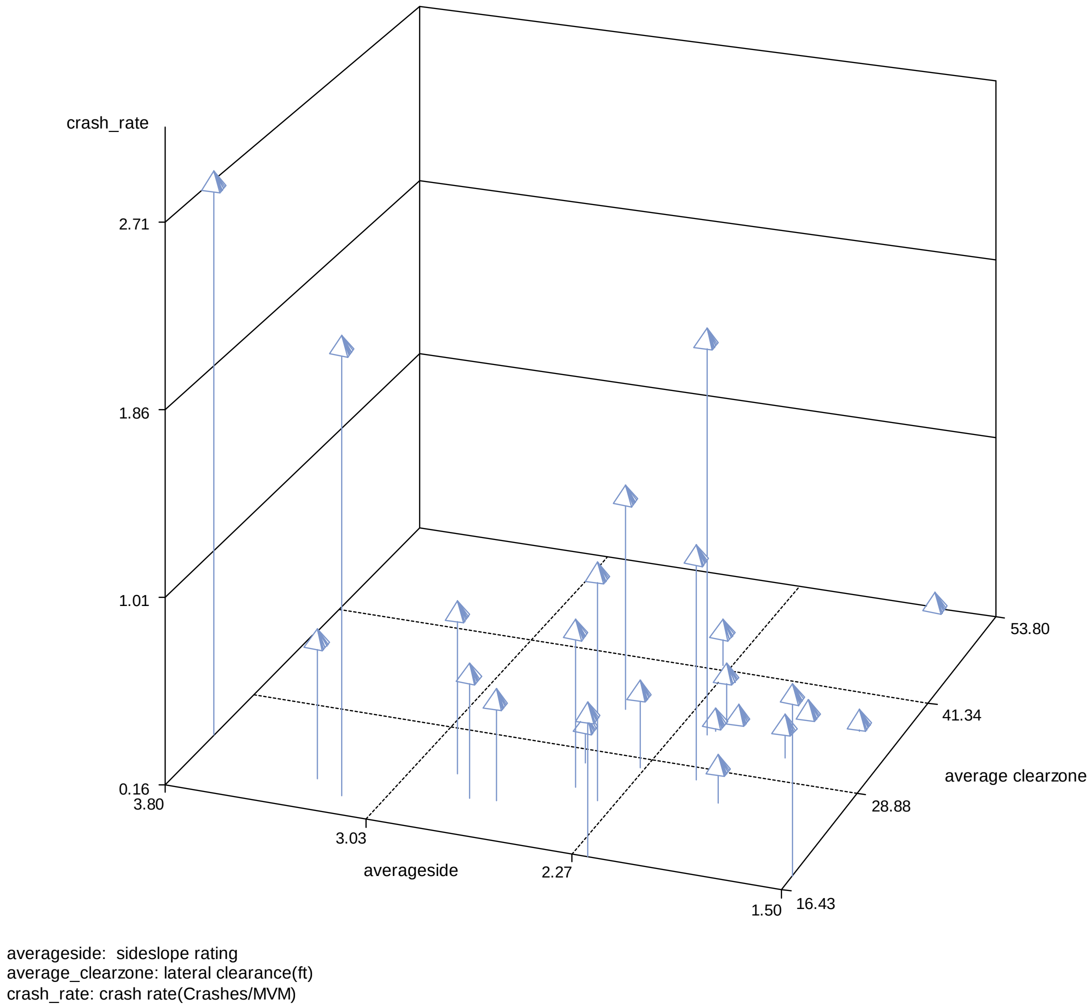


Figure 49. 3-D Relationship between Crash Rate, Lateral Clearance, and Sideslope Ratings.

CHAPTER SUMMARY

This chapter has documented the analyses related to the safety effects of geometric and operational data collected in the field study sites located in four TxDOT districts. The data contained 31 control sections, which were divided into 1,757 roadway segments and covered 340 miles. Eight highway geometric and operational variables were collected and analyzed in this study. The analysis results for the safety effects of these design and operational variables on ROR KABC crashes are as follows:

- The crash rate and count seem to decrease as the posted speed limit increases. This relationship appears to be counterintuitive, but it can be attributed to the fact that the two-lane highway sections with higher posted speed limits are designed to higher standards and have a smaller number of curves per mile.
- The crash rate and count increase substantially as the curve density increases.
- The crash rate slightly increases as the driveway density increases. There was a stronger positive relationship between crash count and driveway density.
- As expected, the crash rate and count decrease as the shoulder width increases.
- The crash rate and count also decrease as the lane width increases.
- The crash rate and count decrease as the lateral clearance increases. Furthermore, there is a significant drop in observed crash rates for clearances greater than 35 ft.
- The crash rate and count increase as the sideslope condition ratings become more severe.

CHAPTER 7: ENGINEERING COUNTERMEASURES

INTRODUCTION

This chapter describes potential countermeasures that could be implemented by TxDOT for reducing the risk for drivers to run-off-the-road or reducing the severity of the collision in the event of a roadway departure. The proposed countermeasures focus on low- to medium-cost treatments that could realistically be applied by TxDOT. The majority of the countermeasures were extracted from the following documents:

- TxDOT Roadway Design Workbook. (http://tcd.tamu.edu/documents/rsd_workbook.htm)
- Highway Safety Manual, Vol. 3 (1st Edition).
- Safety Evaluation of Improved Curve Delineation (FHWA-HRT-09-045). (http://www.fhwa.dot.gov/publications/research/safety/09045/index.cfm)
- Toolbox of Countermeasures and Their Potential Effectiveness for Roadway Departure Crashes (FHWA-SA-07-013).
- Driving Down Lane-Departure Crashes. (http://www.transportation1.org/lanedeparture/keepingdrivers.html)
- NCHRP Report 500 Series. (http://safety.transportation.org/guides.aspx)
    - Volume 3: A Guide for Addressing Collisions with Trees in Hazardous Locations.
    - Volume 4: A Guide for Addressing Head-On Collisions.
    - Volume 6: A Guide for Addressing Run-Off-Road Collisions.
    - Volume 7: A Guide for Reducing Collisions on Horizontal Curves.
- Safety Evaluation of the Safety Edge Treatment (FHWA-HRT-11-024).
- Low Cost Treatments for Horizontal Curve Safety (FHWA-SA-07-002).
- Treatments for Crashes on Rural Two-Lane Highways in Texas (TTI Report 4048-2).

The chapter is divided into three sections. The first section focuses on treatments that are specific to reducing roadway departure crashes on horizontal curves; as discussed in the two previous chapters, a large proportion of roadway departures occur on or near curves. The second section describes general treatments. The last section covers innovative and experimental treatments, many of which are currently under study.

For each treatment, the description contains its general characteristics, key design features, safety effectiveness, cost (when it is available), and additional resources where the reader can find more detailed information about the treatment. It should be pointed out that the safety effectiveness of each treatment has been found to be statistically significant at the 5 percent level. This is not a guarantee that this level of effectiveness will result from each installation; the reader needs to be aware that the anticipated benefits may not always be as large as the values reported in the original document.

HORIZONTAL CURVE TREATMENTS

This section discusses the following treatments:

- Edgeline Markings.
- Advisory Signs.
- Chevrons.
- Post-Mounted Delineators.
- Flashing Beacon.
- Reflective Barrier Delineation.
- Profile Thermoplastic Markings.
- Dynamic Curve Warning System.
- Speed Limit Advisory Marking Lane.
- Paved Shoulders.
- Install/Improve Lighting.
- Skid Resistive Pavement Surface Treatment.

Edgeline Markings

General Characteristics

Edgeline markings are used to delineate the edge of the traveled way. They provide visual reference for motorists regarding the shoulder or roadside areas (see Figure 50).

Figure 50. Centerline and Edgeline for Two-Lane Road (FHWA, 2006).

Key Design Features

The typical standard edgeline width varies between 4 and 6 inches, but some states have used 8-inch to 12-inch width on curves (FHWA, 2006). Figure 51 shows an example of two different edgeline widths. This wider marking has been utilized to "emphasize" the curved section of the highway.

Safety Effectiveness

A recent New York study has shown that standard edgelines on curvy rural two-lane highways reduced the total number of crashes by 5 percent and collisions with fixed objects by 17 percent (FHWA, 2006). Gan et al. (2005) reported a reduction of 30 percent in ROR crashes for all types of roads in Florida. This reduction was not specific for horizontal curves, however. Amjadi and Eccles (2011) noted that the improvement in curve delineation reduced the total number of crashes by 27.5 for total crashes and 25 percent for ROR crashes. The safety evaluation included several treatments that were simultaneously implemented (e.g., edgeline with chevrons, etc.).

Cost

As discussed in FHWA (2006), the cost of the edgeline markings is dependent on the material used, such as paint or thermoplastic, and the size of the crew needed to apply the material, as well as the quantity bought by the DOT (e.g., curves only versus an entire roadway segment). According to TxDOT's online bid unit price database, typical costs for Type I solid white edgeline markings range from $0.19 to $0.39 per linear foot for 4-inch markings and $0.60 to $0.96 for 6-inch markings. The average typical cost for Type I solid white edgeline markings are

$0.3 per linear foot for 4-inch markings, $0.66 for 6-inch markings, and $0.94 for 8-inch markings. The average typical cost for Type II solid white edgeline markings are $0.12 per linear foot for 4-inch markings and $0.25 for 6-inch markings and $0.35 for 8-inch markings.

(a) Roadway with 4-inch edgeline.

(b) Roadway with 8-inch edgeline.

Figure 51. Examples of Edgeline Widths (McGee and Hanscom, 2006).

Additional Resources

Amjadi, R. and K. Eccles (2011). *Twisting Roads Still Spell Trouble, Public Roads, Vol. 74, No. 4*. Report No. FHWA-HRT-11-002. Federal Highway Administration, U.S. Department of Transportation, Washington, DC.

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

Srinivasan, R., J. Baek, D. Carter, B. Persaud, C. Lyon, K. Eccles, F. Gross, and N. Lefler (2009). *Safety Evaluation of Improved Curve Delineation*. Report No. FHWA-HRT-09-045. Federal Highway Administration, U.S. Department of Transportation, Washington, DC.

Advisory Signs

General Characteristics

The Texas MUTCD states that the horizontal alignment Turn (W1-1), Curve (W1-2), Reverse Turn (W1-3), Reverse Curve (W1-4), or Winding Road (W1-5) signs (see Figure 52) may be used in advance of situations where the horizontal alignment changes. If the change in horizontal alignment is 135 degrees or more, the Hairpin Curve (W1-11) sign (see Figure 2C-1) may be used.

An Advisory Speed (W13-1) plaque may be used to indicate the speed for the change in horizontal alignment. The supplemental distance plaque NEXT XX MILES (W7-3a) may be installed below the Winding Road sign where continuous roadway curves exist.

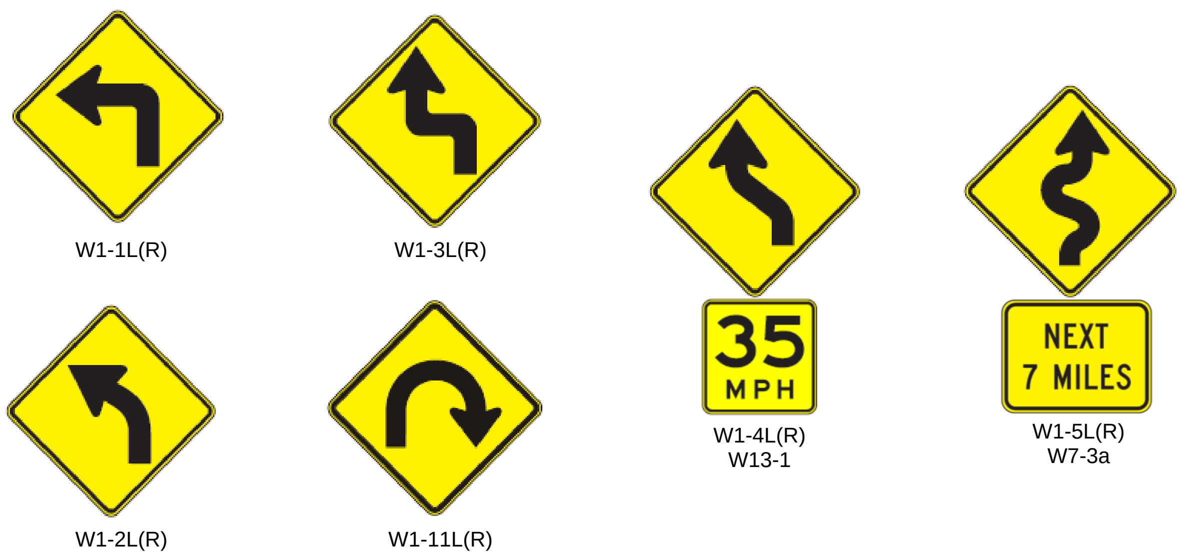


Figure 52. Advance Warning Signs for Horizontal Curves (Texas MUTCD).

Key Design Features

The placement of advance warning signs is dependent of the posted speeds. Table 49 shows the guidelines for the placement of advance curve warning signs, as adapted from Table 2C-4 in the 2006 Texas MUTCD.

Table 49. Guidelines for the Advance Placement of Curve Warning Signs (TxDOT, 2006).

Advance Placement Distance								
Posted or 85th-Percentile Speed	**Condition C: Deceleration to the listed advisory speed (mph) for the condition**							
	10	20	30	40	50	60	70	75
20 mph	N/A	-	-	-	-	-	-	-
25 mph	N/A	N/A	-	-	-	-	-	-
30 mph	N/A	N/A	-	-	-	-	-	-
35 mph	N/A	N/A	N/A	-	-	-	-	-
40 mph	N/A	N/A	N/A	-	-	-	-	-
45 mph	125 ft	N/A	N/A	N/A	-	-	-	-
50 mph	200 ft	150 ft	100 ft	N/A	-	-	-	-
55 mph	275 ft	225 ft	175 ft	100 ft	N/A	-	-	-
60 mph	350 ft	300 ft	250 ft	175 ft	N/A	-	-	-
65 mph	425 ft	400 ft	350 ft	275 ft	175 ft	N/A	-	-
70 mph	525 ft	500 ft	425 ft	350 ft	250 ft	150 ft	-	-
75 mph	625 ft	600 ft	525 ft	450 ft	350 ft	250 ft	100 ft	-
80 mph	725 ft	700 ft	625 ft	550 ft	475 ft	350 ft	200 ft	125 ft

Safety Effectiveness

A few studies have examined the safety effects advance warning signs for horizontal curves. Gan et al. (2005) and the HSM (AASHTO, 2010) reported a 30 percent reduction for the total number of crashes following the installation of advance warning signs. In another study, Montella (2005) noted a reduction of only 10 percent.

Cost

According to the TxDOT online bid unit price database, typical costs for aluminum advisory signs range from $250 to $350 each, and the average cost is $300 each.

Additional Resources

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

FHWA (2009). *Manual on Uniform Traffic Control Devices.* Federal Highway Administration, Washington, DC.

Chevrons

General Characteristics

Chevrons are signs used to emphasize and guide drivers through a change in horizontal alignment. The Chevron Alignment (W1-8) sign (see Figure 53) may be used to provide additional emphasis and guidance for a change in horizontal alignment. A Chevron Alignment sign may be used as an alternate or supplement to standard delineators on curves or to the One-Direction Large Arrow (W1-6) sign. Figure 54 shows an example from the Atlanta District of chevrons on a curve with an advisory curve warning sign.

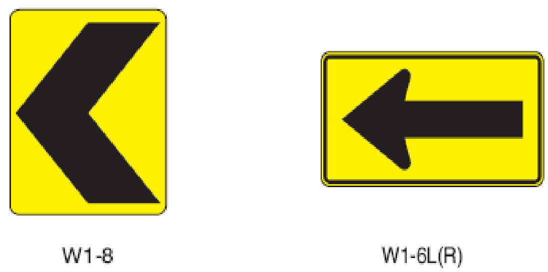


Figure 53. Chevron and One-Direction Large Arrow Signs (Texas MUTCD).

Figure 54. Example of Chevrons on a Two-Lane Road.

Key Design Features

If used, Chevron Alignment signs shall be installed on the outside of a turn or curve, in line with and at approximately a right angle to approaching traffic. A Chevron Alignment sign may be used on the far side of an intersection to inform drivers of a change of horizontal alignment for through traffic. Spacing of Chevron Alignment signs should be such that the road user always has at least two in view, until the change in alignment eliminates the need for the signs. Chevron Alignment signs should be visible for a sufficient distance to provide the road user with adequate time to react to the change in alignment. For guidelines on chevron spacing, refer to Table 50.

Table 50. Recommending Chevron Spacing (FHWA, 2009).

Advisory Speed	Curve Radius	Sign Spacing
15 mph or less	Less than 200 feet	40 feet
20 to 30 mph	200 to 400 feet	80 feet
35 to 45 mph	401 to 700 feet	120 feet
50 to 60 mph	701 to 1,250 feet	160 feet
More than 60 mph	More than 1,250 feet	200 feet

Note: The relationship between the curve radius and the advisory speed shown in this table should not be used to determine the advisory speed.

Safety Effectiveness

Gan et al. (2005) reported a 30 percent reduction for the total number of crashes, while Montella (2005) noted a 20 percent reduction.

Cost

According to the FHWA (2006), installing 10 signs should cost about $500. Based on the TxDOT online bid unit price database, typical costs for small roadside signs such as chevrons vary between $142 and $735. The average cost is about $433 each.

Additional Resources

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

Post-Mounted Delineators

General Characteristics

Delineators are retroreflective rectangular or circular posts mounted above the roadway surface and located on or adjacent to the shoulders (see Figure 55). They are considered guidance devices rather than advance warning signs. They are most effective at night.

Figure 55. Post Delineators Installed on a Ramp (FHWA, 2006).

Key Design Features

The reflectors should be white to match the pavement marking. The spacing between the delineators is based on the radius of the curve or the advisory speed, as shown in Table 51.

Table 51. Recommended Delineator Spacing (Texas MUTCD).

When Degree or Radius of Horizontal Curve is not known			When Degree or Radius of Horizontal Curve is known			
Advisory Speed (mph)	Spacing in Curve (ft)	Spacing in Straightaway (ft)	Degree of Curve	Radius of Curve (ft)	Spacing in Curve (ft)	Spacing in Straightaway (ft)
	A	2A			A	2A
15	35	70	1	5730	225	450
20	40	80	2	2865	160	320
25	50	100	3	1910	130	260
30	55	110	4	1433	110	220
35	60	120	5	1146	100	200
40	70	140	6	955	90	180
45	75	150	7	819	85	170
50	85	170	8	716	75	150
55	100	200	9	637	75	150
60	110	220	10	573	70	140
65	130	260	11	521	65	130
			12	478	60	120
			13	441	60	120
			14	409	55	110
			15	382	55	110
			16	358	55	110
			19	302	50	100
			23	249	40	80
			29	198	35	70
			38	151	30	60
			57	101	20	40

Safety Effectiveness

Gan et al. (2005) found a 25 percent reduction for the total number of crashes. The HSM reports a 5 percent reduction in crashes on tangent and curved sections.

Cost

According to FHWA (2006), the cost for the delineators is dependent on the number used and the type of retroreflective material. Based on the TxDOT online bid unit price database, typical costs for post-mounted delineators range from $5 to $91 and the average cost is about $31.70.

Additional Resources

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

Migletz, J., J. Fish, and J. Graham (1994). *Roadway Delineation Practices Handbook.* Report No. FHWA-SA-93-001. Federal Highway Administration, U.S. Department of Transportation, Washington, DC.

Flashing Beacon

General Characteristics

Flashing beacons are used in conjunction with another warning sign, and their aim is to attract the motorists' attention to the warning sign. An example of a flashing beacon is shown in Figure 56. They are usually utilized along with the advanced warning signs described above.

Figure 56. Example of a Flashing Beacon.

Key Design Features

The beacons are circular yellow lights that are similar to standard traffic signal heads. One or two beacons may be used per sign, and recommended placement is 12 inches from the edge of the sign.

Safety Effectiveness

Gan et al. (2005) reported a 30 percent reduction for all crashes. FHWA (2006) noted, based on a study performed in the 1970s, that the flashing beacon has been shown to reduce vehicle speed on horizontal curves.

Cost

According to TxDOT's online bid unit price database, typical average costs for installing flashing beacons are approximately $2,300 for traditional units and $4,900 for solar-powered units.

Additional Resources

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

Reflective Barrier Delineation

General Characteristics

Strips of reflective sheeting or individual reflectors are applied to concrete barriers or W-beam guardrails to warn drivers that they are approaching a horizontal curve. This treatment focuses on reducing nighttime crashes. An example of reflective barrier delineation can be seen in Figure 57.

Figure 57. Example of Reflective Barrier Delineation (FHWA, 2006).

Key Design Features

Installation of reflective sheets between 18 and 23 inches apart is recommended, running parallel to the direction of traffic (see Figure 58). They should be the same color as the adjacent edgelines (white on both sides of a two-lane highway).

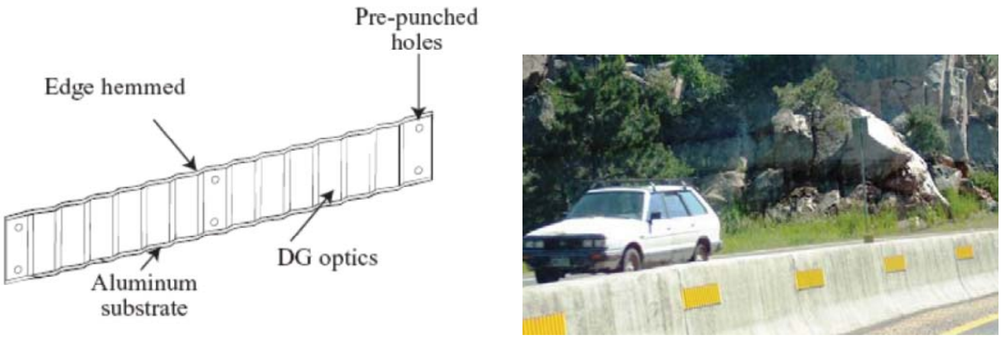


Figure 58. Reflective Sheeting Shaped to Provide Linear Reflectorization (FHWA, 2006).

Safety Effectiveness

Montella (2005) reported a reduction of 8 percent for fatal and non-fatal injury crashes.

Cost

FHWA (2006) noted that each individual reflector costs about $3. Strips should cost about $2.33 per linear foot for a 4-inch wide white material. According to TxDOT's online bid unit price database, typical average costs for each individual reflector are about $3.42. Strips should cost $0.30 per linear foot for 4-inch markings, $0.66 for 6-inch markings, and $0.94 for 8-inch markings.

Additional Resources

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

Profile Thermoplastic Markings

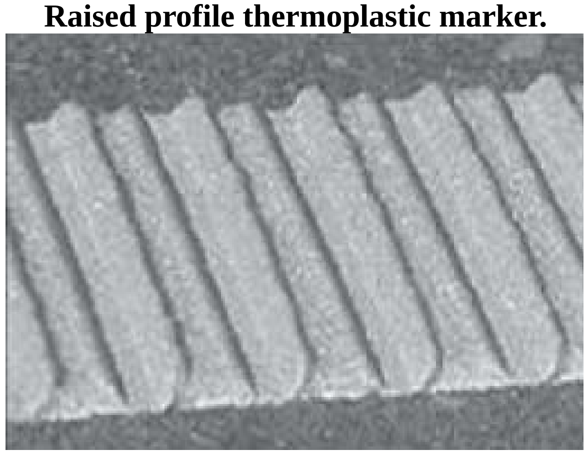
General Characteristics

Profile thermoplastic markings are a special pavement marking that also produces rumble effects and increases visibility.

Key Design Features

Two types of designs are available: raised and inverted profile patterns (see Figure 59).

Raised profile thermoplastic marker.



Inverted profile thermoplastic marker.

Figure 59. Example of the Two Types of Designs for Thermoplastic Markings (FHWA, 2006.).

Safety Effectiveness

Though some DOTs have conducted some preliminary evaluations (e.g., VDOT, 2009), no studies have formally evaluated this treatment.

Cost

According to the TxDOT online bid unit price database, typical costs for thermoplastic markings range from \$0.87 to \$0.94, with an average cost equal to \$0.93.

Additional Resources

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

VDOT (2009). *Durable, Retroreflective Pavement Markings & Markers Increase Visibility for Drivers In Wet, Night Conditions.* Virginia Department of Transportation, Charlottesville, VA.

Dynamic Curve Warning System

General Characteristics

The purpose of dynamic curve warning systems is to warn drivers that travel too fast for the curve conditions to slow down. They are vehicle-actuated signs that are activated when vehicles approaching the curve travel above a pre-defined speed threshold. The vehicle speed is measured using loop detectors or radar, which activates flashing beacons or variable message signs when a vehicle triggers the device. Figure 60 shows a dynamic curve warning system used in Camp County.

Figure 60. Dynamic Curve Speed Warning System in Camp County, Texas.

Key Design Features

For most DOTs, this treatment has generally been limited to sites experiencing high crash rates. It is often used after other less expensive treatments have failed to reduce curve-related crashes. Different systems exist, and there is no uniform design features among the states that have used a similar system.

Safety Effectiveness

According to the FHWA (2006), which cites a Caltrans study, a 44 percent reduction in the total number of crashes was observed following the installation in California.

Cost

The cost will vary according to the specific design. The FHWA (2006) noted that systems installed in Texas and California were about $18,000 and $61,000, respectively. According to TxDOT's online bid unit price database, average cost for a typical dynamic curve warning system is spread across multiple components: among them are vehicle loop detector installation ($10/ft) and flashing beacon installation ($2,285 each). In addition, typical costs for aluminum advisory signs range from $250 to $350 each, and mast arm installation varies by length, beginning at $4,000 for a 20-ft unit.

Additional Resources

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

NCHRP. "A Guide for Reducing Collisions on Horizontal Curves". NCHRP Report No. 500, Transportation Research Board, Washington, DC.

Speed Limit Advisory Pavement Marking

General Characteristics

Pavement markings showing an advisory speed are usually employed in combination with other advance warning signs. They are used to supplement existing warning information. This treatment is very similar to the PennDOT treatment discussed below.

Key Design Features

The MUTCD presents specifications for designing and placing speed limit advisory pavement markings (section 3B.19). Figure 61 is an example of a speed limit advisory pavement marking.

Figure 61. Speed Limit Advisory Pavement Marking (FHWA, 2006).

Safety Effectiveness

No studies have examined the safety effectiveness for this treatment. The FHWA (2006) nonetheless reported that reductions in speed were observed in Texas.

Cost

According to TxDOT's online bid unit price database, typical costs for speed limit advisory pavement marking range from $58 to $153, with an average cost equal to $116.

Additional Resources

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

Paved Shoulders

General Characteristics

Replace uneven or narrow shoulders with paved shoulders to increase usable width and driver safety.

Key Design Features

The construction usually includes removing and recompacting a new shoulder. Some transportation agencies have used pavement with different texture and color to clearly distinguish the shoulders from the traveled-way lanes.

Safety Effectiveness

According to numerous studies documented in the literature, widening paved shoulders can reduce the number and severity of crashes. Figure 62 shows an example of the relationship. Furthermore, changing the type of shoulders also influences the crash risk. Table 52 summarizes the change in safety for different types of shoulders. Researchers estimated these values for segments containing both straight and curved sections.

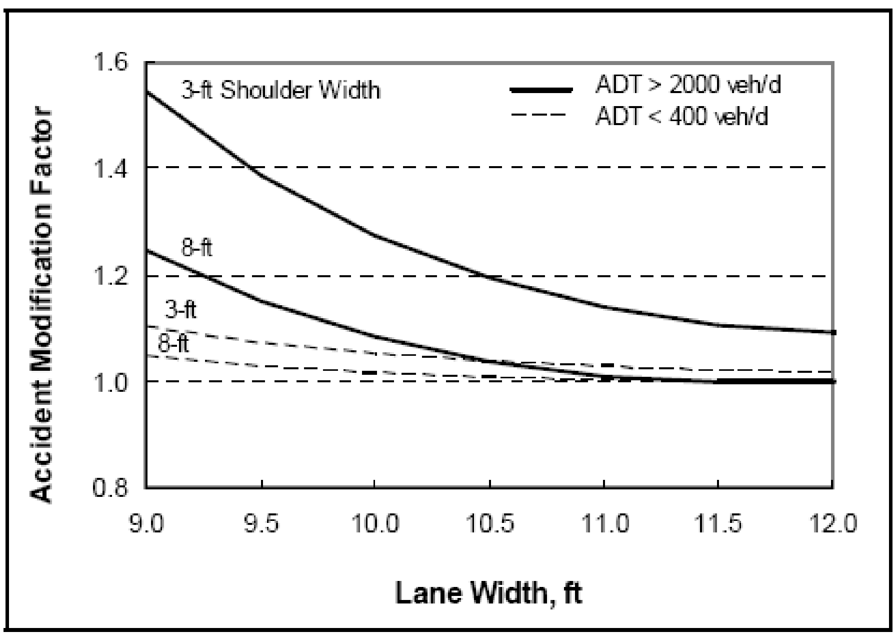


Figure 62. Lane and Shoulder Width AMF (Figure 3-9 in Bonneson and Pratt 2009).

Table 52. Crash Modification Factors for Shoulder Types and Shoulder Widths on Roadway Segments (CMF_{tra}) (Table 10-10 in HSM Vol. 2, 2010).

Shoulder Type	Shoulder Width (ft)						
	0	1	2	3	4	6	8
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11
Note: The values for composite shoulders in this table represent a shoulder for which 50 percent of the shoulder width is paved and 50 percent of the shoulder width is turf.							

Cost

According to TxDOT's online bid unit price database, typical costs for paved shoulders are dependent on different asphalt and aggregates. The costs for asphalt range from $2.75 to $4.50 per gallon. The average cost is about $3.80 per gallon. The costs for aggregates range from $54 to $140 per cubic yard, with an average cost equal to $72 per cubic yard.

Additional Resources

AASHTO (2010). *Highway Safety Manual*, 1st Edition. American Association of State Highway Transportation Officials, Washington, DC.

Bonneson, J.A., and Pratt, M.P. (2009). *Roadway Safety Design Workbook*. Report No. FHWA/TX-09/0-4703-P2. Texas Department of Transportation, Austin, TX.

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

Install/Improve Lighting

General Characteristics

Installing or improving lighting can make a curve more conspicuous and enhance the driver's available sight distance during nighttime conditions (see Figure 63). Lighting can also be useful during adverse weather conditions.

Figure 63. Safety Improvement by Adding Lighting.

Key Design Features

Should be used on only very sharp curves, since it may not be a cost-effective treatment.

Safety Effectiveness

The safety effectiveness for lighting on curves has not been established. Most of the research has been conducted for tangent sections. Those studies show a reduction of 20 percent in injury crashes.

Cost

According to TxDOT's online bid unit price database, typical costs for lighting are dependent upon the materials for the pole and lighting equipment. The costs for lighting range from $700 to $5,180, with an average cost equal to $2,336 each.

Additional Resources

NCHRP. Report 500 Series Volume 7: *A Guide for Reducing Collisions on Horizontal Curves*. Transportation Research Board, Washington, DC.

Skid-Resistant Pavement Surface Treatment

General Characteristics

Provide grooved or a special kind of pavement overlay in curves to increase the skid resistance by improving drainage. This treatment focuses on reducing wet-pavement related crashes on curves. Figure 64 is an example of the application of skid resistive surface applied to a curve's pavement.

Figure 64. Application of Skid-Resistant Pavement Surface in Curve (FHWA, 2006).

Key Design Features

The treatment can be provided using surface overlay or by installing grooved design on existing pavement. For the former, specific particle gradations are used to create voids to allow for the water to run off more easily, hence increasing the friction factor between the wheel and the surface. For the latter, grooves are installed longitudinally or transversely on existing pavement also with the goal of improving drainage. Grooved designs are usually more suitable for concrete pavement.

Safety Effectiveness

The safety effectiveness is dependent upon the type of overlay and grooved design. Some studies have shown a reduction of 50 percent in wet-related crashes and a 20 percent reduction for the total number of crashes for new pavement overlays. For grooved pavement, a 72 percent reduction was observed for wet-pavement related crashes, but only a 7 percent reduction for dry-related crashes. TxDOT has just funded a study that will examine the safety effectiveness of high-friction pavement on horizontal curves.

Cost

A 2-mile section cost the California DOT $200,000 in 1996.

Additional Resources

Amjadi, R. and K. Eccles (2011). *Twisting Roads Still Spell Trouble, Public Roads, Vol. 74, No. 4*. Report No. FHWA-HRT-11-002. Federal Highway Administration, U.S. Department of Transportation, Washington, DC.

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

GENERAL TREATMENTS

This section discusses the following treatments:

- Modify Lane Width.
- Modify Shoulder Width and Type.
- Shoulder Rumble Strip.
- Centerline Rumble Strip.
- Raised Pavement Markings (RPM).
- Install Barriers/Shielding.
- Reduce Driveway Density.

Modify Lane Width

General Characteristics

Roadway width is a critical factor influencing the safety performance of a rural two-lane highway. Generally, wider lanes will result in fewer crashes (see Figure 65).

Figure 65. Lane Width Being Modified.

Key Design Features

The geometric design practices related to lane width must consider the needs for motor vehicle, pedestrian, and bicycle traffic. The AASHTO *Policy on Geometric Design of Highways and Streets (Green Book)* offers guidelines on the selection of appropriate lane widths considering primarily the needs of motor vehicle traffic. In Chapter 7 of the *Green Book,* lane widths from 3.0 to 3.6 m (10 to 12 ft) are addressed along with specific circumstances for which each width should be considered.

Safety Effectiveness

Widening a lane by as little as 1 ft (0.3 m) can reduce the frequency of related crashes by as much as 12 percent. Although 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.

Cost

The cost of widening lane width is relatively high. According to NCHRP Report 486, the cost of widening lane width by 1 ft in both directions is usually around $52,000 per mile. Based on the TxDOT online bid unit price database, typical costs for widening lane width by 1 ft in both directions range from $58,000 to $74,000 per mile. The average cost is estimated to be $64,000 per mile.

Additional Resources

AASHTO (2010). *Highway Safety Manual*, 1st Edition. American Association of State Highway Transportation Officials, Washington, DC.

Bonneson, J.A., and M.P. Pratt (2009). *Roadway Safety Design Workbook*. Report No. FHWA/TX-09/0-4703-P2. Texas Department of Transportation, Austin, TX.

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

Harwood, D.W., E.R. Kohlman Rabbani, K.R. Richard, H.W. McGee, G.L. Gittings (2003). *Safety and Human Performance*. Systemwide Impact of Safety and Traffic Operations Design. Decisions for 3R Projects. NCHRP Report 486, Transportation Research Board, Washington DC.

Zegeer, C.V., J. Hummer, D. Reinfurt, L. Herf, W. Hunter (1987). *Safety Effects of Cross-Section Design for Two-Lane Roads,* – Volumes I and II. Report No. FHWA/RD-87/008. Federal Highway Administration, Washington, DC.

Modify Shoulder Width and Type

General Characteristics

The shoulder is the portion of the roadway located adjacent to the traveled-way. Shoulders are designed to accommodate stopped vehicles and to provide side support for the roadside in close proximity to the travel lane. Shoulders are strongly related to safety because they provide space that allows drivers to move away from the travel lane and avoid crashes (see Figure 66).

Figure 66. Two-Lane Roadway with Narrow Shoulder.

Two types of shoulders are: paved and unpaved. It is generally accepted that paved shoulders are essential for highway design, as they provide recovery space for errant vehicles and lateral support for the pavement structure. In addition, paved shoulders help accommodate non-motorized and slow-moving vehicles and provide operational benefits.

Key Design Features

Shoulder widths can vary from approximately 2 ft on minor rural roads to 12 ft on major roads where the entire shoulder may be stabilized or paved. Agencies should stabilize widened shoulders and ensure roadside slopes comply with AASHTO guidelines. Agencies can texturize the paved surface to provide visual, audible, and tactile clues to a driver leaving the travel lane. For distinguishing the texture of the surfaces, a larger, uncoated seal can be used on the shoulder while a smaller aggregate seal coat can be used on the driving lanes.

Safety Effectiveness

Table 53 lists the estimated reductions in related crashes resulting from widening paved or unpaved shoulders. Related crashes that are affected by shoulder widening include single-vehicle run-off-road and multiple-vehicle head-on and sideswipe crashes. For example, widening an unpaved shoulder by 4 ft (e.g., from 2 ft to 6 ft) would reduce related crashes by an estimated 25 percent. Adding 8-ft paved shoulders to a road with no shoulders would reduce related crashes by an estimated 49 percent.

Table 53. Crash Reductions Related to Shoulder Widening (FHWA, 2006).

Shoulder Widening (ft)	Reduction in Related Crash Types (%)	
	Paved	Unpaved
2	16	13
4	29	25
6	40	35
8	49	43

Cost

The costs of widening shoulders and paving shoulders are relatively high. Specific cost about a particular project should take into account the project's unique circumstances. According to NCHRP Report 486, the cost of widening shoulder width by 1 ft is usually around $61,000 per mile. The approximate cost of seal-coating a gravel shoulder is $1.00/yd^2 (when not resurfacing the roadway).

Additional Resources

AASHTO (2010). *Highway Safety Manual,* 1st Edition. American Association of State Highway Transportation Officials, Washington, DC.

Bonneson, J.A., and M.P. Pratt (2009). *Roadway Safety Design Workbook*. Report No. FHWA/TX-09/0-4703-P2. Texas Department of Transportation, Austin, TX.

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

Harwood, D.W., E.R. Kohlman Rabbani, K.R. Richard, H.W. McGee, G.L. Gittings (2003). *Safety and Human Performance*. Systemwide Impact of Safety and Traffic Operations Design. Decisions for 3R Projects. NCHRP Report 486, Transportation Research Board, Washington DC.

Shoulder Rumble Strips

General Characteristics

A shoulder rumble strip is a longitudinal design feature installed on a paved roadway shoulder near the travel lane (see Figure 67). It is made of a series of indented or raised elements intended to alert drowsy or inattentive drivers through vibration and sound that their vehicles have left the travel lane.

Figure 67. Illustration of Rumble Strip for Shoulder.

Key Design Features

Most states offset shoulder rumble strips just outside the edgeline of the travel lane by a distance of 4 to 12 inches. Standard milled rumble strips, installed as close to the edgeline as practical, should be used when an 8-ft clear shoulder width remains available after installation of the rumble strip. This is the recommended treatment for roadways with 10-ft shoulders.

A modified design should be used along shoulders 6 or 8 ft wide when the remaining available clear shoulder width is less than 6 ft, and the road can be used by bicyclists.

Safety Effectiveness

Research studies have found that shoulder rumble strips are an effective countermeasure to reduce ROR crashes (FHWA, 2006, 2007). These reports show reductions between 15 and 70 percent.

Cost

The costs can vary according to the length of the section, type of design and the location of the highway. According to recent average bid costs from TxDOT's online database, the average cost of shoulder rumble strips is about $8.63 per linear foot.

Additional Resources

AASHTO (2010). *Highway Safety Manual*, 1st Edition. American Association of State Highway Transportation Officials, Washington, DC.

Bonneson, J.A., and M.P. Pratt (2009). *Roadway Safety Design Workbook*. Report No. FHWA/TX-09/0-4703-P2. Texas Department of Transportation, Austin, TX.

Chaudoin, J.H. and G. Nelson (1985). *Interstate Routes 15 and 40 Shoulder Rumble Strips*. Report No. Caltrans-08-85-1, California Department of Transportation, Sacramento, CA..

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

Griffith, M. (1999). *Safety Evaluation of Continuous Shoulder Rumble Strips Installed on Freeways*. Transportation Research Record 1665. Transportation Research Board, Washington D.C.

Hickey, J.J. (1997). *Shoulder Rumble Strip Effectiveness*. Transportation Research Record 1573, Transportation Research Board, Washington, D.C.

Perrillo, K. (1998). *The Effectiveness and Use of Continuous Shoulder Rumble Strips*. Federal Highway Administration, Washington, D.C.

Centerline Rumble Strips

General Characteristics

A centerline rumble strip is a longitudinal design feature installed at or near the centerline of a paved roadway (see Figure 68). It is made of a series of indented or raised elements intended to alert inattentive drivers through vibration and sound that their vehicles have left the travel lane. In most cases, the centerline pavement marking is placed over the rumble strip, which is sometimes referred to as a centerline rumble stripe.

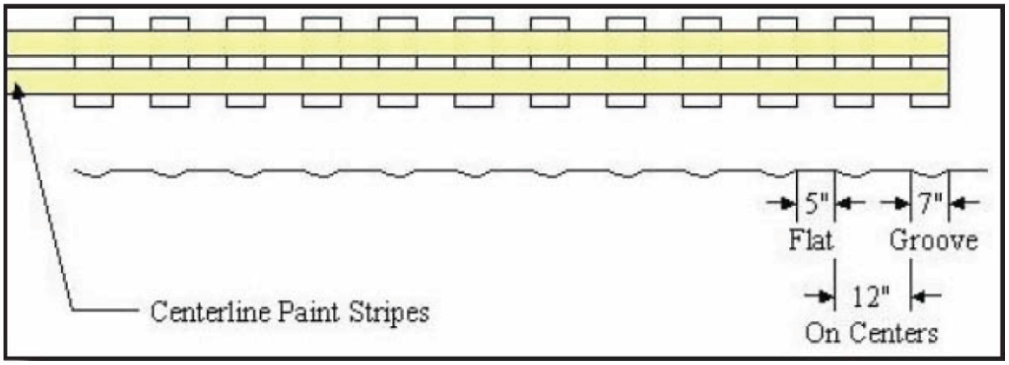


Figure 68. Example of Centerline Rumble Strips Installation (FHWA, 2006).

Key Design Features

There are four basic rumble strip designs or types: milled-in, raised, rolled-in, and formed. Typically, only milled rumble strips are used in centerline applications (see Figure 69).

Optimum dimensions for milled centerline rumble strips depend on operating conditions, cross-sectional characteristics, and potential road users. Two key dimensions to increase sound and vibration, and thereby effectiveness, are depth and width longitudinal to the road. Some study showed the variation in length transverse to the road had the least effect on noise produced compared to the other dimensions. The same study indicated that a rumble acting on the driver side tires, such as a centerline rumble strip, produced more noise in the vehicle than rumbles to the right, indicating a centerline rumble strip may not need to be as deep as a shoulder rumble strip to provide the same audible warning to the driver.

Figure 69. Illustration of Rumble Strip for Centerline.

Safety Effectiveness

The target crashes for centerline rumble strips are head-on and opposite-direction sideswipe collisions and single-vehicle ROR crashes to the left. For these crash types, centerline rumble strips are among the most cost-effective safety features available. Some studies have reported a reduction of 15 percent for the total number of crashes (FHWA, 2007).

Cost

Costs for centerline rumble strips are similar to those for shoulder rumble strips, about $8.63 per linear foot according to recent TxDOT bid items.

Additional Resources

FHWA (1999). *Rumble Strips: A Sound Investment*. Report No. FHWA-SA-99-017. Federal Highway Administration, Washington, DC.

FHWA. Accessed from: http://safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/. Accessed April 2002.

Fitzpatrick, K., D.W. Harwood, I.B. Anderson, and K. Balke (1999). *Accident Mitigation Guide for Congested Rural Two-Lane Highways*. NCHRP Report 440, Transportation Research Board, Washington DC.

Raised Pavement Markers

General Characteristics

Pavement markings are used to supplement traffic signs or signals and to communicate information that cannot be obtained with other types of traffic control devices. In many situations, agencies will install raised pavement markers (RPMs) to supplement or substitute for pavement markings.

Key Design Features

There are a variety of types of RPMs, and they can be reflective or non-reflective. For geographic areas where snow is common, the reflective device is encased in an iron casting or recessed below the pavement surface in a grooved section to prevent damage by snowplows (see Figure 70). The color of raised pavement markers under both daylight and nighttime conditions needs to conform to the color of the marking for which they serve as a positioning guide, or for which they supplement or substitute. The MUTCD states that, when used, internally illuminated raised pavement markers shall be steadily illuminated and shall not be flashed.

(a) Standard Raised Pavement Marker (yellow for centerline).

(b) Snowplowable Raised Pavement Marker.

Figure 70. Example of Raised Pavement Markers (FHWA, 2006).

Safety Effectiveness

While studies of the operational effects have shown RPMs can reduce the variation in lane placement and move vehicles away from the centerline, studies of crash changes have produced mixed results. They show a safety benefit on roadways with gentle curvature (less than 3.5 degrees) and relatively high volumes (greater than 5,000 veh/day), and safety non-benefits for roadways with sharper curvature (greater than 3.5 degrees) under all volume conditions. It has been hypothesized that the non-benefit results from the higher speeds because motorists feel safer with the RPMs providing alignment information even under wet nighttime conditions.

Cost

The cost is relatively low compared to other countermeasures and depends on different materials. Table 54 shows the estimated cost of common pavement markings.

Table 54. Estimated Cost of Pavement Markings.

Pavement Marking Material	Cost ($/mile)
Paint	1,056
Thermoplastic	1,584
Tape	3,960
Buttons	2,233

Additional Resources

AASHTO (2010). *Highway Safety Manual*, 1st Edition. American Association of State Highway Transportation Officials, Washington, DC.

Bonneson, J.A., and M.P. Pratt (2009). *Roadway Safety Design Workbook*. Report No. FHWA/TX-09/0-4703-P2. Texas Department of Transportation, Austin, TX.
FHWA (2009). *Manual on Uniform Traffic Control Devices*. Federal Highway Administration, Washington, DC.

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

Fitzpatrick K., A.H. Parham, and M.A. Brewer (2002). *Treatment for Crashes on Rural Two-Lane Highways in Texas*. Report No. FHWA/TX-02/4048-2. Texas Department of Transportation. Austin, TX.

Migletz, J., J. Fish, and J. Graham (1994). *Roadway Delineation Practices Handbook.* Report No. FHWA-SA-93-001. Federal Highway Administration, U.S. Department of Transportation, Washington, DC.

Songchitruksa, P., G. Ullman, and A. Pike (2010). *Guidance for Cost-Effective Selection of Pavement Marking Materials for Work Zones*. Journal of Infrastructure Systems, ASCE Journal of Transportation Engineering, Volume 17 Issue 2 2010.

Install Barriers/Shielding

General Characteristics

Barriers are used to shield motorists from natural or man-made obstacles located near the road. The primary purpose of the guardrail is to prevent the vehicle to strike a fixed object or travel a terrain feature that is considered more dangerous than hitting the guardrail barrier when it inadvertently leaves the road (see Figure 71).

Figure 71. Guardrail Used as a Barrier and Shield.

Key Design Features

Shielding non-traversable terrain or a roadside obstacle is usually warranted only when it is within the clear zone and cannot practically or economically be removed, relocated, or made breakaway, and it is determined that the barrier provides a safety improvement over the unshielded condition. Marginal situations, with respect to placement or omission of a barrier, will usually be decided by accident experience, with at the site or at a comparable site. Where feasible, all sign and luminaire supports should be a breakaway design regardless of their distance from the road if there is reasonable likelihood of their being hit by an errant motorist.

Safety Effectiveness

Some studies have shown that guardrails along the road edge reduce the number of crashes and their severity. Guardrails reduce crash rates by approximately 30 percent and, when a crash occurred, the number of fatality and injury crashes by approximately 50 percent. Other studies have shown that guardrails protect drivers from potential hazards. Barriers themselves are fixed objects and could also lead to injuries if struck by a vehicle in a crash.

Cost

The costs are presented in Table 55 for post-mounted barrier systems and concrete barrier systems, respectively.

Table 55. Capital Cost Comparison of Alternative Barrier Systems (FHWA, 2005).

Barrier System	**Base Rate Range**
Weak post W-beam barrier	$12–16/ft
Strong post W-beam barrier	$16–25/ft
Modified beam barrier	$22–35/ft
High tension cable barrier	$18–30/ft
Concrete safety shape	$80–110/ft
Precast concrete guardwall, type 1	$175–225/ft

Additional Resources

AASHTO (2002). *Roadside Design Guide.* American Association of State Highways and Transportation Officials, Washington, DC.

Fitzpatrick K., A.H. Parham, and M.A. Brewer (2002). *Treatment for Crashes on Rural Two-Lane Highways in Texas*. Report No. FHWA/TX-02/4048-2. Texas Department of Transportation, Austin, TX.

FHWA (2005). *Barrier Guide for Low Volume and Low Speed Roads*. Federal Highway Administration, Washington, DC.

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

Reduce Driveway Density

General Characteristics

Driveway density is very important in access management because accident rates increase dramatically as the number of driveways per mile increases along roadways. Driveway consolidation is the process of reducing the density of driveways along a major roadway by closing driveways, creating alternative access ways, creating shared driveways, relocating entrances to side streets, or promoting cross access (see Figure 72).

Figure 72. Driveway Intersecting a Rural Road in the Lufkin District.

Key Design Features

Spacing between driveways or farm-field entrances is especially critical in rural areas because travel speeds are high. Higher vehicle speeds mean that driver reaction and stopping distances are longer. In rural areas, a maximum driveway density standard of about four access points per mile per roadway side is appropriate on many arterial roads.

Safety Effectiveness

Most of the case studies of reducing driveway density conducted in previous projects led to an absolute reduction in highway crashes. All were reported in reductions in crash rates per million vehicle-miles of travel; the range of crash rate reductions varied between 10 and 70 percent, with 40 percent being a typical reduction. The most significant reductions occurred in terms of property-damage-only crashes, rear-end collisions, and broadside collisions. For ROR collisions, the effect is currently unknown.

Cost

The cost of reducing driveway density is variable and depends on different specific projects. The major disadvantage is that it will decrease the mobility of local residents.

Additional Resources

AASHTO (2004). *A Policy on Geometric Design of Highways and Streets.* AmericanAssociation of State Highways and Transportation Officials, Washington, D.C.

Bonneson J., K. Zimmerman, and K. Fitzpatrick (2005). *Roadway Safety Design Synthesis*. Texas Department of Transportation, Austin, TX.

FHWA (2000). *Roundabouts: An Informational Guide*. Report FHWA-RD-00-067. Federal Highway Administration, U.S. Department of Transportation, Washington, DC.

TRB (2003). *Access Management Manual*. Transportation Research Board. Washington, DC.

INNOVATIVE AND EXPERIMENTAL TREATMENTS

This section discusses the following treatments:

- Optical Speed Bars.
- PENNDOT Curve Advance Marking.
- Safety Edge.

Optical Speed Bars

General Characteristics

Optical speed bars are transverse stripes that are spaced at gradually decreasing distances located along the edgelines. The goal is to increase the driver's perception of speed and consequently influence the driver to reduce his or her speed (see Figure 73).

Figure 73. Optical Speed Bars Used to Reduce Vehicle Speed.
(Courtesy of Virginia Department of Transportation)

Key Design Features

The transverse painted lines are 18 inches wide and 12 inches long. The space between the bars gradually narrows as the bars get closer to the curve (ex: 24 inches to 12 inches). The length where the bars are installed are dependent upon the difference between the curve posted speed and the approach speed of the traffic. This treatment should only be installed where important reduction in speed is sought, especially at sites experiencing more crashes than expected.

Safety Effectiveness

A few studies have shown significant reductions in the 85th percentile speeds, but their effect on safety is still unknown.

Cost

According to FHWA, the pavement marking for a project in Virginia cost approximately $2,000 in 2006.

Additional Resources

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

PennDOT Curve Advance Marking

General Characteristics

Figure 74 is a special kind of pavement marking that was tested by the Pennsylvania DOT that includes two transverse bars, the word 'SLOW', and an arrow indicating the direction of the upcoming curve.

Figure 74. PennDOT Curve Advance Marking (FHWA, 2006).

Key Design Features

This treatment was only installed on curves located on two-lane rural highways experiencing more crashes than expected. This marking needs to be supplemented with proper regulatory and warning signs, delineation and traditional pavement markings. PennDOT followed the MUTCD guidelines for the placement and size of the letters and arrows on the pavement.

Safety Effectiveness

PennDOT noted reductions in vehicular speeds by about 6 or 7 percent. The effects on crashes have not yet been determined.

Cost

Cost is unknown, but it should be equivalent to costs of similar in-lane pavement markings.

Additional Resources

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

Safety Edge

General Characteristics

The Safety Edge™ is a treatment used for reducing the crashes associated with shoulder edge-pavement drop-off (see Figure 75). Drop-offs happen when unstabilized pavement edges get eroded, which creates a large height difference between the pavement and the foreslope. A driver leaving the traveled way may have difficulties regaining control of the vehicle and returning to the travel lane.

Figure 75. Safety EdgeSM System (Hallmark et al., 2011).

Key Design Features

With this treatment, the pavement edge is formed at a sloped angle of about 30 degrees, which helps reduce the resistance to remounting the drop-off after a vehicle leaves the traveled-way. The sloped angle allows more control for the driver when moving back onto the traveled way. The Safety Edge™ treatment can be applied when the roadway is built as new or retrofitted.

Safety Effectiveness

A recent FHWA study showed a reduction of 5 percent in the total number of crashes. To obtain a more reliable result, further studies are currently underway to evaluate the safety effects of the Safety Edge™ treatment.

Cost

According to the FHWA report, the treatment is cost effective. This report states that the average costs per mile should be between $536 and 2,145 per mi for 1.5 inches and 3.0 inches drop-off, respectively.

Additional Resources

FHWA (2006). *Low-Cost Treatments for Horizontal Curve Safety*. Report No. FHWA-SA-07-002. Federal Highway Administration, Washington, DC.

FHWA (2011). *Safety Evaluation of the Safety Edge Treatment*. Report No. FHWA-HRT-11-024. Federal Highway Administration, U.S. Department of Transportation, Washington, DC.

Hallmark S., J. Graham, R. Patel, and F. Council (2006). *Safety Impacts of Pavement Edge Drop-offs*. AAA Foundation for Traffic Safety, Washington, DC.

CHAPTER SUMMARY

This chapter described a series of low-cost treatments that can be used to potentially reduce the number and severity of ROR crashes occurring on rural two-lane highways. The treatments were separated into three categories. The first category focused on treatments that specifically target reducing roadway departure crashes on horizontal curves. The second category described general treatments. The third category covered innovative and experimental treatments, many of which are currently under study. There were 12 low- to medium-cost treatments for horizontal curves, seven for general treatments, and three for the experimental treatments.

For each treatment, the information focused on the general characteristics, key design features, safety effectiveness, cost (when it is available), and additional resources where the reader can find more detailed information about the treatment.

CHAPTER 8: CONCLUSIONS AND FURTHER WORK

The research team undertook this research effort to address the following objectives:

- Identify contributing factors associated with roadway departures on rural two-lane highways in Texas.
- Provide engineering countermeasures to reduce the number and injury related to this type of crash.

This research study contained two components. The first component sought to identify global factors that influence this type of crash by region and district. The second component focused on identifying factors that may not be captured by the state databases, but can be extracted from site visits and the analysis of original crash reports. Input from the various districts was also obtained for this component.

In summary, the research team identified several factors that influence the number and severity of roadway departures on rural two-lane highways in Texas. Further, the research team proposed several low- to medium-cost treatments that could be realistically implemented by TxDOT. These findings and additional conclusions are described in greater detail in the next few sections.

CONTRIBUTING FACTORS

The research team first analyzed crash data that occurred on rural two-lane highways between 2003 and 2008. Then, the research team conducted an engineering analysis by analyzing crash reports and visiting more than 80 sites located in four TxDOT districts. The primary objective of these analyses was to identify key characteristics, patterns, and trends associated with roadway departure crashes on the identified network. Various types of statistical analyses were conducted on the data and were performed for the entire state, by region and on a per-district basis. The results of these analyses were as follows:

- The proportion of roadway departure crashes for the districts vary between 25 percent and 52 percent of all crashes that occurred on the rural two-lane highway network.
- The annual number of roadway departure injury crashes (KABC) has slightly diminished between 2003 and 2008.
- Wider shoulders on horizontal curves have a greater positive impact on safety than tangent sections for districts categorized as having high crash rates.
- Wider shoulders on horizontal curves with a larger degree of curve have a greater positive impact on safety.
- The crash rate and count increase substantially as the curve density increases.
- More fatal crashes occur during nighttime conditions than during daytime.
- The regression models showed that driveway density had little influence on roadway departure crashes; however, the number of driveways per mile is associated with higher values of all crashes (mainly multi-vehicle crashes).
- As expected, more drivers are involved in roadway departure crashes between Friday and Sunday, which may be partly attributed to people driving under the influence of alcohol.

- There are more drivers leaving the traveled way in east Texas (Lufkin, Fort Worth, Tyler, Bryan, San Antonio) per 100 MVM than West Texas. However, districts that experience a large number of roadway departures per 100 MVM are not limited to a single region in Texas.
- The crash rate decreases as the lateral clearance increases. Furthermore, there is an important drop in observed crash rates for clearances greater than 35 ft.
- The crash rate and count increase as the sideslope condition ratings become more severe.

An engineering analysis based on the review of 394 crash reports on 81 control sections led to the following findings:

- Key factors are the presence of horizontal curves, nighttime conditions, unsafe/illegal speeds, motorcycles, and/or drivers who were distracted, fatigued, asleep, or impaired.
  - Horizontal curves were the site of nearly two-thirds of all study-site crashes.
  - More than one-third of the crashes occurred at night.
  - Just over half of the crashes were due in some part to a vehicle traveling at a speed unsafe for conditions. In addition, another 21 crashes were affected by a driver exceeding the speed limit.
  - About 23 percent of study-site crashes involved a distracted driver.
  - Nearly two-thirds of fatigued/asleep crashes occurred at night, compared to 31 percent of non-F/A crashes. F/A drivers were twice as likely to be involved in a fatality (16 percent) as alert drivers (8 percent).
  - Impaired drivers made up 16 percent of study-site crashes, and they contributed to more than a third of fatal crashes, compared to 14 percent of non-fatal crashes.
  - Motorcycles were commonly involved in crashes attributed to speeding/unsafe speed, representing 30 percent of such crashes as opposed to 15 percent of non-S/US crashes. A full 80 percent of S/US crashes occurred on curves.
- Common results from roadway departure crashes are overturned vehicles, crossing the centerline of the roadway, and leaving the roadway on both sides of the traveled way as a result of overcorrecting.
  - Over 40 percent of observed crashes resulted in an overturned vehicle.
  - Nearly 80 percent of the crashes (313) resulted in the vehicle departing the roadway on the right side of the road.
  - Almost half of the crashes (187) involved a vehicle that crossed the centerline and most of those crashes (164) resulted in the vehicle leaving the road on the left side. As a result, there were 83 crashes (21 percent) of the 394 in which a vehicle actually left the roadway on both the left and right sides.
- Combinations of these factors typically present in roadway departures often lead to crashes with higher severities than crashes of other types (i.e., fatalities and serious injuries make up a greater share of these types of crashes as compared to crashes without these factors).

COUNTERMEASURES

The research team documented several low- to medium-cost treatments that can possibly be used for reducing the number and severity of roadway departure crashes occurring on rural two-lane highways. The treatments were separated into three categories. The first category focused on treatments that are specifically targeted to reducing roadway departure crashes on horizontal curves. The second category described general treatments. The third category covered innovative and experimental treatments, many of which are currently under study. There were 12 low- to medium-cost treatments for horizontal curves, seven for general treatments, and three for the experimental treatments, shown in Table 56. The majority of the countermeasures were extracted from the following documents (for references purposes):

- TxDOT Roadway Design Workbook. (http://tcd.tamu.edu/documents/rsd_workbook.htm)
- Highway Safety Manual, Vol. 3 (1st Edition).
- Safety Evaluation of Improved Curve Delineation (FHWA-HRT-09-045). (http://www.fhwa.dot.gov/publications/research/safety/09045/index.cfm)
- Toolbox of Countermeasures and Their Potential Effectiveness for Roadway Departure Crashes (FHWA-SA-07-013).
- Driving Down Lane-Departure Crashes. (http://www.transportation1.org/lanedeparture/keepingdrivers.html)
- NCHRP Report 500 Series. (http://safety.transportation.org/guides.aspx)
  - Volume 3: A Guide for Addressing Collisions with Trees in Hazardous Locations.
  - Volume 4: A Guide for Addressing Head-On Collisions.
  - Volume 6: A Guide for Addressing Run-Off-Road Collisions.
  - Volume 7: A Guide for Reducing Collisions on Horizontal Curves.
- Safety Evaluation of the Safety Edge Treatment (FHWA-HRT-11-024).
- Low Cost Treatments for Horizontal Curve Safety (FHWA-SA-07-002.)
- Treatments for Crashes on Rural Two-Lane Highways in Texas (TTI Report 4048-2).

Table 56. Summary of Proposed Treatments.

Horizontal Curve Treatments
Edgeline Markings
Advisory Signs
Chevrons
Post-Mounted Delineators
Flashing Beacon
Reflective Barrier Delineation
Profile Thermoplastic Markings
Dynamic Curve Warning System
Speed Limit Advisory Marking Lane
Paved Shoulders
Install/Improve Lighting
Skid Resistive Pavement Surface Treatment
General Treatments
Modify Lane Width
Modify Shoulder Width and Type
Shoulder Rumble Strip
Centerline Rumble Strip
Raised Pavement Markings (RPM)
Install Barriers/Shielding
Reduce Driveway Density
Innovative and Experimental Treatments
Optical Speed Bars
PENNDOT Curve Advance Marking
Safety Edge

For each treatment, the information in Chapter 7 of this report focused on the general characteristics, key design features, safety effectiveness, cost (when it is available), and additional resources where the reader can find more detailed information about the treatment.

FUTURE RESEARCH NEEDS

As discussed in this document, many factors associated with roadway departure crashes are human-related (e.g., Liu and Ye, 2011). In many cases, a driver commits an error, and the end result that governs the type and severity of the crash is related to where the error is committed, whether it is on a curve or a tangent section, or at a location with a high pavement edge drop-off. With this in mind, future research should examine countermeasures that would help reduce the likelihood for these errors to occur and those that would minimize the severity when the driver leaves the traveled-way. A number of these countermeasures are currently in the experimental stage, including those documented in Chapter 7. At the time this project is concluding, a TxDOT-funded project that will examine the safety of high pavement friction on horizontal curves is scheduled to begin. It is suggested that other similar projects be funded by TxDOT in the near future that will focus on new and innovative treatments that could be used for reducing roadway departure crashes.

Given the characteristics of the roadway departure crashes observed in this project, it may be worthwhile to examine how data collected from the national naturalistic study currently underway could be used for developing driver-centric countermeasures. These data are currently being collected and should become available within the next two years. Since roadway data are also being assembled, it may also be possible to examine roadway-centric treatments as a result of that project.

CHAPTER 9:
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APPENDIX A: CRASH VARIABLES USED IN THE ELECTRONIC DATABASE

RHINO DATA CODES

Format	Item Name	Details
N1	**RECORD-TYPE**	1=Mainlanes 2=Right Frontage 3=Left Frontage 4=Designated, but not built yet 5=County + Other Public roads 6=FC City Streets 7=Local Streets
N2	**DISTRICT-ID**	01 – 25
N4.3	**LENGTH-OF-SECTION**	00.001 – 99.999 (Calculated as To-DFO minus From-DFO)
N1	**RURAL-URBAN-CODE**	1=Rural (< 5000) 2=Small Urban (5000 – 49,999) 3=Large Urban (50,000 – 199,999) 4=Urbanized (200,000+)
N3	**NUMBER-OF-LANES**	Does not include turning or climbing lanes
N4	**ROW-WIDTH-USUAL**	001 – 999
N4	**SURFACE-WIDTH**	Does not include Shoulder-Widths
N1	**SHOULDER-TYPE-LEFT**	1=None 2=Surfaced 3=Stabilized-Surfaced with Flex 4=Combination-Surface/Stabilized 5=Earth-with or without turf
N3	**SHOULDER-WIDTH-LEFT**	000 - 999
N1	**SHOULDER-TYPE-RIGHT**	(See Shoulder-Type-Left)
N3	**SHOULDER-WIDTH-RIGHT**	(See Shoulder-Width-Left)
N3	**MEDIAN-WIDTH**	Does not include inside Shoulder Widths

PHINI DATA CODES

Column No.	Field Size	Decimal Place	Field Type	Item Name	Column Name	Definitions
91	2		N	ROADWAY-FEAT-CODE	RFC	25=Ferry 34=Structure 31=Connector 36=Tunnel 32=Ramp 41=Roadside Feature 33=Intersection 99=Other Feature
92	2		N	INT-FEAT-TYPE	INT_FTYP	11=On-System Mainlane 73=Culv to Left 21=Local Road 74=Culv to Right 31=On-System Frontage 75=Culv both 41=Federal Lands 80=Pipeline 51=State Lands 81=Transmission 61=Toll Road 82=Telephone 65=Crossover 83=Waterline 66=Turnaround Backwards 90=Ped Pass 67=Turnaround Forwards 91=Cattle Guard 70=Railroad Crossing 92=Gate 71=Stream Flowing to Left 93=Overhead Sign 72=Stream Flowing to Right 99=Other Int Feat
94	1		A	ROADWAY-FEAT-GRADE	RFG	U=Feature is Up above grade G=Feature is at Grade D=Feature is Down below grade
98	1		A	INT-TYPE	INT_TYPE	A=At Grade Intersection B=Grade-separated Intersection (no ramps/cons)

DPS CRASH DATA CODES

Item Name	Details
COLLISION	Movement of vehicle in other than motor-with-motor accidents: 01=Vehicle going straight 02=Vehicle turning right 03=Vehicle turning left 04=Vehicle backing 05=Other
ROADWAY	2=Off roadway on shoulder 3=Off roadway beyond shoulder
NUMVEHS	(Total number of vehicles involved in crash)
INTRSECT	4=Non-intersection
1STHARM	7=Fixed Object
OBJECT	09=Vehicle hit train on tracks parallel to road – no crossing 20=Vehicle hit highway sign 21=Vehicle hit curb 22=Vehicle hit culvert – headwall 23=Vehicle hit guardrail 24=Vehicle hit railroad signal pole or post 25=Vehicle hit railroad crossing gates 26=Vehicle hit traffic signal pole or post 27=Vehicle hit overhead (signal light, wires, signs, etc.) 29=Vehicle hit luminaire pole 30=Vehicle hit utility pole 31=Vehicle hit mailbox 32=Vehicle hit tree or shrub 33=Vehicle hit fence 34=Vehicle hit house, building, or building fixture 35=Vehicle hit commercial sign 36=Vehicle hit other fixed object 39=Vehicle hit median barrier 40=Vehicle hit end of bridge (abutment or rail end) 41=Vehicle hit side of bridge (bridge rail) 42=Vehicle hit pier or support at underpass, tunnel, or overhead sign bridge 43=Vehicle hit top of underpass or tunnel 44=Vehicle hit bridge crossing gate 45=Vehicle hit attenuation device

CRIS CRASH DATA CODES

Item Name	Details
COLLISION	01 OMV going straight 02 OMV turning right 03 OMV turning left 04 OMV backing 05 OMV other
ROAD_RELAT	2 Off roadway 3 Shoulder 4 Median
VEHCOUNT	(Total number of vehicles involved in crash)
INTRSCT_RELAT	4 Non-intersection
HARM _EVNT	7 Fixed Object
OBJECT	09 Hit train on tracks parallel to road – no crossing 20 Hit highway sign 21 Hit curb 22 Hit culvert – headwall 23 Hit guardrail 24 Hit railroad signal pole or post 25 Hit railroad crossing gates 26 Hit traffic signal pole or post 27 Hit overhead signal light (wires, signs, etc.) 29 Hit luminaire pole 30 Hit utility pole 31 Hit mailbox 32 Hit tree (shrub, landscaping) 33 Hit fence 34 Hit house (building or building fixture) 35 Hit commercial sign 36 Hit other fixed object 37 Hit bus stop structure (bench) 39 Hit median barrier 40 Hit end of bridge (abutment or rail end) 41 Hit side of bridge (bridge rail) 42 Hit pier or support at underpass (tunnel or overhead sign bridge) 43 Hit top of underpass or tunnel 44 Hit bridge crossing gate 45 Hit attenuation device 57 Hit delineator or marker post 58 Hit retaining wall 60 Hit guard post 61 Fire hydrant 62 Ditch 63 Embankment

APPENDIX B: DEFINITIONS OF ROADWAY DEPARTURE CRASHES

(Originally Published as Technical Memorandum #3)

INTRODUCTION

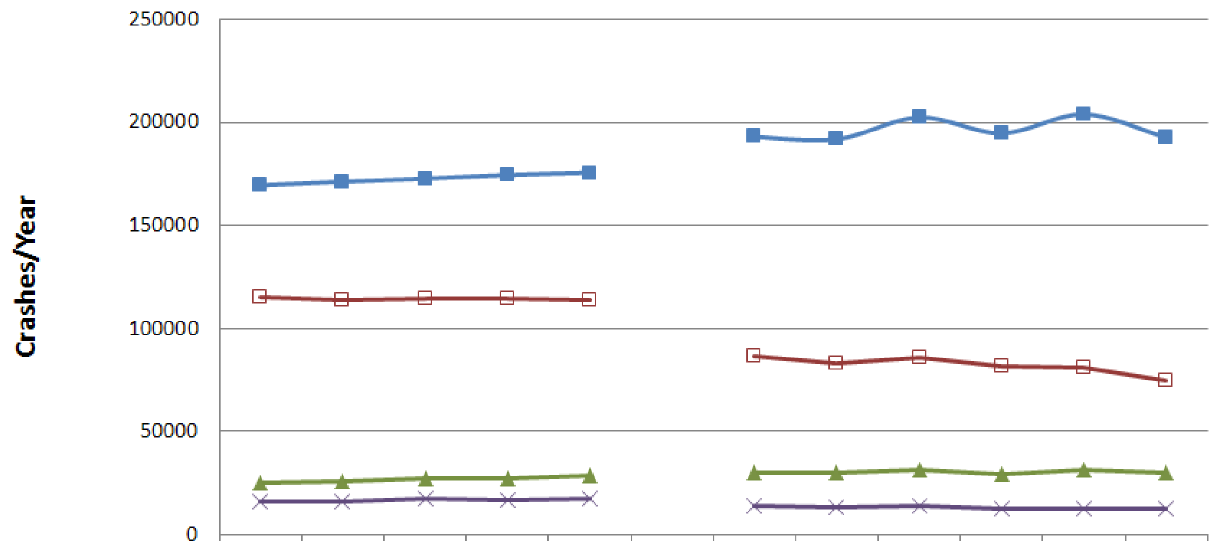
There is ongoing discussion in the areas of traffic engineering and safety about how to define a roadway departure, or run-off-road, crash. Many practitioners "know it when we see it," but applying a formal definition is much more complicated. Therefore, there are a number of definitions used by various state and federal agencies, researchers, and others to determine exactly what constitutes a roadway departure crash. The issue is more than an academic exercise, in that ROR crashes often result in serious injury or fatality, and they are the subject of many studies on safety treatments for locations or corridors with high crash rates. In fact, queries of the FARS database indicate that 50 to 80 percent of fatal crashes could be termed roadway departure crashes, depending on the definition used (*1*). Thus, determining the most appropriate definition of a roadway departure crash is important, not only within the scope of this research project, but in other safety applications as well. This technical memorandum will compare the number of crashes identified using different roadway departure definitions.

Crashes on Texas Highways

Technical Memorandum #2 described some of the annual trends of crashes on the Texas highway network, using the typical definition of a roadway departure crash as provided by TxDOT (*2*). Figure B-1 illustrates the number of crashes on the entire Texas highway system along with the number of crashes on two-lane rural roads. These crash numbers include all severity levels:

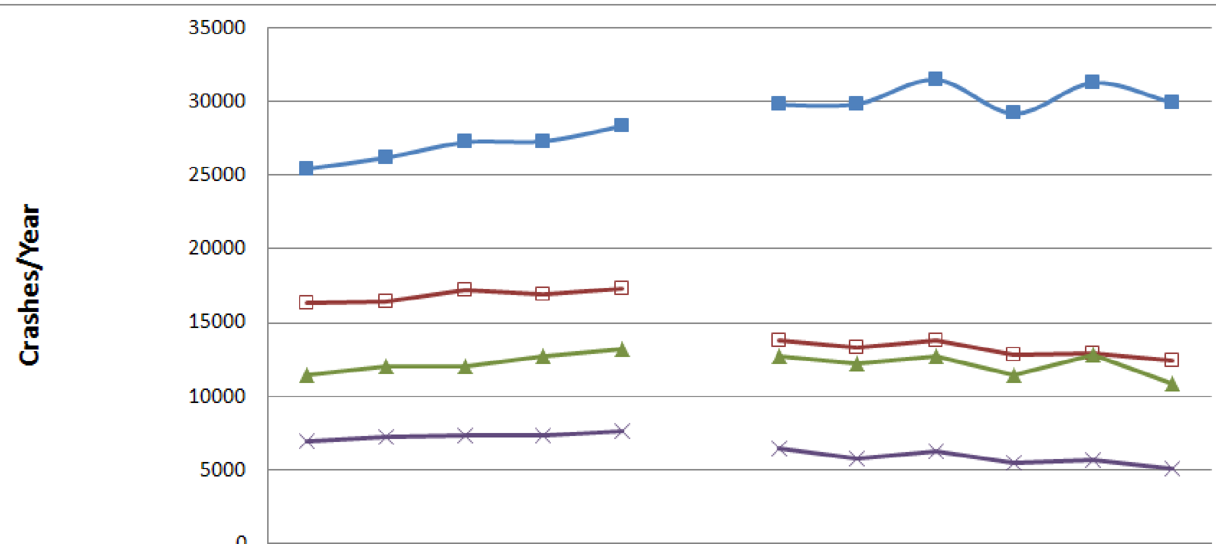
- Fatal (K).
- Incapacitating-injury (A).
- Non-incapacitating injury (B).
- Minor injury (C).
- Property damage only (O).

Figure B-2 illustrates the number of KABCO and KABC crashes on two-lane rural roads. The two figures show that there is an increase in the total number of KABCO crashes during the after period (2003–2008) while the total number of KABC crashes decreases compared with the before period (1997–2001), which means there is an increase in the number of property damage only (PDO) crashes for the after period. This increase in PDO collisions can be explained by the change in definition of a reportable collision. In the before period, reported PDO crashes only included those in which a vehicle was towed away from the site. In the after period, a reportable PDO crash included damages to a vehicle that were estimated to be at least $1,000.



	1997	1998	1999	2000	2001		2003	2004	2005	2006	2007	2008
TX KABCO	169520	171245	172730	174475	175582		193079	191847	202443	194722	203946	192664
TX KABC	115397	114098	114442	114220	113841		86513	83422	86107	81493	81065	74728
Rural 2-L KABCO	25436	26181	27227	27300	28337		29780	29836	31470	29183	31260	29940
Rural 2-L KABC	16342	16425	17242	16941	17287		13762	13256	13791	12819	12922	12400

Figure B-1. Annual KABCO Crashes on the Entire Texas Highway System and on Two-Lane Rural Roads.



	1997	1998	1999	2000	2001		2003	2004	2005	2006	2007	2008
Rural 2-L KABCO	25436	26181	27227	27300	28337		29780	29836	31470	29183	31260	29940
Rural 2-L KABC	16342	16425	17242	16941	17287		13762	13256	13791	12819	12922	12400
Rural 2-L ROR KABCO	11469	11984	12049	12756	13220		12704	12250	12671	11419	12825	10885
Rural 2-L ROR KABC	6975	7213	7360	7385	7633		6441	5823	6269	5512	5658	5057

Figure B-2. Annual KABCO and KABC Crashes on Two-Lane Rural Roads.

Description of Roadway Departure Definitions

As shown in Figure B-1, crashes on two-lane rural roads comprise about 15 percent of all crashes on the state highway system from 1997 to 2008. Further examination of two-lane rural road crashes reveals that about 40 to 50 percent of them are single-vehicle roadway departure crashes. While the approximate share of two-lane rural road crashes that are roadway departure crashes can be estimated, the issue is determining what definition of roadway departure best identifies the desired crashes.

In May 2009, the Federal Highway Administration revised their definition of roadway departure to be "a non-intersection crash which occurs after a vehicle crosses an edge line, a centerline, or otherwise leaves the traveled way" (*3*). A more thorough reading of the FHWA memorandum describing the new definition reveals the following explanation: "Fixed objects should not occur on the roadway, so it was determined that the crashes where these were indicated as the first event in the majority of cases should have had run-off-road or cross median as a first event" (*3*). The FHWA memorandum emphasizes that the "criteria used as a basis for this definition and for counting Roadway Departure fatal crashes more accurately reflects the focus of FHWA's Roadway Departure (RD) program. ... State DOT's are not being asked to change the methods they use for counting roadway departure crashes, or the similar grouping used by AASHTO and many States, called lane departure crashes. The new definition likely will align somewhat better with some States' criteria and less well with others."

The typical definition of a roadway departure crash, as provided by TxDOT and currently used within this project, uses the CRIS data for crashes with the following characteristics:

$collision \leq 5$ and $roadway$=2, 3, or 4

The *collision* values are defined by the codes pertaining to crashes other than motor-vehicle-to-motor-vehicle, and the roadway values are those that are reported to be other than on the travel lane of the roadway. This definition provides a simple, straightforward way to define a roadway departure crash, and it is fairly easy to search in both DPS and CRIS database.

As mentioned in the Introduction, there is a lack of a uniform definition on single-vehicle ROR crashes in the areas of traffic engineering and safety. Thus, comparing the differences between commonly used single-vehicle ROR crash definitions and identifying the variations in number of crashes for different roadway departure crash definitions is of value. Five commonly used definitions of single-vehicle roadway departure crash have been compared in this research project in addition to the current TxDOT definition. Table B-1 lists six potential definitions for single-vehicle ROR crashes.

Table B-1 Comparison of Roadway Departure Definitions.

Name	Criteria		Explanation of codes
	DPS[a] Data (1997–2001)	CRIS[b] Data (2003–2008)	
D1	• Collision ≤ 5 • Roadway =2, 3	• Collision ≤ 5 • Road_relat=2, 3, or 4	• Movement of vehicle in other than motor with motor crashes. • Crashes happened not on the travel lane of the roadway.
D2	• Numvehs=1 • Roadway =2, 3	• Veh_count=1 • Road_relat=2, 3, or 4	• Total number of vehicles involved in crashes is one. • Crashes happened not on the travel lane of the roadway.
D3	• Numvehs=1 • Intrsect =4 • Roadway =2, 3	• Veh_count=1 • Intrsect_relat=4 • Road_relat=2, 3, or 4	• Total number of vehicles involved in crashes is one. • Non-intersection related. • Crashes happened not on the travel lane of the roadway.
D4	• Numvehs=1 • Intrsect =4 • 1stharm=7 AND Object=9, 20-27, 29-36, 39-45	• Veh_count=1 • Intrsect_relat=4 • Harm_event=7 AND Object=9, 20-27, 29-37, 39-45, 57, 58, 60-63	• Total number of vehicles involved in crashes is one. • Non-intersection related. • First harmful event is striking a fixed object, and that fixed object is in a category listed in the FHWA definition.
D5	• Collision ≤ 5 • Intrsect =4 • Roadway =2, 3	• Collision ≤ 5 • Intrsect_relat=4 • Road_relat=2, 3, or 4	• Movement of vehicle in other than motor with motor crashes. • Non-intersection related. • Crashes happened not on the travel lane of the roadway.
D6	• Collision ≤ 5 • Intrsect =4 • 1stharm =7 AND Object=9, 20-27, 29-36, 39-45	• Collision ≤ 5 • Intrsect_relat=4 • Harm_event=7 AND Object=9, 20-27, 29-37, 39-45, 57, 58, 60-63	• Movement of vehicle in other than motor with motor crashes. • Non-intersection related. • First harmful event is striking a fixed object, and that fixed object is in a category listed in the FHWA definition.

[a] Based on the DPS codes (shown in Appendix A).
[b] Based on the CRIS codes (shown in Appendix A).

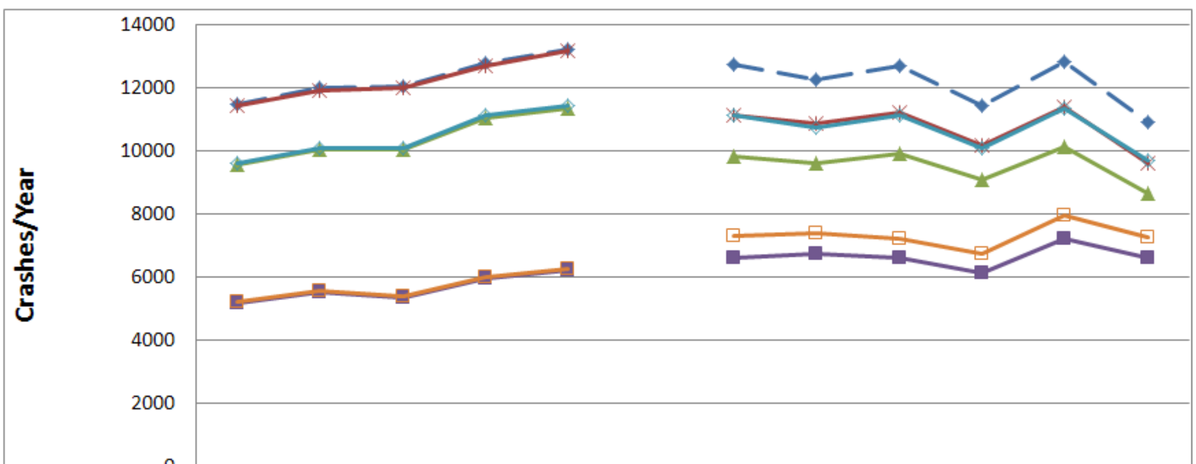
COMPARISON OF FINDINGS

This section describes the results of the comparison analysis for KABCO and KABC crashes.

ROR KABCO Crashes

Figure B-3 shows the annual number of single-vehicle ROR KABCO crashes and illustrates a comparison of the six definitions listed in Table B-1. The following conclusions can be made from Figure B-3:

- All six definitions show a similar trend in the annual number of single-vehicle ROR crashes. There is very little difference between three pairs: D1 and D2, D3 and D5, and D4 and D6, which is more obvious in the DPS dataset from 1997 to 2001. The *collision* variable generates a few more single-vehicle ROR crashes than the *veh_count* variable.
- The number of single-vehicle ROR crashes when using Definitions 3 and 5 is lower than Definitions 1 and 2, because intersection-related ROR crashes are not included.
- There is a much more noticeable reduction in the number of single-vehicle ROR crashes by using definitions 4 and 6, which returns about half of the crashes in the DPS database and two-thirds in the CRIS database as compared to D1 and D2.
- Because there is a larger difference between D1 and D2 (using *veh_count* and *collision* to define single-vehicle status, respectively) in the CRIS data from 2003-2008 than in the DPS data from 1997–2001, it is possible that the definition of *veh_count* or *collision* may have been applied differently in these two datasets.
- There seems to be larger year-to-year variation in the 2003–2007 period than the 1997–2001 period. This characteristic is observed for all roadway departure definitions.

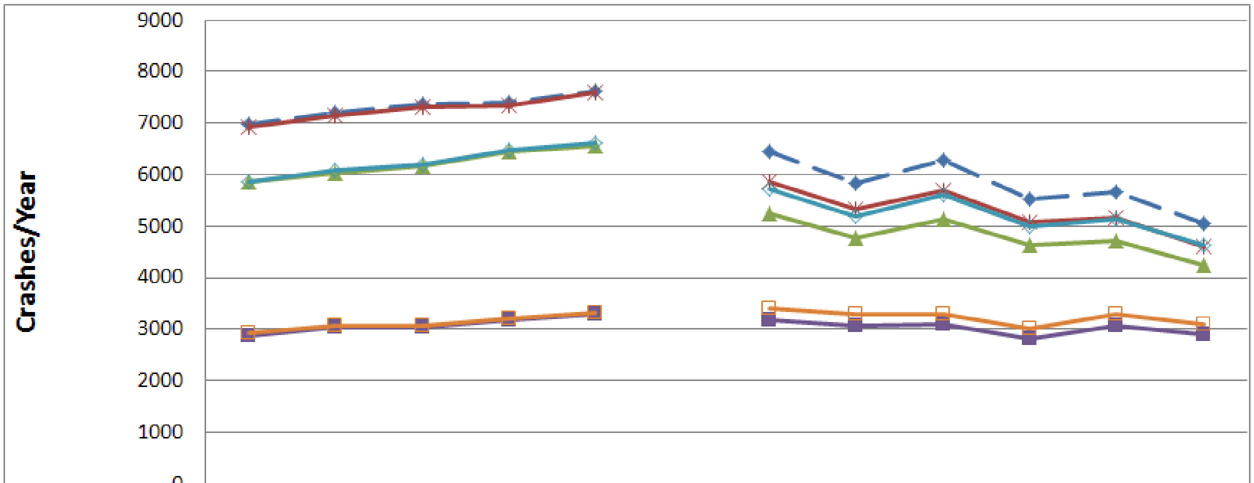


	1997	1998	1999	2000	2001		2003	2004	2005	2006	2007	2008
definition1	11469	11984	12049	12756	13220		12704	12250	12671	11419	12825	10885
definition2	11409	11917	11995	12687	13141		11126	10867	11197	10177	11371	9590
definition3	9565	10024	10037	11045	11343		9808	9583	9910	9057	10126	8630
definition4	5167	5504	5350	5933	6187		6614	6744	6608	6131	7214	6611
definition5	9614	10080	10082	11102	11407		11127	10729	11132	10071	11334	9679
definition6	5209	5544	5384	5976	6236		7288	7393	7224	6741	7946	7265

Figure B-3. Annual ROR KABCO Crashes on Two-Lane Rural Roads for Six Definitions.

ROR KABC Crashes

Figure B-4 shows the number of annual single-vehicle ROR KABC crashes using each definition. In comparison to Figure B-3, it can be seen that approximately 60 percent of the KABCO crashes in the DPS dataset are KABC crashes compared to about half in the CRIS dataset. The absence of PDO crashes in Figure B-4 reveals that there is a substantial decrease in the number of KABC crashes identified by most definitions in the years covered by the CRIS dataset, as compared to the period covered by the DPS dataset. The overall annual trend in Figure B-4, however, is very similar to that of KABCO crashes shown in Figure B-3.



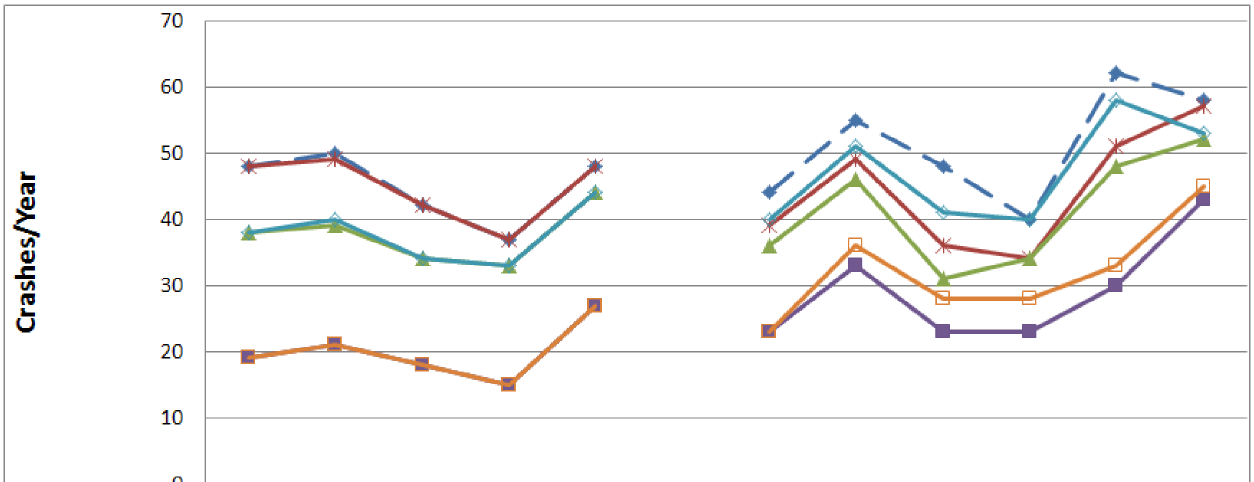
	1997	1998	1999	2000	2001		2003	2004	2005	2006	2007	2008
definition1	6975	7213	7360	7385	7633		6441	5823	6269	5512	5658	5057
definition2	6927	7159	7322	7340	7586		5856	5318	5688	5087	5175	4604
definition3	5861	6033	6172	6448	6566		5242	4759	5131	4630	4722	4243
definition4	2884	3029	3048	3187	3286		3182	3057	3097	2816	3061	2891
definition5	5857	6077	6205	6482	6608		5735	5189	5622	4993	5143	4628
definition6	2917	3057	3075	3211	3314		3409	3288	3303	3022	3293	3092

Figure B-4. Annual ROR KABC Crashes on Two-Lane Rural Roads for Six Definitions.

ROR KABCO and KABC Crashes on Nine Sites

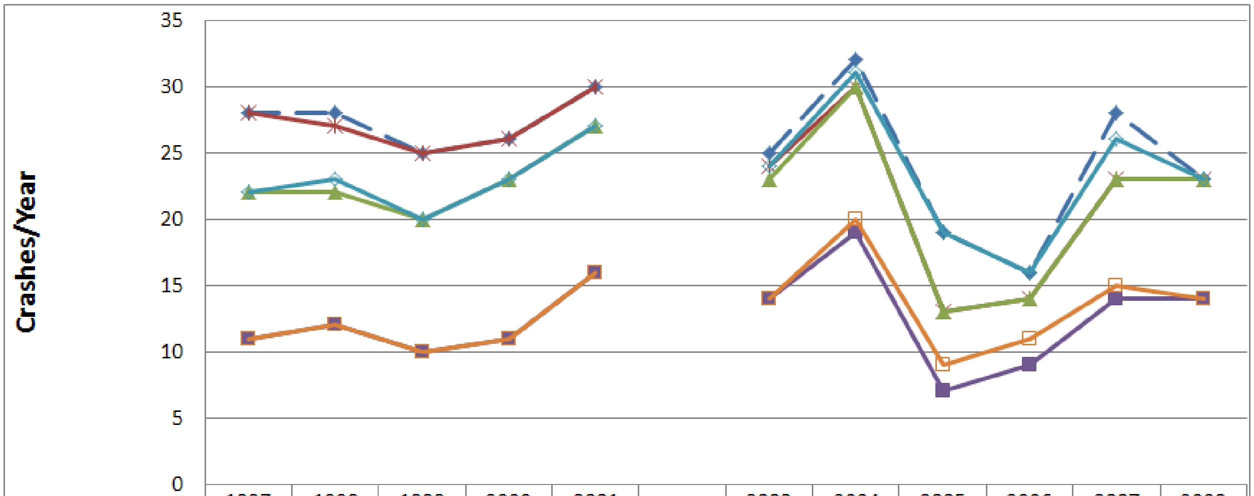
As reported above, the research team previously selected two districts familiar to the team or the previous project director. Within those districts, nine specific sites on which the number of crashes were relatively high during the ten-year study period were selected and then rural two-lane highways were identified that would result in a reasonable data collection route.

Figures B-5 and B-6 show the comparison of annual single-vehicle ROR crashes at the nine sites using each definition for KABCO and KABC crashes, respectively. The trend is similar to ROR crashes discussed in Figures B-3 and B-4. The number of ROR crashes in the DPS dataset is nearly identical whether using *collision* or *veh_count*. In addition, the number of ROR crashes using D3 and D5 are similar to those using D1 and D2, which means that most ROR crashes at these sites are not occurring at intersections.



	1997	1998	1999	2000	2001		2003	2004	2005	2006	2007	2008
definition1	48	50	42	37	48		44	55	48	40	62	58
definition2	48	49	42	37	48		39	49	36	34	51	57
definition3	38	39	34	33	44		36	46	31	34	48	52
definition4	19	21	18	15	27		23	33	23	23	30	43
definition5	38	40	34	33	44		40	51	41	40	58	53
definition6	19	21	18	15	27		23	36	28	28	33	45

Figure B-5. Annual ROR KABCO Crashes on Nine Two-Lane Rural Road Sites for Six Definitions.



	1997	1998	1999	2000	2001		2003	2004	2005	2006	2007	2008
definition1	28	28	25	26	30		25	32	19	16	28	23
definition2	28	27	25	26	30		24	30	13	14	23	23
definition3	22	22	20	23	27		23	30	13	14	23	23
definition4	11	12	10	11	16		14	19	7	9	14	14
definition5	22	23	20	23	27		24	31	19	16	26	23
definition6	11	12	10	11	16		14	20	9	11	15	14

Figure B-6. Annual ROR KABC Crashes on Nine Two-Lane Rural Road Sites for Six Definitions.

DISCUSSION

This section presents a discussion about the key variables used to extract and compare the data as well as the differences observed between the variables used in the DPS and CRIS databases.

Discussion on Variables *collision* and *veh_count*

The definition of *veh_count* is the total number of vehicles involved in a crash, regardless if they were in the first impact. There are some single-vehicle ROR crashes that cannot be identified according to this variable for the reason that a single-vehicle running off the road and colliding with another vehicle will not be identified as a single-vehicle ROR crash while in fact it is.

The *collision* variable is used to show the manner of collision and vehicular movements in crashes. It more accurately reflects the total number of single-vehicle ROR crashes compared to *veh_count* because it includes some crashes that cannot be identified using *veh_count*.

Discussion on DPS Codes and CRIS Codes

In general, the codes and variables in both datasets considered in this report are very similar, but some key differences should be noted:

- There are only three possible values for the *roadway* variable in the DPS database while there are six values in CRIS. For example, crashes occurring on a median are labeled as such in CRIS codes.

- Values for "not applicable" and "not reported" crash variables are available in the CRIS database, but not in DPS.
- Based on the annual crash totals shown in Figure B-3, the definition (or the application) of *collision* or *veh_count* in DPS codes and CRIS codes may be different, although it cannot be determined from the description of the variables, which are reproduced in the appendices.

Discussion on Printed Crash Reports from Nine Sites

Following the comparison of definitions for the nine sites selected for more detailed investigation, the research team reviewed the printed crash reports at those sites for the periods 1999–2001 and 2005–2007. In the opinion of the researchers, approximately half of the crashes occurring at the nine sites in each year are not single-vehicle ROR crashes (see Table B-2). Based on the narratives and diagrams submitted by the reporting officers, the non-ROR crashes tend to be those where vehicles do come to rest outside of the travel lane (not necessarily beyond the shoulder), but the cause was a multiple-vehicle collision (often due to an inappropriate turning or passing maneuver) or contact with animals or debris in the roadway. Table B-2 summarizes a comparison of crashes identified through Definition 1 (D1) and through the research team's review of the crash reports.

Table B-2. Comparison of ROR KABCO Crash Totals between D1 and Report Review.

	1999	2000	2001	2005	2006	2007
Crashes by Definition						
Total Crashes Recorded	84	76	89	100	85	119
ROR Crashes Identified by D1	**42**	**37**	**48**	**48**	**40**	**62**
ROR as Percent of Total	50	49	54	48	47	52
Crashes by Printed Report						
Total Printed Reports Available	83	28	85	100	83	117
ROR Crashes Identified by Review of Printed Report	**34**	**14**	**47**	**43**	**40**	**59**
ROR as Percent of Total	42	50	56	43	48	51
ROR Crashes Identified by D1 but Not Printed Report Review	8	0	3	10	2	7
ROR Crashes Identified by Printed Report Review but Not D1	1	0	2	5	2	5

Table B-2 shows that the annual totals of single-vehicle ROR crashes between D1 and the report review are similar for years in which most of the printed reports are available, and ROR crashes as a percent of total crashes are consistently between 40 and 60 percent. For crashes identified by D1 and not the report review, common causes were that the crash did not occur on a two-lane rural highway (a specific criterion for this project but otherwise valid); the crash was intersection-related; or that there was a collision with another vehicle, an animal, or debris in the roadway. For crashes identified only by the report review, the causes tended to be a single-vehicle that left the roadway after losing control in a curve, because of a fishtailing trailer, or due to a vehicle defect (e.g., tire blowout), or due to a driver action or condition (e.g., DWI, distracted driver).

Results from the printed report review suggest that a definition of ROR should require that the first object struck (or first event in the sequence of events) is not a collision with another motor vehicle in the travel lane. Some ROR crashes are caused by avoidance of animals or of other vehicles, while other ROR crashes tend to involve a driver negotiating a curve too fast and overcorrecting; these are legitimately labeled as ROR crashes, but are sometimes more difficult to identify in the electronic crash database.

The report review also indicates that ROR crashes can occur at intersections but should not be intersection-related. If a driver happens to leave the roadway near an intersection or driveway, and the same maneuver would cause the vehicle to leave the road at another location not near an intersection or driveway, that is a legitimate ROR crash; however, if the crash involves someone failing to properly execute a turn at an intersection, it is not truly an ROR crash. Similarly, there could be more than one vehicle involved in a "single-vehicle" ROR crash, as long as the causal factor is not a collision that causes the vehicle to leave the road; for example, a vehicle could leave the road, then return to the road after overcorrecting, and collide with another vehicle. The sequence of events becomes important in these crashes, rather than the number of vehicles. Again, these crashes are more difficult to identify in the database by reviewing electronic codes.

CONCLUSIONS

Based on the findings from comparing possible definitions and reviewing printed crash reports for selected high-crash locations, the research team reached the following conclusions:

- Run-off-road crash definitions D1, D5, and D6 have a sensible basis because they identify the manner of collision instead of the number of vehicles involved. They allow for the possibility that a single-vehicle leaving the roadway may strike a parked vehicle or otherwise include a second vehicle, even though the crash is still formally a single-vehicle crash. However, D5 and D6 do not identify non-turning vehicles that depart the roadway near an intersection or driveway.
- There is some benefit to the FHWA approach of listing the legitimate objects to be struck in a single-vehicle ROR crash, but there is a concern that definitions using the FHWA approach will not identify crashes that do not have an applicable code in DPS/CRIS, which places D4 and D6 at a disadvantage.
- As used in this investigation, D1 was the most inclusive definition, identifying at least as many crashes as any other definition studied. However, D1 seems to include too many intersection-related crashes and on-road crashes where vehicles come to rest on the shoulder. D1 also seems to underreport crashes involving loss of control while in a curve or due to a fishtailing trailer.
- In terms of the best results for the easiest input, D1 is easily preferable over the other definitions studied, and it would seem to return results that are sufficient for evaluations that involve statewide or even district-wide searches; however, a more refined definition involving extensive use of contributing factors, first harmful events, relation to intersection, objects struck, and other factors could be beneficial for a more localized crash study, to the extent that the relevant variables in DPS/CRIS exist.

REFERENCES

1. Queries of the Fatality Analysis Reporting System (FARS). http://www-fars.nhtsa.dot.gov/main/index.aspx. National Highway Traffic Safety Administration, Washington, DC. August 2009.
2. *Comparison Analysis: 1997-2001 and 2005-2007 Time Periods*. TxDOT Project 0-6031 Technical Memorandum #2, July 2009.
3. *Updated Roadway Departure Definition, Related Crash Data, and Implementation*. Memorandum to FHWA Division Administrators from Office of Safety Design. Federal Highway Administration, Washington, DC. May 22, 2009.

APPENDIX C: CHARACTERISTICS OF KEY HIGHWAY AND OPERATIONAL FEATURES FOR THE FOUR DISTRICTS

INTRODUCTION

The process of collecting and processing site characteristics and geometric data for field study sites was a multifaceted one, with much more detail than was described in Chapter 3. This appendix provides further description of the characteristics of important geometric design features for each district.

FIELD SIDE SLOPE RATING COMPARISON FOR EACH DISTRICT

The sideslope rating presents a way to estimate the hazard associated the roadside area poses to a driver who runs off the road. As discussed in Chapter 3, sideslope ratings were assigned on a five-point scale, and they are described as follows:

1. Little grade, if any; generous area to correct for an errant vehicle.
2. Some rise or fall with low grade, but still highly correctible at highway speeds.
3. Definite rise or fall with moderate grade, (e.g., drainage ditch), probably not correctible at moderate to high speeds, good possibility for non-injury.
4. Definite rise or fall with high grade and possible guardrail, similar to bridge over a shallow creek: not correctible, and high chance of B injury at highway speed.
5. High grade and significant elevation change, such as a cut into a cliff; not correctible and high chance of KA injury at highway speed.

The figures shown in this section of the appendix illustrate the distribution of sideslope ratings for each district. The data were collected on both sides of the traveled-way. These figures show that the distribution of sideslope ratings for both sides of the traveled-way is very similar within each district. The sideslope conditions for the segments in the Odessa District have the least severe average ratings with most of the ratings being equal to 2. The majority of the sideslope ratings for segments located in the Lufkin and Atlanta Districts are between 2 and 3. The sideslope conditions for segments located in San Angelo District have the most severe ratings, with many segments having a rating equal to 4 or 5.

Figures C-1 and C-2 show the distribution of sideslope ratings in the Odessa District for the left side and right side of the traveled way, respectively. Researchers collected 118 observations in the Odessa District. Figures C-3 and C-4 show the left-side and right-side ratings distributions for the San Angelo District, based on 817 observations. Figures C-5 and C-6 plot sideslope distributions for the 463 observations in the Atlanta District, and Figures C-7 and C-8 provide corresponding information for the 241 sideslope ratings at Lufkin District sites.

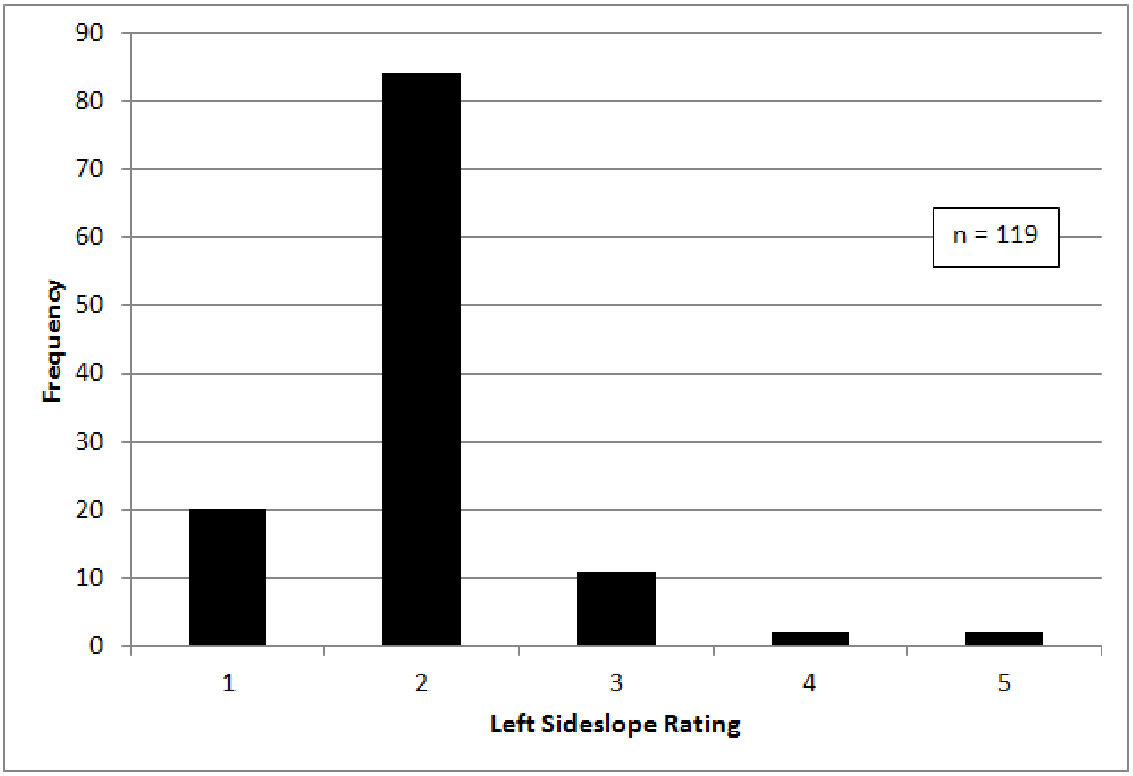


Figure C-1. Distribution of Left Sideslope Ratings for Segments in the Odessa District.

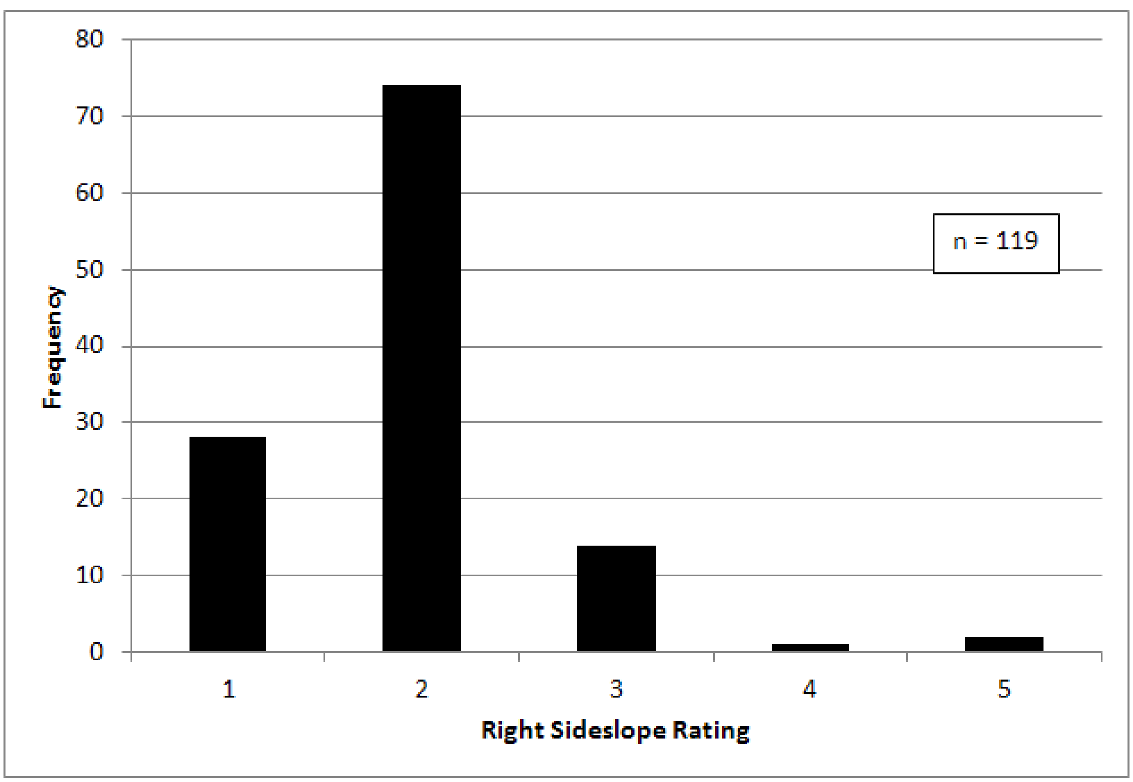


Figure C-2. Distribution of Right Sideslope Ratings for Segments in the Odessa District.

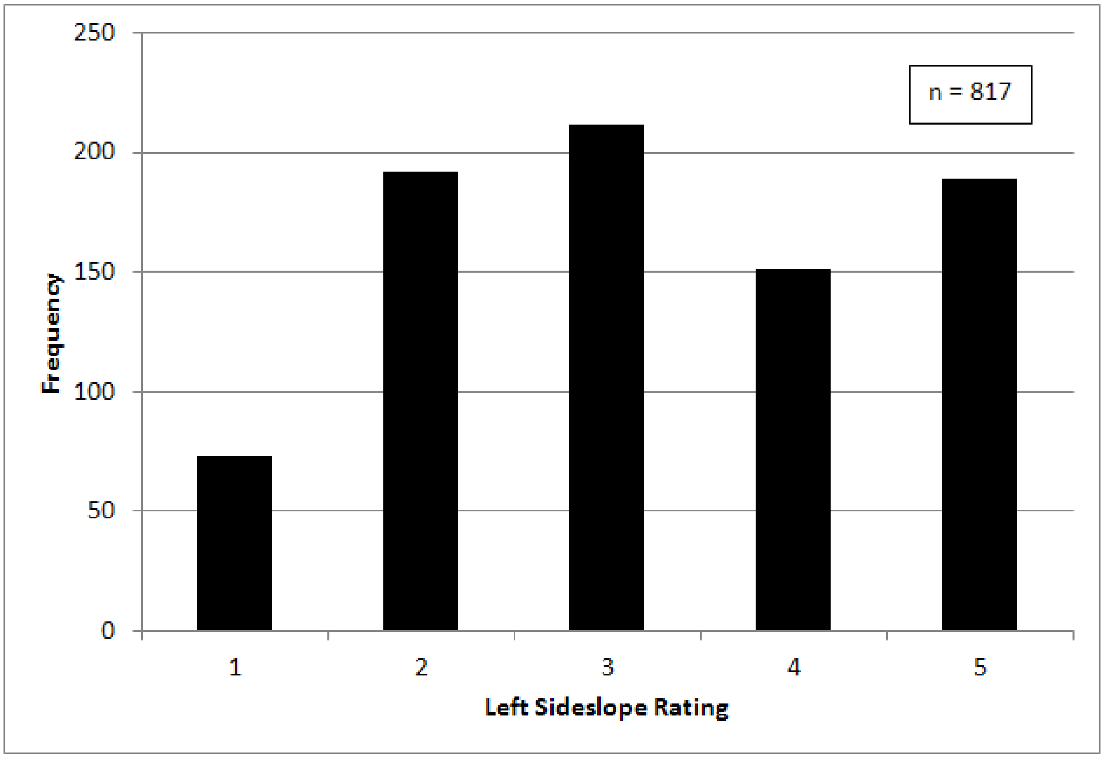


Figure C-3. Distribution of Left Sideslope Ratings for Segments in the San Angelo District.

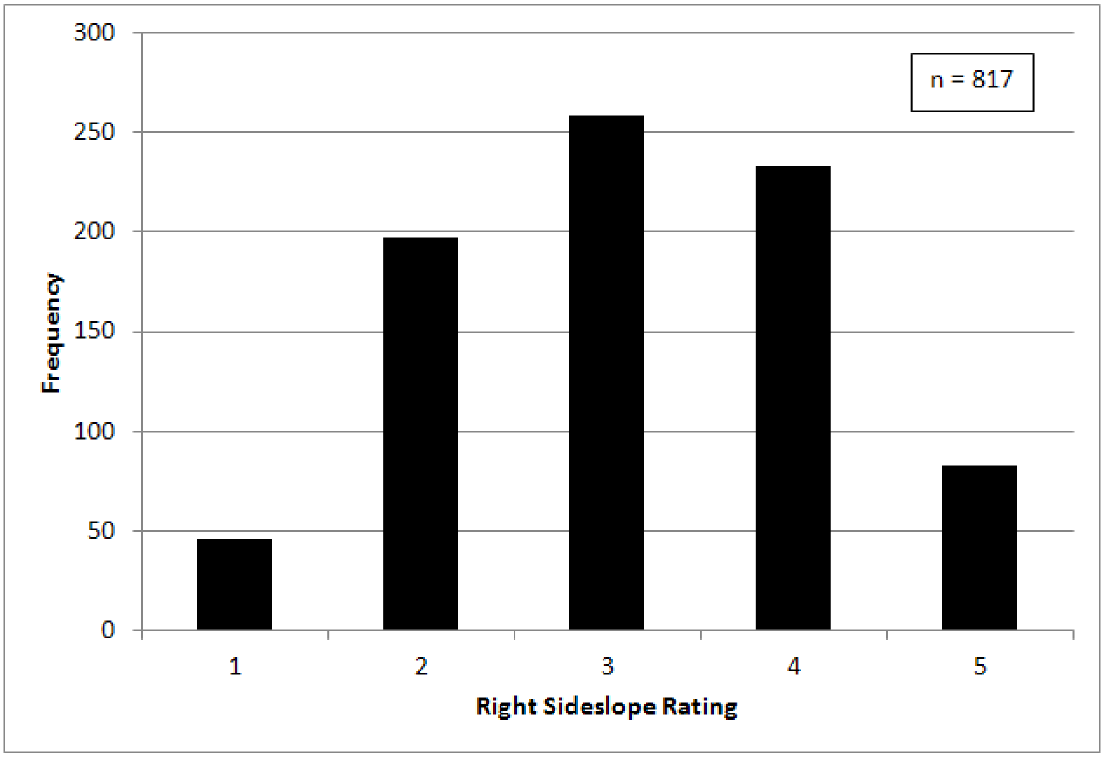


Figure C-4. Distribution of Right Sideslope Ratings for Segments in the San Angelo District.

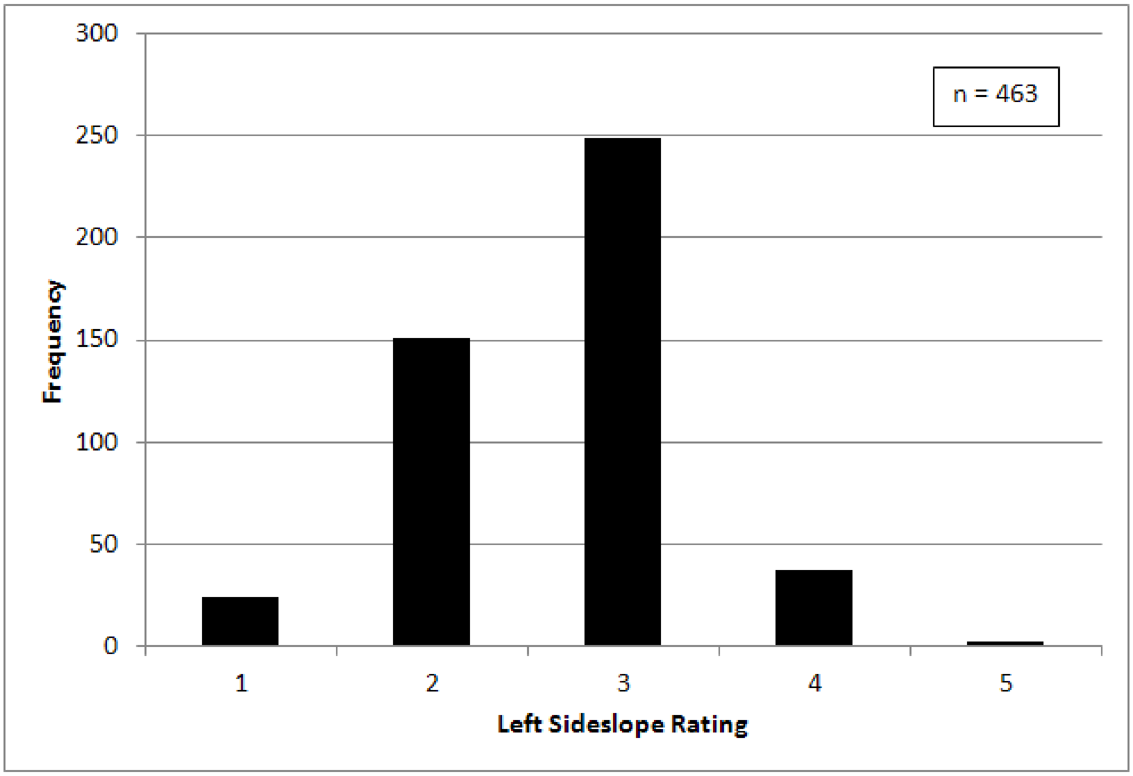


Figure C-5. Distribution of Left Sideslope Ratings for Segments in the Atlanta District.

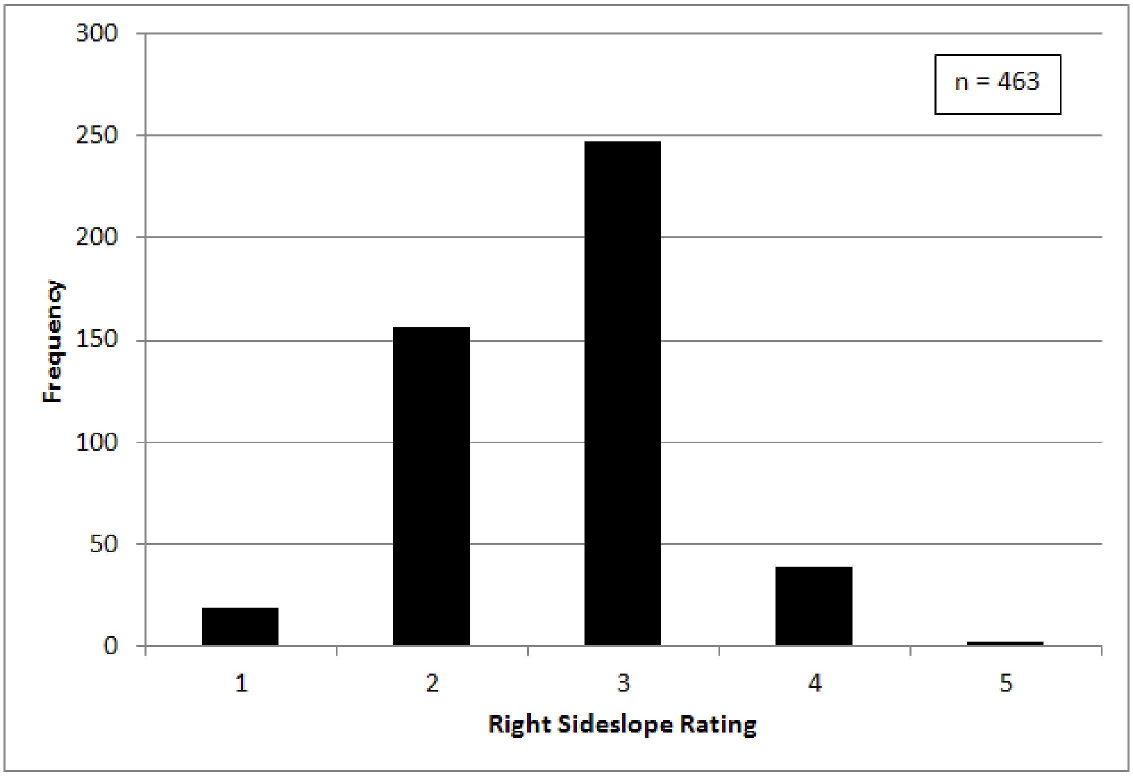


Figure C-6. Distribution of Right Sideslope Ratings for Segments in Atlanta District.

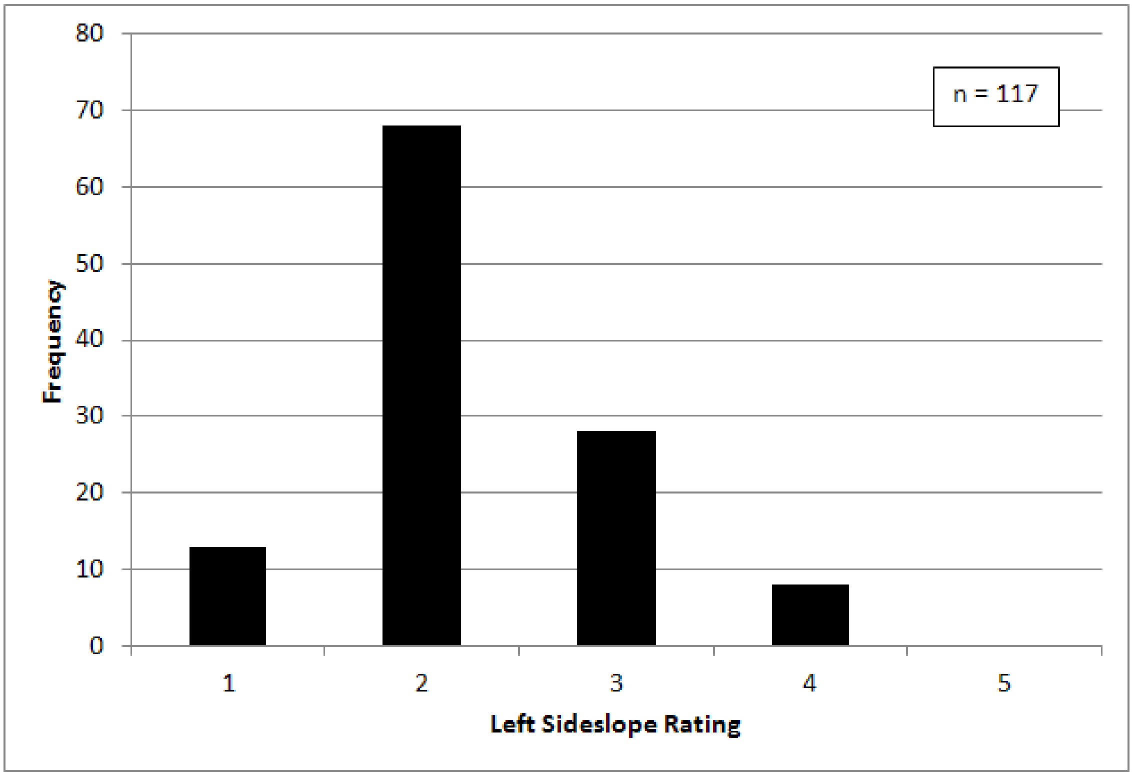


Figure C-7. Distribution of Left Sideslope Ratings for Segments in the Lufkin District.

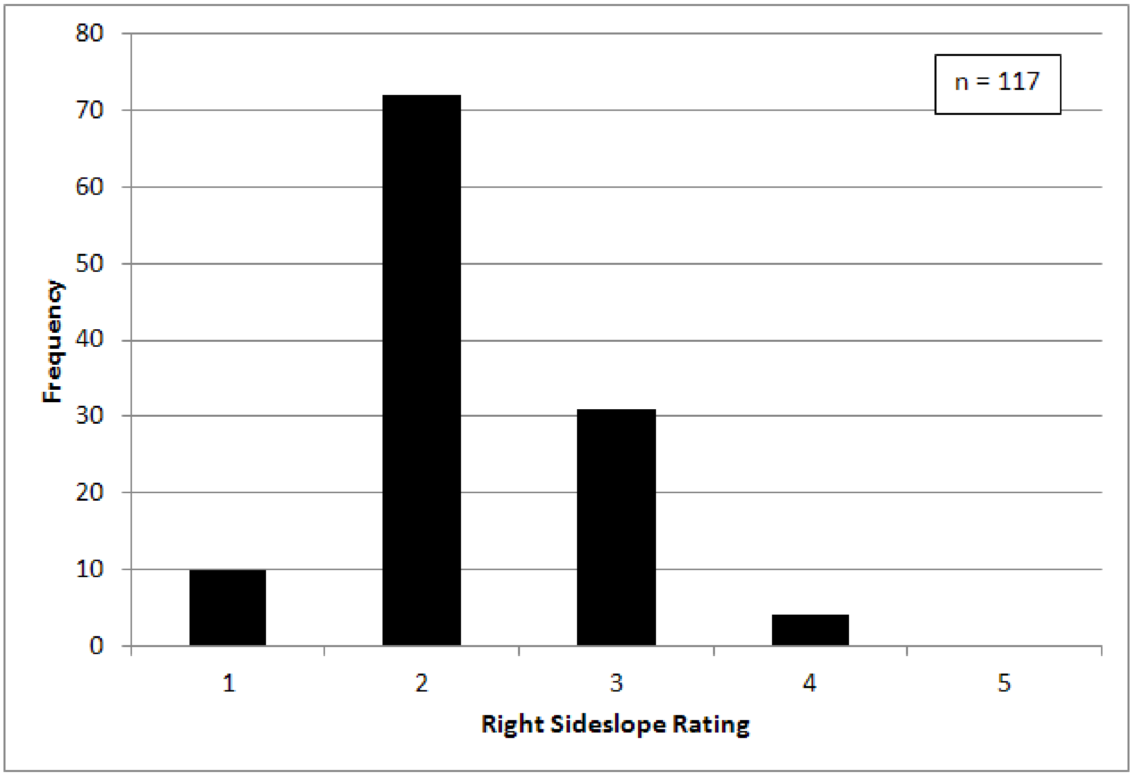


Figure C-8. Distribution of Right Sideslope Ratings for Segments in the Lufkin District.

LATERAL CLEARANCE COMPARISON FOR EACH DISTRICT

Figures C-9 through C-12 show the distribution of lateral clearance distances for each district. These figures show that the average lateral clearance distance in Odessa is the largest, with most of the observations between 30 and 50 ft. For the San Angelo and Atlanta Districts, most of the clearance distances are between 20 and 30 ft, but there is also a large portion of segments with clearance distances below 10 ft. Most of the observations in the Lufkin District have a clearance distance between 20 and 40 ft.

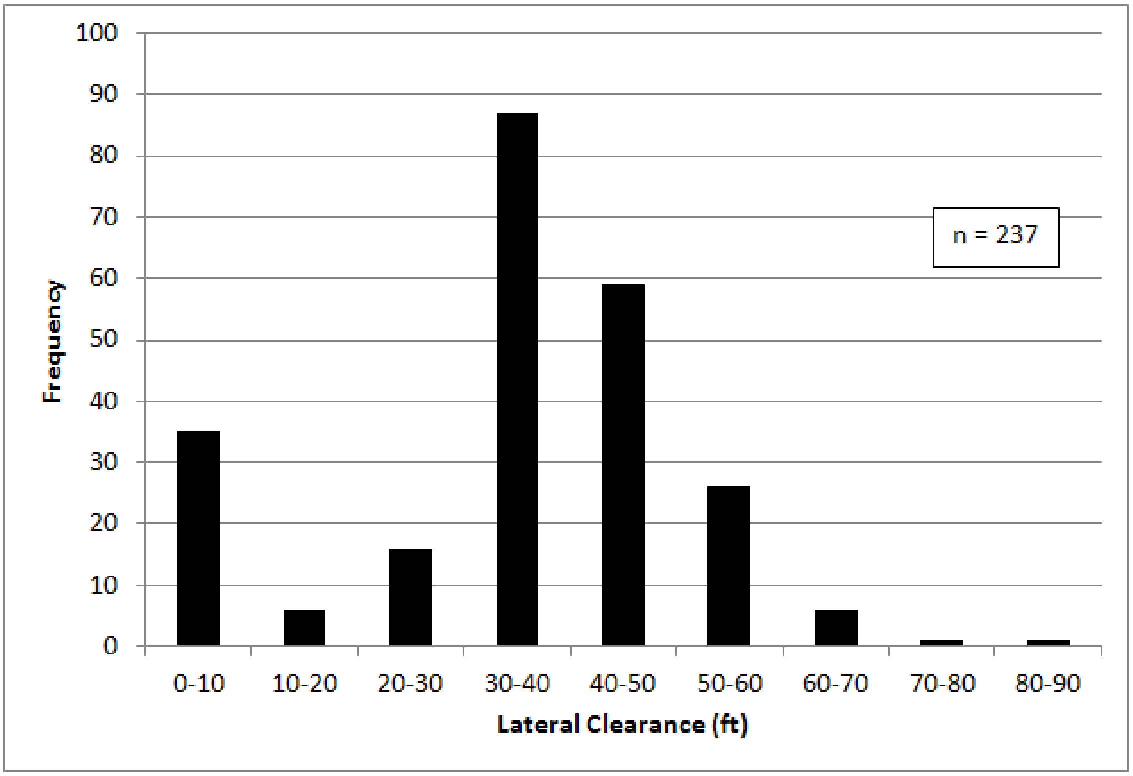


Figure C-9. Distribution of Lateral Clearance Distances in the Odessa District.

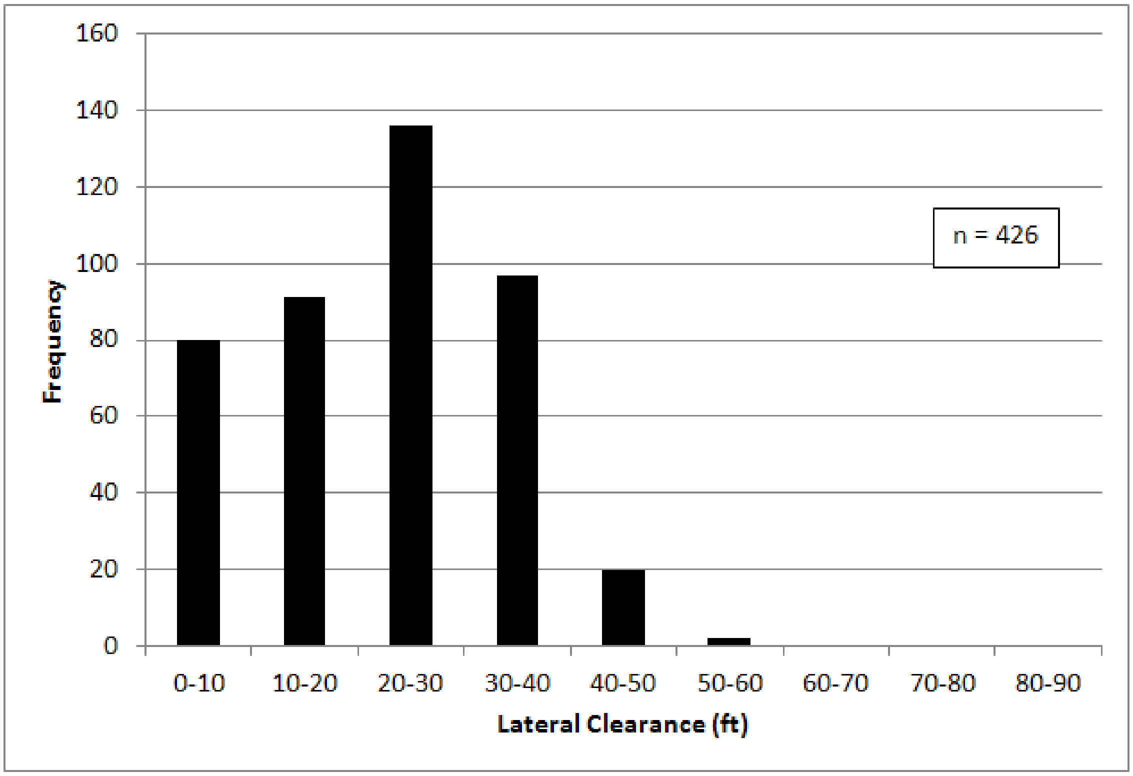


Figure C-10. Distribution of Lateral Clearance Distances in the San Angelo District.

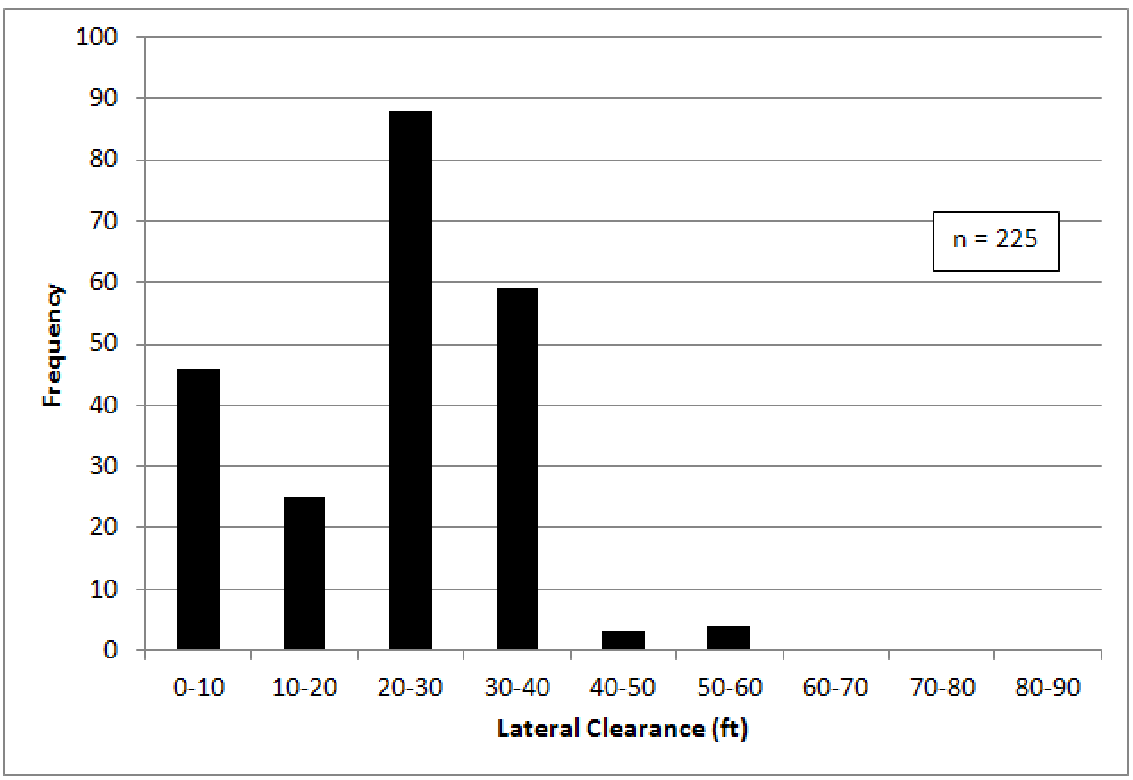


Figure C-11. Distribution of Lateral Clearance Distances in the Atlanta District.

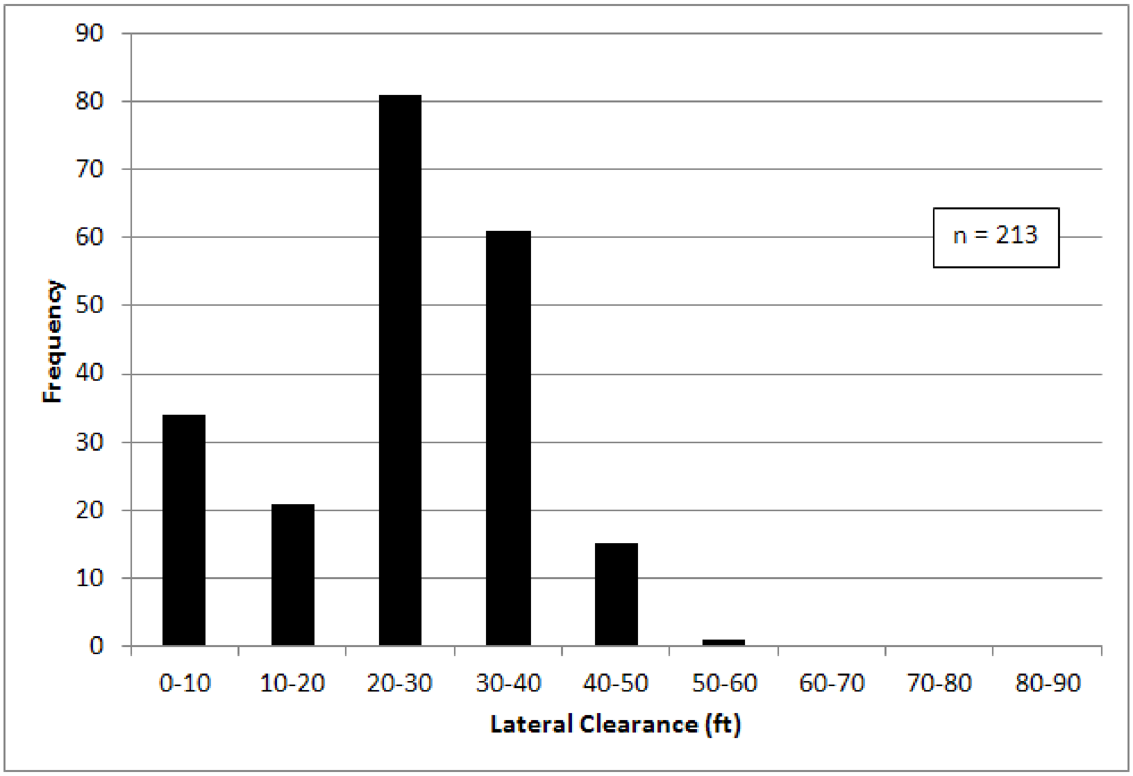


Figure C-12. Distribution of Lateral Clearance Distances in the Lufkin District.