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16. Abstract The selection of the cross section for a roadway is a critical decision in the design process. This decision substantially impacts safety, capacity, and cost. Although capacity and cost considerations are generally readily evaluated, the impact of the cross section on safety is not always apparent. Lane width and shoulder width can have a significant impact on safety of rural two-lane and four-lane highways. Prediction models were used to generate estimates of the percent change in crashes between different shoulder or lane width decisions. These values can be used when evaluating alternatives. The prediction equations can also be used to identify the mean crash value over roadway segments of similar conditions. An upgrade for a rural two-lane highway to a rural four-lane divided highway with full shoulders can provide significant crash reductions. A conversion from a two-lane with wide shoulder cross section to a four-lane with narrow shoulder cross section should be considered only at very high average daily traffic counts and wide surface widths based on safety. Several variables were found through the literature and through this research that affect crash prediction at rural intersections. Those elements that can be influenced by designers with the greatest benefits in decreasing crashes include left-turn lanes, lighting, and wider right shoulders.					
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COMPARISONS OF CRASHES ON RURAL TWO-LANE AND FOUR-LANE HIGHWAYS IN TEXAS

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DISCLAIMER

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 Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. The engineer in charge was Kay Fitzpatrick, P.E. (TX-86762).

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TABLE OF CONTENTS

	Page
DISCLAIMER.....	v
ACKNOWLEDGMENTS	vi
LIST OF FIGURES	ix
LIST OF TABLES	xi
CHAPTER 1: INTRODUCTION.....	1
RESEARCH OBJECTIVES	1
ORGANIZATION	2
CRASHES VERSUS ACCIDENTS.....	3
CHAPTER 2: REVIEW OF PREVIOUS RESEARCH.....	5
SAFETY EFFECT OF CHANGE IN CROSS SECTION	5
SAFETY EFFECT OF WIDENING LANES AND SHOULDERS	9
RURAL INTERSECTIONS	13
CHAPTER 3: COLLECTION OF FIELD DATA	19
PROCEDURE.....	19
ROADWAY SEGMENT SITE SELECTION.....	19
INTERSECTION SITE SELECTION.....	22
DATA COLLECTION EQUIPMENT	23
PRE-DATA COLLECTION PROCEDURE.....	25
FIELD DATA COLLECTION PROCEDURE	27
CHAPTER 4: REDUCTION OF FIELD DATA	29
DESCRIPTION OF ROADWAY SEGMENT DATASET	29
TWO-LANE OR FOUR-LANE HIGHWAY PERFORMANCE	34
COMPARISON OF TWO-LANE AND FOUR-LANE HIGHWAYS	34
DESCRIPTION OF INTERSECTION DATASET.....	35
ADDITION OF CRASH RECORDS TO INTERSECTION DATASET	39
CHAPTER 5: CRASH PREDICTION FOR RURAL TWO-LANE HIGHWAYS	41
OVERVIEW	41
CRASHES.....	41
DATA	41
MODELS	42
COMPARISON BETWEEN ACTUAL DATA AND PREDICTED VALUES	51
EFFECTS OF VARIABLES	53
RATIO	54
COMPARISON WITH TOTAL CRASHES AND KAB CRASHES.....	61
WIDEN SHOULDER OR WIDEN LANE FIRST?.....	67
CHAPTER 6: CRASH PREDICTION FOR RURAL FOUR-LANE HIGHWAYS.....	69
OVERVIEW	69
CRASHES AND DATA.....	69
MODELS	72
COMPARISON BETWEEN ACTUAL DATA AND PREDICTED VALUES	78
EFFECTS OF VARIABLES	80
RATIO	80

COMPARISON WITH TOTAL CRASHES AND KAB CRASHES.....	87
CHAPTER 7: FINDINGS FROM COMPARISON OF CRASHES ON 44- TO 54-FT	
SURFACE WIDTH	93
OVERVIEW	93
CRASHES.....	93
DATA	94
MODELS	95
TOTAL CRASHES AND KAB CRASHES	107
COMPARISON	107
CHAPTER 8: CRASH PREDICTION FOR RURAL INTERSECTIONS	115
OVERVIEW	115
CRASHES AND DATA.....	115
MODELS	123
CRASH PREDICTION FOR INTERSECTIONS WITH CROSS-ROAD ADT.....	123
CRASH PREDICTION FOR ALL INTERSECTIONS	127
CHAPTER 9: SUMMARY AND CONCLUSIONS	133
SUMMARY OF RESEARCH.....	133
CONCLUSIONS.....	140
APPENDIX: SUGGESTIONS ON MATERIAL FOR REFERENCE DOCUMENTS.....	143
POTENTIAL MATERIAL FOR CHAPTER 3 <i>ROADWAY DESIGN MANUAL</i>	143
POTENTIAL MATERIAL FOR CHAPTER 4 <i>ROADWAY DESIGN MANUAL</i>	151
POTENTIAL MATERIAL FOR SAFETY REFERENCES	151
REFERENCES.....	155

LIST OF FIGURES

	Page
Figure 2-1. All Crashes for Different Roadway Cross Sections (7).....	8
Figure 2-2. Nonintersection Crashes for Different Roadway Cross Sections (7).....	8
Figure 2-3. Accident Modification Factors for Shoulder Width (2).....	11
Figure 2-4. Accident Modification Factors for Lane Width (2).	12
Figure 2-5. Example of Left-Turn Lanes.....	15
Figure 3-1. Districts with Roads Included in Dataset.....	20
Figure 3-2. Example of Video Camera Mounted on Windshield.....	23
Figure 3-3. Example of DMI and Video Recording System along with Text Box of Information Recorded on the Video.....	24
Figure 3-4. View of the Calibration Grid from the Video Camera.....	26
Figure 3-5. Schematic of the Experimental Setup Used to Calibrate the Research Vehicle.	27
Figure 5-1. Distribution of Variables per Number of Miles for Rural Two-Lane Highway Dataset.....	43
Figure 5-2. Comparison of Results from Prediction Equation to Actual Data for Roadway Segments with ADT Greater Than 2000.	52
Figure 5-3. Comparison of Results from Prediction Equation to Actual Data for Roadway Segments with ADT 2000 or Less.....	52
Figure 5-4. Comparison of Results from Prediction Equation by Shoulder Width for a Range of ADT Values.	53
Figure 5-5. Comparison of Results from Prediction Equation by Lane Width for a Range of ADT Values.....	54
Figure 5-6. Plot of Ratios for Lane Width and Shoulder Widths for Rural Two-Lane Highways.	55
Figure 5-7. Comparison of Texas Findings to <i>Draft Prototype Chapter</i> for Shoulder Width.....	59
Figure 5-8. Comparison of Texas Findings to <i>Draft Prototype Chapter</i> for Lane Width.....	61
Figure 5-9. Comparison of Total Crash to SWIC for Shoulder Width.....	63
Figure 5-10. Comparison of Total Crash to SWIC for Lane Width.	64
Figure 5-11. Comparison of Total Crash KABs and SWIC KABs to Total Crashes and SWICs for Shoulder Width.	65
Figure 5-12. Comparison of Total Crash KABs and SWIC KABs to Total Crashes and SWICs for Lane Width.....	65
Figure 6-1. Distribution of Crashes by Mile for Rural Four-Lane Highway Dataset.....	70
Figure 6-2. Distribution of Variables by Mile for Rural Four-Lane Highway Dataset.	71
Figure 6-3. Comparison of Results from Prediction Equation to Actual Data for Roadway Segments with ADT Less Than 5000.....	79
Figure 6-4. Comparison of Results from Prediction Equation to Actual Data for Roadway Segments with ADT Greater than 5000.....	79
Figure 6-5. Comparison of Results From Prediction Equation by Shoulder Width for a Range of ADT Values.....	80
Figure 6-6. Plot of Ratios for Shoulder Widths for Rural Four-Lane Highways Based on SWICs.	81
Figure 6-7. Comparison of Ratios.....	82
Figure 6-8. Comparison of Texas Findings to <i>Draft Prototype Chapter</i> for Shoulder Width.....	86

Figure 6-9. Comparison of Total Crash to SWIC for Shoulder Width.....	88
Figure 6-10. Comparison of Total Crash KABs and SWIC KABs to SWICs for Shoulder Width.	91
Figure 7-1. Distribution of Variables per Mile by Number of Lanes.....	96
Figure 7-2. Comparison of SWIC Predictions for Two-Lane and Four-Lane Highways (10 mile Segment and ADT of 6000).....	109
Figure 7-3. Examples of Predicted Number of Annual SWICs by Surface Width for Different ADT Levels.....	110
Figure 7-4. Comparison of Total Crash Predictions for Two-Lane and Four-Lane Highways (10- mile Segment and ADT of 6000).....	112
Figure 7-5. Comparison of SWIC KAB Predictions for Two-Lane and Four-Lane Highways (10- mile Segment and ADT of 6,000).....	112
Figure 7-6. Comparison of Results Using Different Crash Types.....	113
Figure 8-1. Crash Frequency Data by Number of Intersections for Intersections on Rural Two- Lane Highways (3109 Intersections).	120
Figure 8-2. Crash Frequency Data by Number of Intersections for Intersections on Rural Four- Lane Highways (630 Intersections).	121
Figure 8-3. Crash Frequency Data by Number of Intersections for Intersections with Known Cross-Road ADT (265 Intersections).	122
Figure 9-1. Examples of Roadway Segments Included in Dataset.....	134
Figure A-1. Reproduction of <i>Roadway Design Manual</i> Table 3-8.....	144
Figure A-2. Reproduction of <i>Roadway Design Manual</i> Table 4-2.....	145
Figure A-3. Material from <i>Roadway Design Manual</i> on Conversion.	146
Figure A-4. Reproduction of <i>Roadway Design Manual</i> Table 3-12.....	147
Figure A-5. Reproduction of <i>Roadway Design Manual</i> Table 4-1.....	148
Figure A-6. Reproduction of <i>Roadway Design Manual</i> Material on Intersections in Chapter 3, Section 4, Rural Two-Lane Highway Section.	149
Figure A-7. Reproduction of <i>Roadway Design Manual</i> Material on Intersections in Chapter 3, Section 5, Multi-lane Rural Highway Section.	150
Figure A-8. Reproduction of <i>Roadway Design Manual</i> Table 3-11.....	150

LIST OF TABLES

	Page
Table 2-1. Accident Reduction Factors for Related Accident Types for Combination of Lane and Shoulder Widening (8).....	10
Table 2-2. Equations for Accident Modification Factors for Related Accidents Based on Shoulder Width (AMF_{wra}) (2).	11
Table 2-3. Equations for Accident Modification Factors for Related Accidents Based on Lane Width (AMF_{lwa}) (2).	12
Table 2-4. Negative Binomial Regression Results at Rural Four-Leg, Stop-Controlled Intersections from 2000 FHWA Study (11).....	14
Table 2-5. Negative Binomial Regression Results at Rural Three-Leg, Stop-Controlled Intersections from 2000 FHWA Study (11).....	14
Table 2-6. Expected Percentage Reduction in Total Crashes from Installation of Left-Turn Lanes on Major Road Approaches (16).....	16
Table 2-7. Crash Rates Before and After Adding Left-Turn Channelization at Unsignalized Intersections in Rural Areas (17).	17
Table 4-1. Location Data Variables.	30
Table 4-2. Video Data Variables.	31
Table 4-3. DPS-RI Accident Location Information Variables.	32
Table 4-4. Data Variables Gathered from the DPS-RI Accident File.....	33
Table 4-5. Abbreviated Control Section Milepoint Check for Stage 1.....	37
Table 4-6. Abbreviated Control Section Milepoint Check for Stage 4.....	37
Table 4-7. Abbreviated Control Section Milepoint Check for Stage 5.....	38
Table 4-8. Abbreviated Control Section Milepoint Check for Stage 6.....	38
Table 5-1. Range and Average Values for Rural Two-Lane Highways Dataset.	42
Table 5-2. Model 1A Information for 3 yr SWIC Data with Negative Binomial Regression.	46
Table 5-3. Model 1B Information for 3 yr SWIC Data with Negative Binomial Regression.	47
Table 5-4. Model 1C Information for 3 yr SWIC Data with Negative Binomial Regression.	48
Table 5-5. Information for 3 yr TSWIC with Least-Squares Fit.	50
Table 5-6. List of Ratios for Lane Width and Shoulder Widths for Rural Two-Lane Highways Based on Predictions of SWICs.....	56
Table 5-7. Range and Average Values for Rural Two-Lane Highways Roadway Characteristics by ADT Group.	57
Table 5-8. SAS Output for Analysis by ADT Group, ADT<400.	57
Table 5-9. SAS Output for Analysis by ADT Group, ADT between 400 and 2000.	58
Table 5-10. SAS Output for Analysis by ADT Group, ADT>2000.	58
Table 5-11. Ratios for Shoulder Widths for Rural Two-Lane Highways by ADT Groups for Texas Data and <i>DPC</i> Values.....	60
Table 5-12. Ratios for Lane Widths for Rural Two-Lane Highways by ADT Groups for Texas Data and <i>DPC</i> Values.	60
Table 5-13. Model Information for 3 yr Total Crash Data with Negative Binomial Regression. 63	
Table 5-14. List of Ratios for Lane Width and Shoulder Widths for Rural Two-Lane Highways Based on Predictions of Total Crashes.	64

Table 5-15. Model Information for 3 yr Crash KAB and 3 yr SWIC KAB Data with Negative Binomial Regression.....	66
Table 6-1. Range and Average Values for Rural Two-Lane Highways Data Set.....	70
Table 6-2. Model 1B Information for 3 yr SWIC Data with Negative Binomial Regression for Four-Lane Highway.....	73
Table 6-3. Model 1B Information for 3 yr SWIC Data with Negative Binomial Regression for Four-Lane Highway with Right Shoulder, Median Class Revised, LogLen, and Log ADT Included in Model.....	74
Table 6-4. Model 1B Information for 3 yr SWIC Data with Negative Binomial Regression for Four-Lane Highway with Right Shoulder, LogLen, and Log ADT Included in Model.....	75
Table 6-5. Information for 3 yr TSWIC with Least-Squares Fit for Four-Lane Highway.....	77
Table 6-6. List of Ratios for Shoulder Widths for Rural Four-Lane Highways Based on Predictions of SWICs.....	81
Table 6-7. Range and Average Values for Rural Two-Lane Highways Roadway Characteristics by ADT Group.....	83
Table 6-8. SAS Output for Analysis by ADT Group, Four-Lane Highway with ADT < 4320...	84
Table 6-9. SAS Output for Analysis by ADT Group, Four-Lane Highway with ADT Between 4320 and 8800.....	84
Table 6-10. SAS Output for Analysis by ADT Group, Four-Lane Highway with ADT > 8800.	85
Table 6-11. Ratios for Shoulder Widths for SWICs on Rural Four-Lane Highways by ADT Groups for Texas Data and Two-Lane Highway <i>DPC</i> Values.....	87
Table 6-12. Model Information for 3yr Total Crash data with Negative Binomial Regression...	88
Table 6-13. Ratios for Lane Width and Shoulder Widths for Rural Four-Lane Highways Based on Predictions of Total Crashes.....	89
Table 6-14. Model Information for 3 yr Crash KAB and 3 yr SWIC KAB Data with Negative Binomial Regression.....	90
Table 7-1. Range and Average Values for Rural Two-Lane and Four-Lane Highways with Surface Widths of 44 to 54 ft.....	94
Table 7-2. Model Information for SWIC Data with Negative Binomial Regression (Model 1A: Two- and Four-Lane Highways).....	98
Table 7-3. Model Information for SWIC Data with Negative Binomial Regression (Model 1B: Two-Lane Highways).	100
Table 7-4. Model Information for SWIC Data with Negative Binomial Regression (Model 1B: Four-Lane Highways).....	101
Table 7-5. Model Information for SWIC Data with Negative Binomial Regression (Model 1C: Two- and Four-Lane Highways).....	103
Table 7-6. Least-Squares Fit for 3 yr TSWIC for Two-Lane Highways.....	104
Table 7-7. Least-Squares Fit for 3 yr TSWIC for Four-Lane Highways.....	105
Table 7-8. Model Information for Total Crash Data with Negative Binomial Regression (Two- and Four-Lane Highways).	108
Table 8-1. Distribution of Variables for Intersections on Two-Lane Highways (3109 Intersections).....	117
Table 8-2. Distribution of Variables for Intersections on Four-Lane Highways (630 Intersections).....	118
Table 8-3. Distribution of Variables for Intersections with Known Cross-Road ADT (265 Intersections).....	119

Table 8-4. Model Information for Total Crashes with Negative Binomial Regression for Intersections Where Cross-Road ADT is Available.	124
Table 8-5. Model Information for Total Intersection Crashes with Negative Binomial Regression for Intersections Where Cross-Road ADT is Available.	125
Table 8-6. Model Information for Total Crashes KAB with Negative Binomial Regression for Intersections Where Cross-Road ADT is Available.	126
Table 8-7. Model Information for Total Crashes with Negative Binomial Regression for Intersections on Two-Lane Highways.	128
Table 8-8. Model Information for Total Intersection Crashes with Negative Binomial Regression for Intersections on Two-Lane Highways.....	129
Table 8-9. Model Information for Total Crashes with Negative Binomial Regression for Intersections on Four-Lane Highways.	130
Table 8-10. Model Information for Total Intersection Crashes with Negative Binomial Regression for Intersections on Four-Lane Highways.....	131
Table 9-1. List of Ratios for Lane Width and Shoulder Widths for Rural Two-Lane Highways Based on Total Crashes.....	136
Table 9-2. Ratios for Lane Width and Shoulder Widths for Rural Four-Lane Highways Based on Predictions of Total Crashes.	137
Table 9-3. Alpha Level Results from Negative Binomial Regression for Intersections.	140
Table A-1. Suggested New Material for <i>Roadway Design Manual</i> Chapter 4, Section 3.....	151
Table A-2. List of Ratios for Lane Width and Shoulder Widths for Rural Two-Lane Highways Based on Predictions of Total Crashes.	152
Table A-3. Ratios for Lane Width and Shoulder Widths for Rural Four-Lane Highways Based on Predictions of Total Crashes.	153

CHAPTER 1

INTRODUCTION

Selection of a cross section is a major decision and turning point for a roadway design. Decisions regarding number of lanes, presence and width of a median, lane width, and shoulder width greatly affect safety, cost, and capacity of a roadway. The availability of information regarding those factors (safety, cost, and capacity) varies greatly. Cost information is available on a project-specific level as quantities are developed through application of state-wide and district cost estimates. Capacity information is available through application of *Highway Capacity Manual (1)* worksheets and formulas (or software). Previously, safety information was not available on a similar level. Recent efforts both on a national level (2) and within the state of Texas (3), however, are developing guidance materials that can evaluate potential safety effects of different design alternatives.

RESEARCH OBJECTIVES

The objective of the study was to develop guidance suitable for use by an engineer or designer in the decision to upgrade rural two-lane highways and to support the decision regarding lane and shoulder width and use of left-turn lanes. Draft materials that could be incorporated into TxDOT publications are included in the [Appendix](#) of this report. The intent of the material is to improve resources available to TxDOT engineers and designers that can be used in the evaluation of cross-section options.

Additional objectives that supported the development of guidance material included the following:

- Identify the relationship between cross-sectional elements (e.g., lane width and shoulder width) with crashes on rural two-lane highways.
- Identify the relationship between cross-sectional elements (e.g., lane width, shoulder width, and median width or type) with crashes on rural four-lane highways.
- Compare the crash performance between rural two-lane with wide shoulder highways and rural four-lane with narrow shoulder highways.

- Determine intersection characteristics, especially left-turn lanes, effect on intersection crashes.

ORGANIZATION

The research findings are presented in nine chapters and the [Appendix](#). A brief summary of the material in each follows:

Chapter 1: Introduction contains a brief overview of project. It also explains the research objectives and provides an overview of the contents of the report.

Chapter 2: Review of Previous Research presents a summary of previous work.

Chapter 3: Collection of Field Data discusses the methodology used to collect the field data.

Chapter 4: Reduction of Field Data presents the procedure used to create the datasets used in the evaluations.

Chapter 5: Crash Prediction for Rural Two-Lane Highways presents prediction equations that demonstrate the effects of lane width and shoulder width on crash prediction for rural two-lane highways.

Chapter 6: Crash Prediction for Rural Four-Lane Highways presents prediction equations that demonstrate the effects of lane width and shoulder width on crash prediction for rural four-lane highways.

Chapter 7: Findings from Comparison of Crashes on 44 to 54 ft Surface Width contains the results from the analysis of 1999 to 2001 crash data that compares the safety performance of two-lane highways with wide shoulders to four-lane highways with minimal shoulders.

Chapter 8: Crash Prediction for Rural Intersections discusses the findings from evaluation of intersections on two- and four-lane highways.

Chapter 9: Summary and Conclusions summarizes the project and presents the conclusions from the project.

Appendix: Suggestions on Material for Reference Documents presents draft materials that can be included in the *TxDOT Roadway Design Manual* and integrated into safety reference documents.

CRASHES VERSUS ACCIDENTS

Most previous works use the term “accidents.” That is also the term currently used within TxDOT and the Department of Public Safety (DPS) in stored data. The term recommended by the National Highway Traffic Safety Administration (NHTSA) is “crashes,” which is the term primarily used in this report. The term “accident” will be used when referencing other materials which use that term.

CHAPTER 2

REVIEW OF PREVIOUS RESEARCH

SAFETY EFFECT OF CHANGE IN CROSS SECTION

In 1999, Council and Stewart (4) published their findings on estimating the benefits of converting a two-lane highway to a four-lane highway. They noted that a large sample of studies examined the nonsafety operational effects of such improvements but that only three studies examined the safety effects. These four studies (the three studies identified by Council and Stewart along with their study) basically examined three levels of improvements:

- addition of short four-lane passing segments on two-lane arterials,
- conversion of a two-lane facility to an undivided four-lane facility, and
- full-scale upgrade to a divided four-lane facility.

Addition of Short Four-Lane Passing Segments

Harwood and St. John (5) conducted a comparative evaluation of case and control sites in which the former were short four-lane undivided road segments and the latter were sections of two-lane road immediately preceding and immediately following that treated segment. They noted that other improvements may have occurred at the same time. The crash-rate analysis (based on relatively small samples of locations) yielded a nonsignificant decrease in total crash rate of 34 percent, a statistically significant decrease in cross-centerline crashes of 50 percent, and nonsignificant decreases across all other crash types and within injury categories. Importantly, no increase in crash rate was noted for any treated section of roadway. Before-and-after data were available for only one site, which showed an overall crash rate decrease of 40 percent after the lanes were added – a change from 2.16 to 1.3 crashes per million vehicle miles of travel.

Full-Scale Upgrade

Harwood (6) conducted a comparative evaluation of different types of suburban arterials in California and Michigan. He studied suburban arterials for speeds between 35 and 50 mph and

average daily traffic (ADT) greater than 7000 vpd; therefore, the findings are not directly applicable to rural two-lane highways.

Council and Stewart estimated the benefits of converting from a two-lane to a four-lane highway. They used cross-sectional models and produced crash rates for typical sections of two- and four-lane roadways in four states. The assumed typical sections used were:

- two-lane roads:
 - 24-ft paved travelway with 6-ft shoulders,
 - 24-ft paved travelway with 8-ft shoulders, and
 - 22-ft paved travelway with 6-ft shoulders.
- four-lane undivided:
 - 48-ft paved travelway with 8-ft outside shoulders.
- four-lane divided:
 - 24-ft paved travelway in each direction, median width of 16 ft, and shoulder widths of 10 ft;
 - 24-ft paved travelway in each direction, median width of 16 ft, and shoulder widths of 12 ft;
 - 24-ft paved travelway in each direction, median width of 60 ft, and shoulder widths of 10 ft;
 - 24-ft paved travelway in each direction, median width of 60 ft, and shoulder widths of 12 ft;
 - 24-ft paved travelway in each direction, median width between 16 and 60 ft, and shoulder widths of 10 ft; and
 - 24-ft paved travelway in each direction, median width between 16 and 60 ft, and shoulder widths of 12 ft.

Predicted crash reductions for conversion from typical two-lane roadway to a four-lane divided section ranged from 40 to 60 percent. The reduction due to conversion from a two-lane roadway to a four-lane undivided configuration is much less well defined, ranging from no effect to perhaps a 20 percent reduction. Note that the conversion always involved shoulders of at least

8 ft in width; therefore, similar reductions in crashes should not be expected when converting a two-lane with wide shoulders to a four-lane with minimal shoulders.

Conversion of a Two-Lane Facility to an Undivided Four-Lane Facility

A 1980s Texas study by Fambro et al. (7) is the previous research most relevant to this current TxDOT project. It was also a TxDOT study, and it used a comparative analysis and a before-and-after study design to assess the effect of converting a two-lane rural road with paved shoulders to four lanes without paved shoulders (i.e., directly applicable to this current study). The before-and-after study evaluated a total of 60 sites; crash data at each site were recorded over a 4-year period (2 years before and 2 years after the conversion). No comparison sites were included in the study. The sites were divided into three ADT categories – fewer than 3000 vpd, 3000 to 5000 vpd, and 5000 to 7000 vpd. The only statistically significant findings for total crashes were in the 3000 to 5000 ADT range, in which total crashes decreased by 9.1 percent. For nonintersection crashes, a statistically significant increase of 12.6 percent was observed for ADT levels of fewer than 3000 vpd, and statistically significant decreases of 19 and 28 were observed for the two higher ADT ranges.

The comparative analysis used a total of 16,334 crashes with 8815 representing nonintersection crashes for the years 1975 to 1977. The authors generated Figures 2-1 and 2-2 to illustrate the results of the crash rate investigation for the all-crash and nonintersection crash datasets, respectively. The authors observed from these figures that the crash rate for each highway type increased as the traffic volume increased. Two-lane highways without paved shoulders had the highest crash rates and were the most sensitive to changes in traffic volumes. Two-lane highways with paved shoulders had the lowest crash rates. Four-lane highways with no shoulders were the least sensitive to volume level and had a crash rate between the other two types of highways. The researchers concluded that the presence of paved shoulders had a noticeable effect in reducing the crash rate on rural Texas highways.

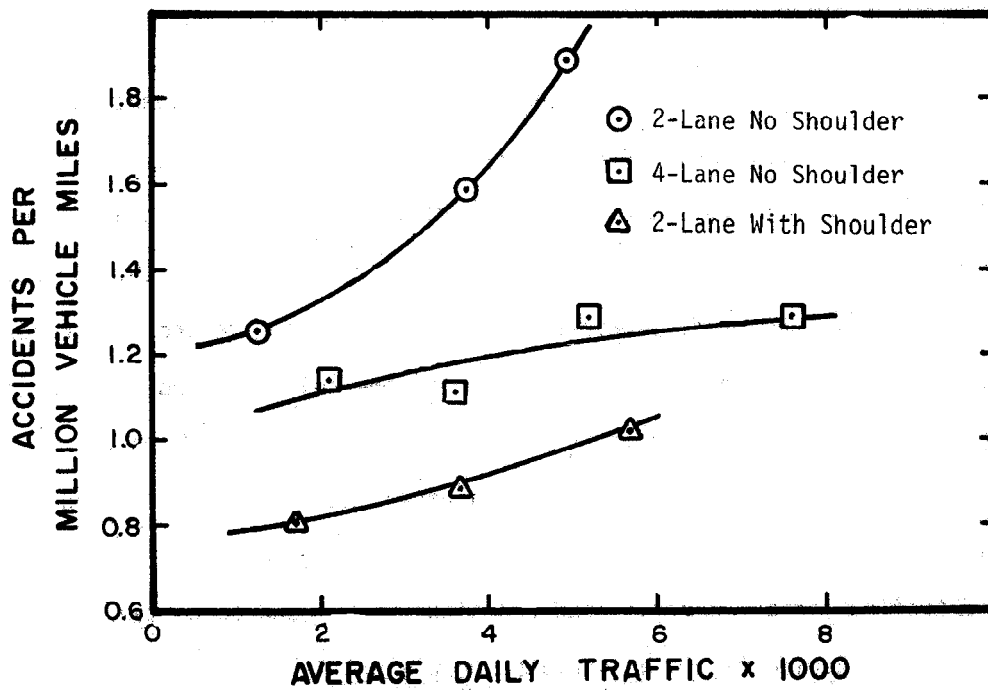


Figure 2-1. All Crashes for Different Roadway Cross Sections (7).

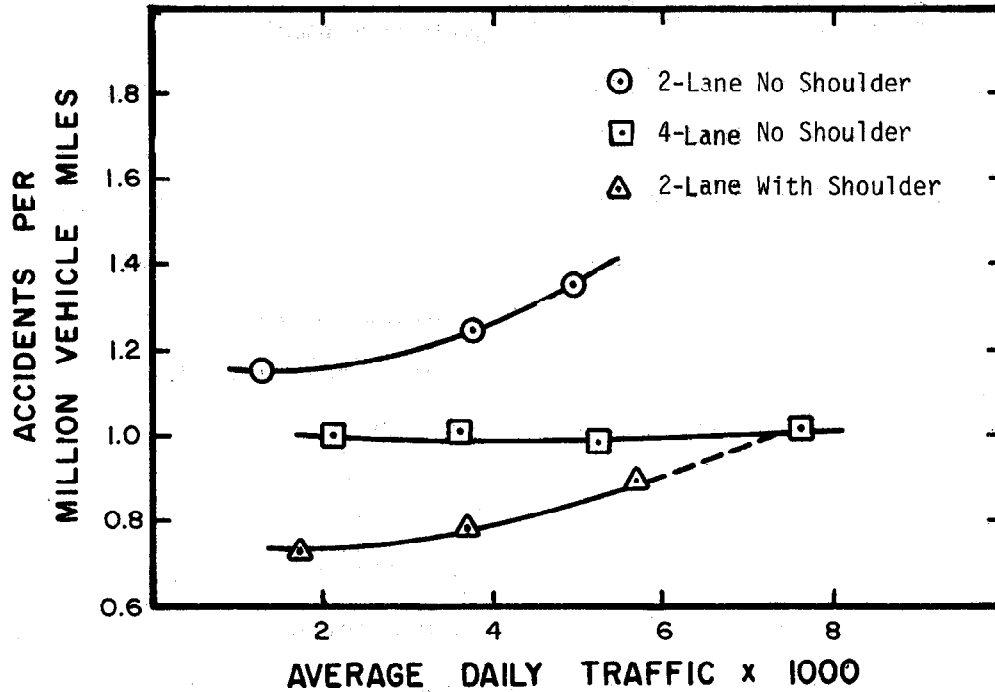


Figure 2-2. Nonintersection Crashes for Different Roadway Cross Sections (7).

SAFETY EFFECT OF WIDENING LANES AND SHOULDERS

Numerous studies have been conducted to determine the effects of lane width, shoulder width, and shoulder type on crash experience. A 1987 FHWA study by Zegeer et al. (8) quantified the effects of lane width, shoulder width, and shoulder type on highway crash experience based on an analysis of data for nearly 5000 miles of rural two-lane highways from seven states. Crash types found to be related to lane and shoulder width, shoulder type, and roadside condition include run-off-road (fixed object, rollover, and other run-off-road crashes), head-on, and opposite- and same-direction sideswipe crashes, which together were termed as “related accidents.” An accident prediction model was developed and used to determine the expected effects of lane- and shoulder-widening improvements on related accidents.

The study found that lane widening of 1 ft (e.g., from 10-ft to 11-ft lanes) is expected to reduce related accidents by 12 percent. Widening lanes by 2 ft, 3 ft, and 4 ft will reduce related accident types by 23 percent, 32 percent, and 40 percent, respectively. Table 2-1 summarizes the accident reduction factors for projects involving combinations of lane and shoulder widening. Factors are also available for paving shoulders (see Zegeer et al.) and combining reductions for multiple treatments. The factors in Table 2-1 are appropriate for two-lane roads with ADTs of 100 to 10,000 vehicles per day, lane widths of 8 to 12 ft, and 0- to 12-ft paved shoulders.

Zegeer and Council (9) reported on several studies that reviewed the effects of roadway widening on rural two-lane highways. The studies used a wide range of sample sizes and analysis techniques and all basically found that crash rates decrease because of wider lanes or shoulders or both, even though there was considerable variation in the exact amount of crash reduction.

Table 2-1. Accident Reduction Factors for Related Accident Types for Combination of Lane and Shoulder Widening (8).

Amount of Lane Widening (ft)	Existing Shoulder Condition (Before Period)	Percent Related Accidents Reduced			
		Shoulder Condition in After Period			
		2-ft Shoulder	4-ft Shoulder	6-ft Shoulder	8-ft Shoulder
3	0	43	52	59	65
	2	32	43	52	59
	4		32	43	52
	6			32	43
	8				32
2	0	35	45	53	61
	2	25	37	46	53
	4		27	38	45
	6			29	35
	8				23
1	0	26	37	47	55
	2	12	26	37	47
	4		12	26	37
	6			12	26
	8				12

- Cells were left blank where they correspond to projects which would decrease shoulder width.
- Values are only for rural two-lane highways.
- Factors are appropriate for two-lane roads with ADTs of 100 to 10,000 vpd, lane widths of 8 to 12 ft, and 0- to 12-ft shoulders that are paved.

Using the findings from the Zegeer's studies along with several other studies, Harwood et al. (10) developed a methodology to predict the expected safety performance of rural two-lane highways. The methodology formed the basis of the rural two-lane highway *Draft Prototype Chapter (DPC)* (2) developed for consideration of the forthcoming *Highway Safety Manual*. Figure 2-3 shows the accident modification factors (AMFs) that would be used with related accidents to determine the impact of different shoulder widths on the prediction of crashes. Table 2-2 provides equations that can be used in place of the figure. For lane width changes, the values in the *DPC* are shown in Figure 2-4 and Table 2-3.

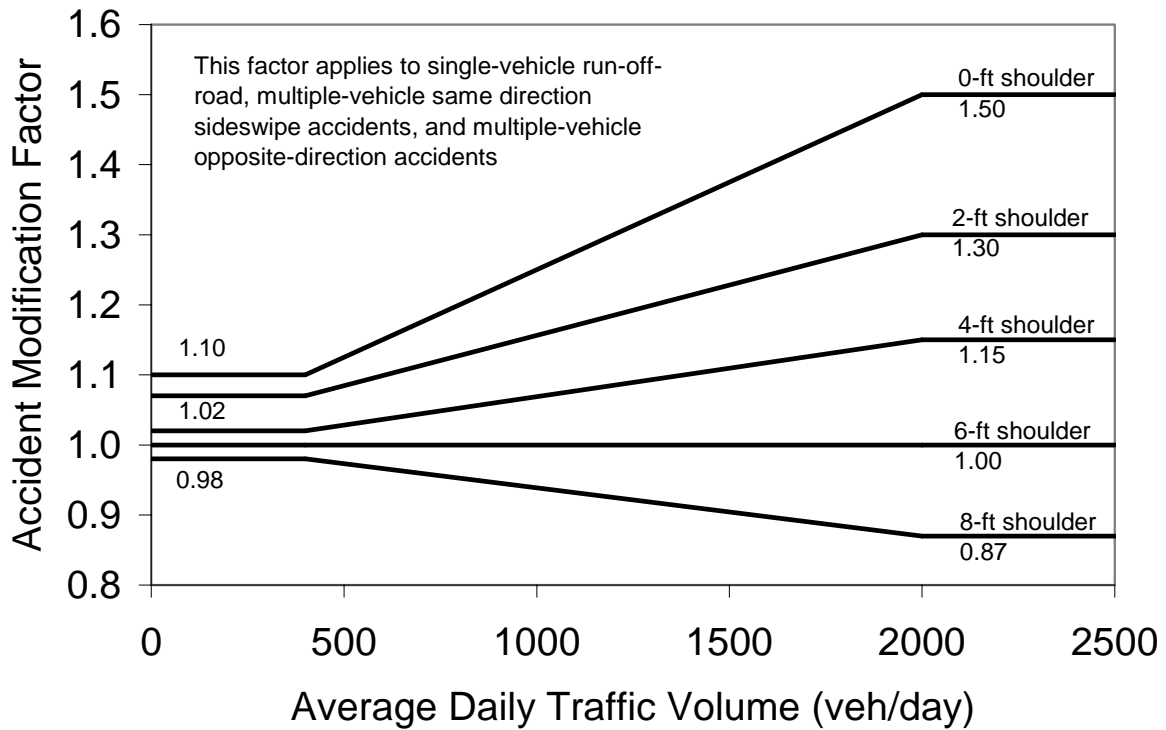


Figure 2-3. Accident Modification Factors for Shoulder Width (2).

Table 2-2. Equations for Accident Modification Factors for Related Accidents Based on Shoulder Width (AMF_{wra}) (2).

Shoulder Width (ft)	ADT		
	<400	400 to 2000	>2000
0	1.10	$1.1 + 2.50 \times 10^{-4} (\text{ADT}-400)$	1.50
2	1.07	$1.07 + 0.43 \times 10^{-4} (\text{ADT}-400)$	1.30
4	1.02	$1.02 + 8.125 \times 10^{-5} (\text{ADT}-400)$	1.15
6	1.00	1.00	1.00
8	0.98	$0.98 - 6.875 \times 10^{-5} (\text{ADT}-400)$	0.87

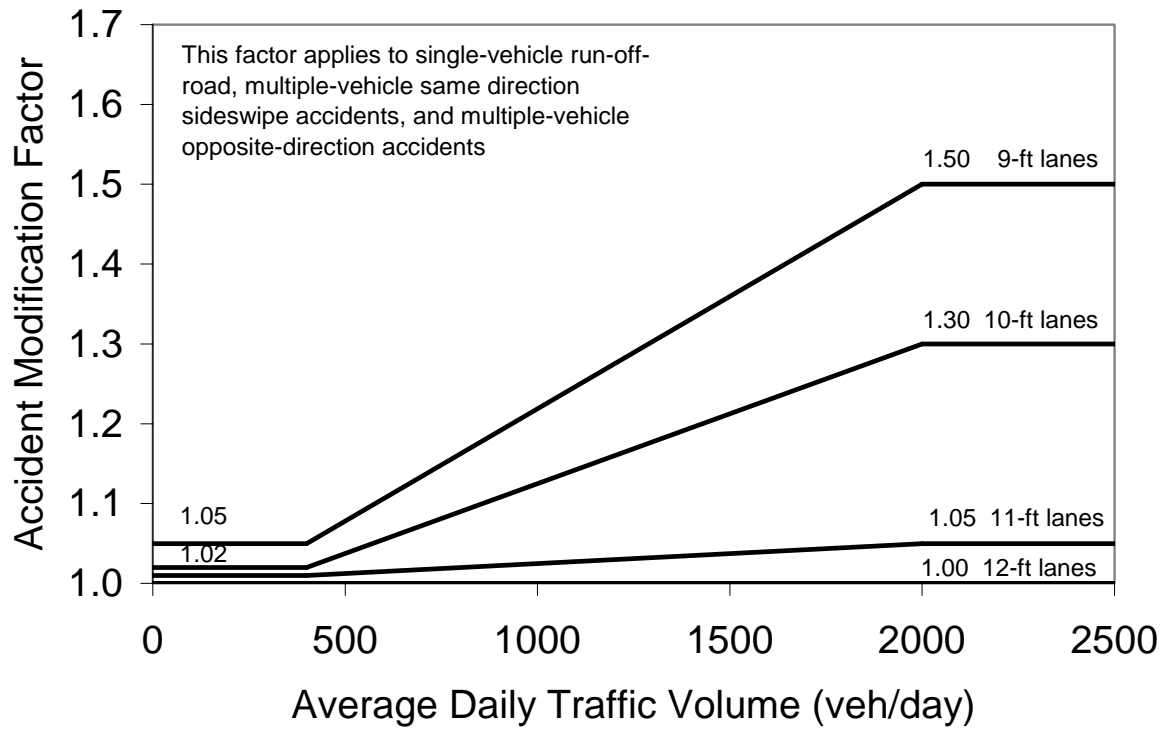


Figure 2-4. Accident Modification Factors for Lane Width (2).

Table 2-3. Equations for Accident Modification Factors for Related Accidents Based on Lane Width (AMF_{lwra}) (2).

Lane Width (ft)	ADT		
	<400	400 to 2000	>2000
9 or less	1.05	$1.05 + 2.81 \times 10^{-4} (ADT-400)$	1.50
10	1.02	$1.02 + 1.75 \times 10^{-4} (ADT-400)$	1.30
11	1.01	$1.01 + 2.50 \times 10^{-5} (ADT-400)$	1.05
12 or more	1.00	1.00	1.00

RURAL INTERSECTIONS

Regression Models

FHWA (11) sponsored a research study to develop statistical models of the relationship between traffic crashes and highway geometric elements for at-grade intersections. Of the several statistical modeling approaches used, negative binomial regression was the preferred approach for rural intersections. Regression models of the relationship between crashes and intersection geometric design, traffic control, and ADT variables explained between 16 and 39 percent of the variability in the crash data. However, most of that variability was explained by the traffic volume variables considered (major road and cross-road ADTs). Geometric design variables accounted for only a small additional portion of the variability.

In the FHWA study, negative binomial regression models were developed to fit the 3-year crash data at rural three- and four-leg, stop-controlled intersections. After the initial run with all available variables, the significance of each regression coefficient was examined. If a coefficient was not significant at the 10 percent level, the corresponding variable was deleted from the model and the negative binomial regression was rerun. Only variables with significance levels higher than 10 percent were included in the model. [Table 2-4](#) lists the independent variables for total crashes and fatal/injury crashes for rural four-leg, stop-controlled intersections. These variables are listed in decreasing order of their ability to explain the variations in intersection crash frequencies as indicated by the chi-square value in the final negative binomial model. The rural four-leg, stop-controlled intersection study was based on 1434 intersections. [Table 2-5](#) lists the results for rural three-leg, stop-controlled intersections. A total of 2692 intersections were available for the evaluation.

Table 2-4. Negative Binomial Regression Results at Rural Four-Leg, Stop-Controlled Intersections from 2000 FHWA Study (II).

Total Crashes	Fatal/Injury Crashes
Intercept	Intercept
Cross-road ADT (log)	Cross-road ADT (log)
Major road ADT (log)	Major road ADT (log)
Number of lanes on major road	Number of lanes on major road
Design speed on major road	Design speed on major road
Access control on major road	Terrain
Functional class of major road	Functional class of major road
Lighting	Lighting
Terrain	
Major road right-turn channelization	

Table 2-5. Negative Binomial Regression Results at Rural Three-Leg, Stop-Controlled Intersections from 2000 FHWA Study (II).

Total Crashes	Fatal/Injury Crashes
Intercept	Intercept
Major road ADT (log)	Major road ADT (log)
Cross-road ADT (log)	Cross-road ADT (log)
Major road left-turn channelization	Outside shoulder width on major road
Access control on major road	Lighting
Functional class of major road	Major road left-turn channelization
Outside shoulder width on major road	Functional class of major road
Terrain	Cross-road right-turn channelization

Left-Turn Lane

The left-turn lane is generally the key auxiliary lane at an intersection (see [Figure 2-5](#) for an example). It creates the opportunity to separate and avoid speed differences between the left-turning vehicle and the through vehicles. It also decreases the delay that can be experienced by through vehicles behind a turning vehicle. Plus increasing the operational efficiency of the intersection increases intersection capacity and safety. Left-turn lanes can also provide increased visibility to the turning vehicle by the opposing traffic.



Figure 2-5. Example of Left-Turn Lanes.

The American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (commonly known as the *Green Book*) (12) indicates that left-turn lanes should be established on roadways where traffic volumes are high enough (see *Green Book* Exhibit 9-75) or safety considerations are sufficient to justify left-turn treatment. Similar information is included in the *TxDOT Roadway Design Manual* (see Chapter 3, Section 4, “Left-Turn Lanes” of the *TxDOT Roadway Design Manual*) (13). Additional information on left-turn treatments at intersections is included in National Cooperative Highway Research Program (NCHRP) Synthesis 225 (14) and NCHRP Report 279 (15). Information on taper designs and deceleration and acceleration lengths for different grades or running speed assumptions is included in the *Green Book* (12).

A 2002 FHWA study found that the addition of a left-turn lane can result in crash reductions of 7 to 48 percent (see [Table 2-6](#)) (16). The study gathered geometric design, traffic control, traffic volume, and traffic crash data for a total of 280 improved sites under the jurisdiction of the participating states, as well as 300 similar intersections that were not improved during the study

period. The types of improvement projects evaluated included installation of added left-turn lanes, installation of added right-turn lanes, installation of added left- and right-turn lanes as part of the same project, and extension of the length of existing left- or right-turn lanes. An observational before-and-after evaluation of these projects was performed.

Table 2-6. Expected Percentage Reduction in Total Crashes from Installation of Left-Turn Lanes on Major Road Approaches (16).

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

A 1967 California study examined the difference in the effectiveness of the raised barrier protected left turn versus the painted left turn in rural areas (17). Both treatments provided a significant reduction in crash rates with relatively little difference between the types of treatment for rural areas (see Table 2-7).

Table 2-7. Crash Rates Before and After Adding Left-Turn Channelization at Unsignalized Intersections in Rural Areas (17).

	Raised Barrier Protected			Painted		
	Rate Before	Rate After	Percent Change	Rate Before	Rate After	Percent Change
Crash Type						
Single Vehicle	0.10	0.07	-30	0.10	0.15	+50
Left-Turn	0.18	0.05	-72	0.28	0.15	-46
Rear-End	0.49	0.02	-96 S	0.51	0.09	-82 S
Crossing	0.28	0.27	-4	0.19	0.16	-16
Other	0.13	0.07	-46	0.07	0.03	-57
Severity						
Property Damage	0.72	0.34	-53 S	0.61	0.31	-49 S
Injury	0.39	0.15	-62 S	0.54	0.25	-54 S
Fatal	0.08	0.00	-100	0.01	0.01	0
Light Condition						
Day	0.67	0.25	-64 S	1.18	0.55	-53 S
Night	0.51	0.24	-53 S	1.13	0.63	-44
TOTAL	1.18	1.049	-58 S	1.16	0.58	-50 S
Changes indicated with "S" are significant at the 0.10 level using the chi-square test. Crash rates are the number of crashes per million entering vehicles.						

CHAPTER 3

COLLECTION OF FIELD DATA

PROCEDURE

To compare the safety relationships for cross-sectional elements on rural two- and four-lane roadways, a dataset containing a range of lane widths and shoulder widths is needed. The dataset of roadway segments was to include the following:

- rural highways (as defined in the TxDOT database),
- two- and four-lane segments,
- range of shoulder widths (between 0 and 12 ft or more),
- range of lane widths (between 9 and 12 ft or more), and
- for the four-lane roadways, a sample of median types and widths.

The overall data collection procedure was to identify roadway segments of interest, to videotape those roadways while driving at or near highway speed, and then to pull geometric information from the video tapes in the office. The videotapes would also be used to identify intersections of interest for the intersection analyses. Supplementing the data from the video was (a) information from straight-line diagrams provided by the districts and (b) data, such as average daily traffic values, from the Texas Reference Marker (TRM) databases.

ROADWAY SEGMENT SITE SELECTION

To obtain the diverse sample, data collection efforts focused on the following districts:

- Bryan,
- Dallas,
- Childress,
- El Paso,
- Lufkin, and
- San Angelo.

The primary evaluation for this study was comparing crash data for two-lane with wide shoulder to four-lane with narrow shoulder highways. A review of the distribution of data gathered from

the above districts revealed that a much larger number of two-lane with wide shoulder highways were available compared to four-lane with minimal shoulder highways. Therefore additional data collection efforts to gather data on four-lane with minimal shoulder highways also occurred in:

- Abilene,
- Austin,
- San Antonio,
- Atlanta, and
- Brownwood.

Figure 3-1 shows the location of the districts with roads included in the dataset.

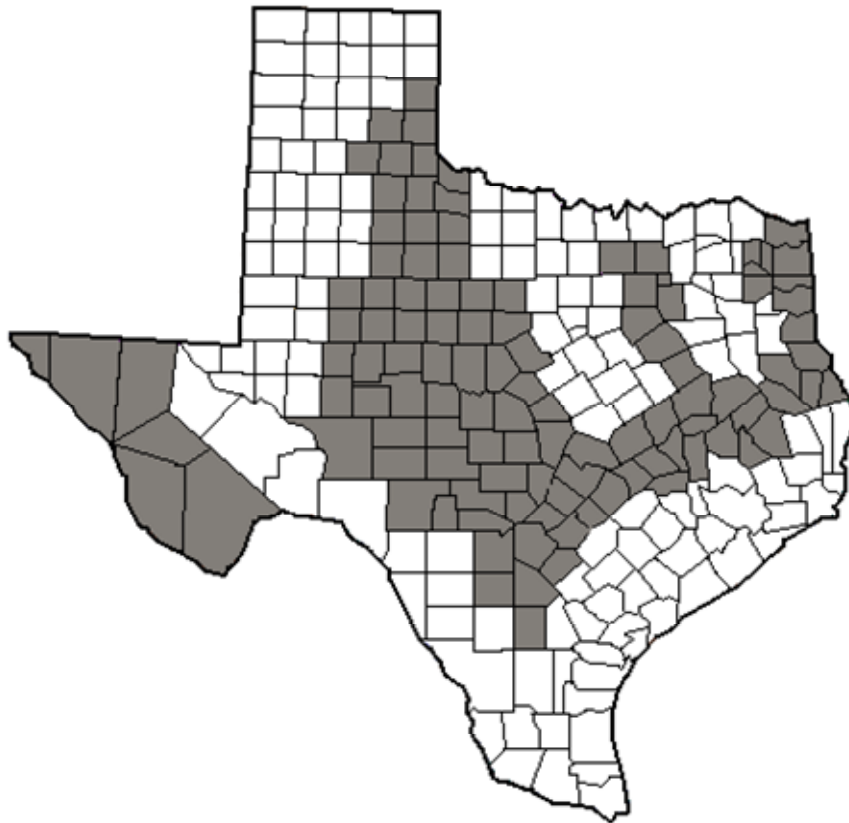


Figure 3-1. Districts with Roads Included in Dataset.

The procedure for identifying sites began with the roadway geometric information for the selected districts. In the beginning the Roadway Inventory (RI) file database was used. The RI

file includes information on the traffic characteristics and geometry for roadway segments for both state highways and county roads. The RI file contains relevant highway and county road information for the years 2000 and earlier.

After 2000, information about state highway segments was superseded by other databases, such as the Texas Reference Marker system, RhiNO, Geo-Hini, and P-HiNI databases. The information in these databases is referenced to the roadside reference markers that are usually placed on route marker signs at approximately 2-mile intervals and the control section and mile point used in the straight-line diagrams. In addition to locating the roadway segments, the RhiNO database provides segment descriptions including surface and shoulder widths, number of lanes, ADTs, and functional classification.

Geometric information used to identify potential study sites for the two- and four-lane rural highway analysis included:

- surface width,
- number of lanes,
- median type,
- median width,
- shoulder (right and left) width, and
- shoulder (right and left) type.

In some cases, the RhiNO database did not include geometric data of interest to this project. One example of a potentially key variable is lane width. Researchers were able to estimate lane width for each segment by dividing the surface width by the number of lanes.

In addition, a number of other variables were pulled from the RhiNO database. These variables included items that would locate the segment, such as highway number, control section, mile point, reference number, and displacement from the reference marker. The TRM provides reference locations in units of reference markers and control sections/mile points. Unlike reference markers, control sections and mile points are used to locate the DPS crash records.

Other variables in addition to locations and geometries were the average daily traffic values for the segment and the functional classification of the roadway.

The target roadway segment study sites were divided into the following classes:

- number of lanes: 2 or 4,
- lane width groups: <11 ft, 11 to 13 ft, and >13 ft; and
- shoulder width groups: <2 ft, 2 to 6 ft, 6 to 12 ft, and >12 ft

These classes were used to select the driving route. Generally, the groups with the largest number of roadway segments were those with 11- to 13-ft lane widths and 6- to 12-ft shoulders, although there was a reasonable sample of roads with the less than 2-ft shoulder criterion compared to other groups. The group with the smallest number of roadway segments when compared to the other groups was the rural four-lane highway group, especially those with the smaller shoulder widths. Therefore, the data collection effort emphasized those roadways and then collected roadways in other groups as available between four-lane segments.

The process to select the driving route began by locating four-lane highways, two-lane highways with less than 6-ft shoulders, and two-lane highways with greater than 6-ft shoulders for each district. The driving route was designed to cover the four-lane highways, any two-lane highways of interest, and then other two-lane highways that created a logical and efficient route.

Approximately 1 to 2 weeks was spent collecting the data in each of the initial six districts (Bryan, Dallas, Childress, El Paso, Lufkin, and San Angelo). The number of miles of roadway collected was a function of the distance between roadway segments of interest.

INTERSECTION SITE SELECTION

In addition to roadway segments, information provided by the TRM included the Geo-Hini and the P-HiNI database. The Geo-Hini database provides information about horizontal curvatures and the P-HiNI database contains attributes about point-specific features of the roadway including the location of intersections.

The intersections dataset was to include the following:

- intersections with turn lanes and
- intersections without turn lanes.

Intersections were identified using the P-HiNI database, straight-line diagrams provided by the district, and the field study video tapes.

DATA COLLECTION EQUIPMENT

Texas Transportation Institute (TTI) researchers developed a video collection system for the field data collection. This video system recorded lane/shoulder/median conditions along with distance traveled while driving at or near highway speeds. The video camera was mounted to the windshield of the vehicle for each trip as shown in [Figure 3-2](#). From this camera, TTI technicians were able to identify the conditions and specific lengths associated with each roadway segment.



Figure 3-2. Example of Video Camera Mounted on Windshield.

The mileage for each segment was determined using a distance measuring instrument (DMI). The DMI was installed and calibrated for each vehicle used in the data collection. While driving, the DMI determined the distance covered by the TTI vehicle. Software developed for this project generated a text block of information that included: roadway name, distance traveled from origin, descriptive information supplied by technician, and date of data collection (see Figure 3-3). The information was recorded on the video every 3 seconds. In the case shown in Figure 3-3, the text box reads Eastbound US 175, 12.899 miles from reference marker 628, on March 23, 2004. Videotaping the roadway with mileage superimposed on the videotape permitted determination of location of changes in the roadway characteristics.



Figure 3-3. Example of DMI and Video Recording System along with Text Box of Information Recorded on the Video.

Lane width was measured as the distance between the centerline and the white edge line. Shoulder width was measured from the white edge line to the edge of pavement. Comparing measurements obtained from the video early in the data collection efforts with measurements in

the field indicated that a technician could estimate lane width and shoulder width within 1-ft accuracy. Measurement of median width, however, could not be as accurate, especially on four-lane highways or on two- or four-lane highways with wide medians. Therefore, median width was estimated as being above or below certain values (e.g., 12 ft for a flush median or 16 ft for a raised or depressed median).

The system was then used on several miles of roadway. A comparison of the lane and shoulder widths measured from the video with the calculated lane width (surface width divided by number of lanes) and shoulder widths in the Reference Marker database indicated sufficient differences to result in the decision to collect all lane and shoulder width data from the video rather than using data contained within the TxDOT databases. This approach permitted the collection of actual roadway conditions visible to the driver (i.e., paved shoulder width beyond an edge line).

PRE-DATA COLLECTION PROCEDURE

The video system was calibrated before each data collection trip. This calibration improved the overall quality control/quality assurance of the data from the field. The video system calibration involved two protocols. The first protocol was calibration of the video recorder attached to the windshield of the vehicle. The second protocol used later in the data collection process involved manual measurement of the lane and shoulder width at the beginning roadway segment in the field. These measurements were compared to values pulled from the video to check the accuracy of the developed grid.

The researchers used a grid system to measure the shoulder widths and median widths for each roadway segment. To create the grid system, markers were placed at a test location to represent 10 ft, 12 ft, 15 ft, 18 ft, 21 ft, and 24 ft away from the centerline of the lane. [Figure 3-4](#) shows a driver's view of the markers that were recorded by the video prior to a data collection trip and used to calibrate the video image.

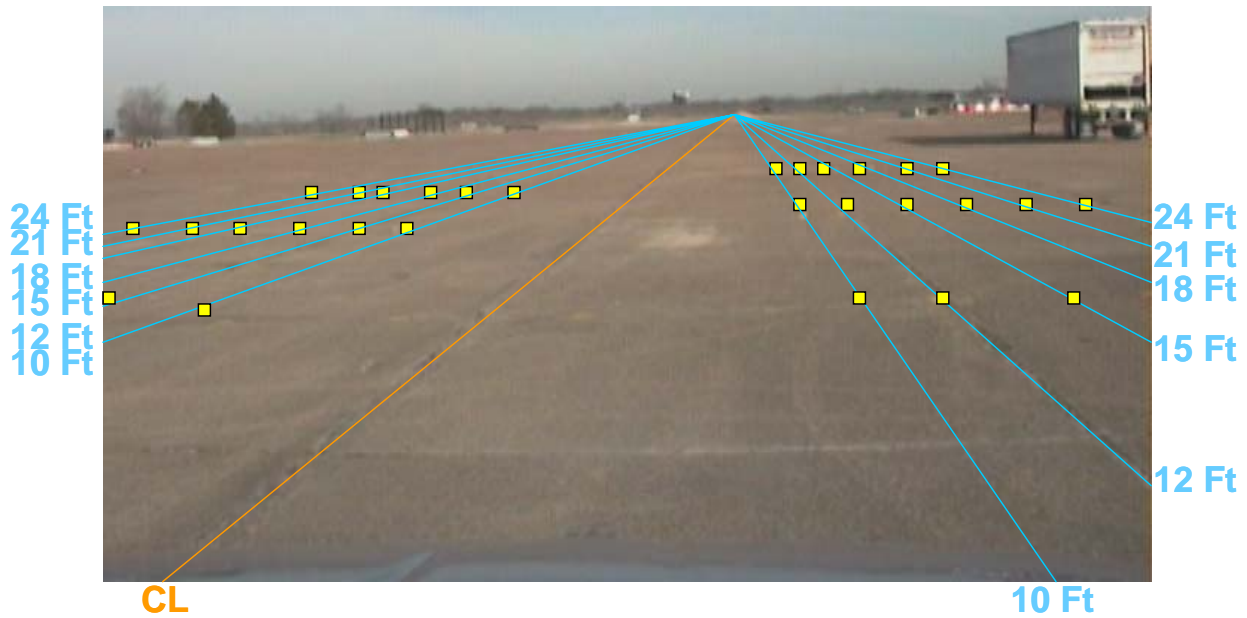


Figure 3-4. View of the Calibration Grid from the Video Camera.

A schematic of the grid system is shown in [Figure 3-5](#). In this figure, lines were added to show the different measured widths with respect to the centerline. The box near the bottom of [Figure 3-5](#) represents the vehicle used in the trip. The horizontal lines show the downstream location of the markers with respect to the front end of the vehicle. The six lines on each side of the centerline were used to measure the lane and shoulder width. These lines illustrate the effects of paradox associated with measuring widths on the horizon.

Video of the markers was recorded for several minutes prior to each data collection trip. In the office, a set of transparencies was created based on the markers. These transparencies were used to measure the shoulder and median widths for the roads traveled during the trip. Because the video camera placement on the windshield varied between data collection trips, the calibration process was completed before each data collection trip. With the completion of the two protocols, the video system used for the data field collection was considered properly calibrated.

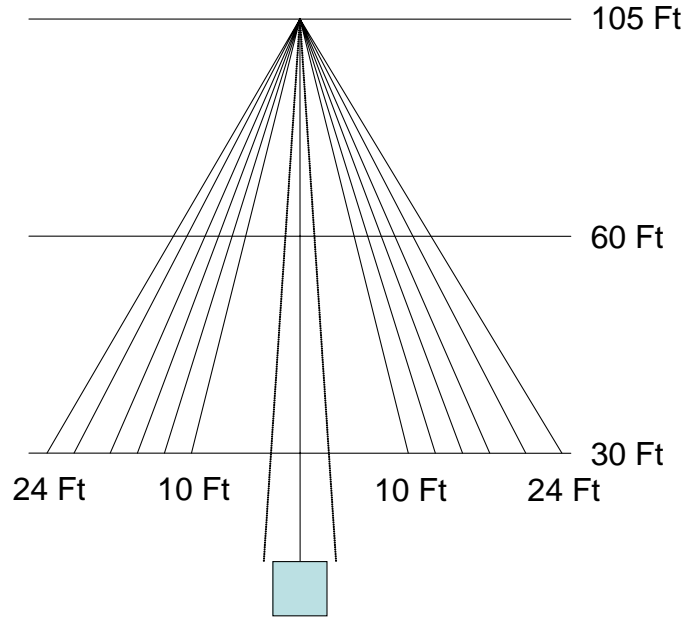


Figure 3-5. Schematic of the Experimental Setup Used to Calibrate the Research Vehicle.

FIELD DATA COLLECTION PROCEDURE

Video taping began at a major intersection or reference marker. At the start of a segment, the technicians recorded the following information: roadway number, direction of travel, starting mile point, description of location, and date. This information was recorded on a laptop and used to process the field data. At this time, the technician also used the laptop to verify the correct location of the segment and mile point. With the added information and confirmed location, the technician began driving. When on a four-lane section, the driver generally remained in the rightmost lane. In most cases, to remain consistent, the technicians traveled at 60 mph while collecting data. When the roadway segment was complete, the technician turned off the video system and proceeded to the next roadway.

CHAPTER 4

REDUCTION OF FIELD DATA

Two datasets were created in this project – segments (RS) and intersections (INTER). The roadway segment dataset includes geometric characteristics for each segment of roadway pulled from the video with crash data added once the specific control section/mile point was determined. A subset of this dataset was created to permit evaluation of crash performance between highways with two lanes with wide shoulders and highways with four lanes with narrow shoulders when the surface width is between 44 and 54 ft. The intersection dataset included geometric information specifically for intersections with crashes occurring within 250 ft of the intersection.

The remaining sections of this chapter describe the development and the quality control protocols used for the RS and INTER datasets.

DESCRIPTION OF ROADWAY SEGMENT DATASET

The roadway segment dataset was developed over three steps. The first step was field data collection. During the field data collection, video was recorded for each road. The second step of the data collection was pulling the correct information from the video and recording this information in the appropriate cell in the RS spreadsheet. The third step of RS development required identifying the crash records for each roadway segment. The variables found in the RS dataset can be divided into three subgroups: location information, data from video, and data from the RI accident file. These subgroups are explained below.

Field Information

The variables in [Table 4-1](#) describe the location of each segment of road. Initial information was from the RhiNO database. The RhiNO database was developed from the Texas Reference Marker System and provides a wide range of geometric and location information associated with each roadway segment. When in the field, the technician began recording at an intersection or reference marker; hence, the mile value recorded on the video may not directly coincide with the

reference marker plus displacement value (or control section/mile point). Therefore, the relationship between the mile value recorded at the start of a segment with the control section/mile point (or reference marker plus displacement) value would be determined. From that relationship, the relative mile points could be calculated.

During the field data collection, it was difficult to find the exact control section/mile point locations; therefore, the video was generally tied to reference markers because they were easier to locate. “Begin V-M” and “End V-M” represent the values generated by the DMI installed in the TTI vehicle. The initial “Begin V-M” was linked to the reference marker and an “equation” or relationship was identified so that the Begin R-MP and End R-MP could be determined for each roadway segment.

Table 4-1. Location Data Variables.

Variable	Description
Trip	Data collection trip (e.g., Bryan, Childress, etc.).
Hwy	Designated highway system from the RhiNO database.
Num	Roadway number from the RhiNO database.
Con-Sec	Control section number from the RhiNO database.
Begin V-M	Beginning mile value shown on the video as determined by the DMI located in the vehicle. New beginning mile points were generated approximately every ¼ mile within a segment.
End V-M	Ending mile value shown on the video as determined by the DMI located in the vehicle. Ending were generated approximately every ¼ mile. Depending on the direction of travel, End V-M may decrease/increase in sequential order when compared with Begin V-M.
Begin R-MP	Beginning mile point determined from Begin V-M converted to the location system used in the RhiNO database. This value was used to obtain crash data.
End R-MP	Ending mile point correlated to the RhiNO database. When needed, the Begin and End MPs were flipped so that End R-MP was sequentially greater than Begin R-MP.
Seg Len	Calculated field representing the difference between End R-MP and Begin R-MP.
ADT	Average annual daily traffic obtained from RhiNO for the Begin R-MP location. The average daily traffic includes the time period between 1999 and 2001.
Tape	Tape number associated with the field collection.
Map Num	Map number associated with the field collection.

ADTs were identified from the RhINO database. The tape and map number were stored to create a quick reference between the RS dataset and the video. This quick reference system was used many times to spot check the consistency of the recorded data.

Video Data

The video data reduction efforts began with assembling relevant materials such as maps, video tapes, the grid system for the roadway, and the spreadsheet file. To record the width measurements, transparencies created during calibration of the video system were placed on the monitors. The variables listed in [Table 4-2](#) were recorded at ¼-mile increments. The compiled RS dataset was developed and stored in a computer spreadsheet.

After the video data reduction was completed for the roads within a district, the dataset was reviewed for errors. Examples of potential errors included recording a lane width as only being 1 ft (rather than 10 or 11 ft) or having an inconsistency between the median width and the median class). When inconsistencies were found, the video for the particular segment of roadway was analyzed and the data in question corrected.

Table 4-2. Video Data Variables.

Variable	Description
LN	Number of through lanes on the roadway segment.
RT Lane	Width of the right lane (ft) measured at Begin V-M.
RT Shou	Width of the right shoulder (ft) measured at Begin V-M.
Med Wid	Width of the median (ft) measured at Begin V-M. In cases where the median could not be determined “unk” was recorded in the data field.
Med Class	Median classification estimated from the video NONE – None, <2 ft; F-N – Flush, >2 ft and <12 ft; F-W – Flush, 12 ft or more; D-N – Depressed, <16 ft; D-W – Depressed, 16 ft or more; R-N – Raised, >2 ft and <12 ft; R-W – Raised, 12 ft or more; T-N – Two-Way Left-Turn Lane, >2 ft and <12 ft; and T-W – Two-Way Left-Turn Lane, 12 ft or more.

Crash Data

The DPS Accident History Database contains information about each reported crash in Texas. The DPS database is linked to the TxDOT RI file through control section/mile points. The linked database is referred to as the TxDOT-DPS database. The most current 3 years (1999 to 2001) of crash data were used in this project. The data listed in [Table 4-3](#) provides location information for each crash. With this information the RI crash information is capable of being merged with the RS dataset. For this portion of the data reduction, there is no major quality control aspect since all of these data are from the DPS RI crash file.

Table 4-3. DPS-RI Accident Location Information Variables.

Variable	Description
Acc_No	Accident number associated with each crash. This variable is used to maintain and guarantee that there are no duplicate records in this analysis.
County	County associated with the crash
Mile1	Mile location on the higher priority road for the crash
Mile2	Mile location on the lower priority road. If there is no additional road this column is left empty and reported as a null field.
Contsec1	Control section for the higher priority road for the crash.
Contsec2	Control section for the lower priority road for the crash. Similar to Mile2, if there is no additional road this column is left empty and reported as a null field.

To begin the integration of the two datasets, common unique values were established between both datasets. In this case both datasets include the control section/mile point. The boundary conditions for the integration of the two datasets were developed on the RS dataset because it provides a beginning and ending mile point, based on observations collected in the field instead of one fixed point in space that is represented by the crash. The crashes were summed based on the condition that the crash occurred at a location that is greater or equal to Begin R-MP and less than End R-MP. The categories used for the crash data are listed in [Table 4-4](#). Data for severity levels 1, 2, and 4 were merged to create the number of fatal/injury crashes (called KAB crashes).

Table 4-4. Data Variables Gathered from the DPS-RI Accident File.

Variable	Description
Total Crash	Total crashes: all crashes that occurred at a location \geq Beg R-M and $<$ End R-M.
Total Inter or Inter-Related Crash	Total intersection or intersection-related crashes: those that occurred at a location greater than or equal to Beg R-M and less than End R-M; counted based on RI file “intersct” \leq 2.
Total DW Crash	Total driveway crashes: crashes \geq Beg R-M and $<$ End R-M; counted based on RI file “intersct” = 3.
Total Non Int Crash	Total nonintersection-related crashes: crashes \geq Beg R-M and $<$ End R-M; counted based on RI file “intersct” = 4.
SWIC Crash	Surface width influence crashes(SWIC): crashes \geq Beg R-M $<$ End R-M; SWICs are nonintersection crashes (intersection related code = 4) with a collision code, vehicle movement/manner of (a) two motor vehicles going same direction, (b) two motor vehicles going opposite directions, or (c) single vehicles.
Severity 1, Incapacitating	Number of crashes for the segment with severity level = 1.
Severity 2, Nonincapacitating	Number of crashes for the segment with severity level = 2.
Severity 3, Possible Injury	Number of crashes for the segment with severity level = 3.
Severity 4, Fatal	Number of crashes for the segment with severity level = 4.
Severity 5, PDO	Number of crashes for the segment with severity level = 5 (property damage only [PDO]).
SWIC, Severity 1, Incapacitating	Number of SWICs for the segment with severity level = 1.
SWIC, Severity 2, Nonincapacitating	Number of SWICs for the segment with severity level = 2.
SWIC, Severity 3, Possible Injury	Number of SWICs for the segment with severity level = 3.
SWIC, Severity 4, Fatal	Number of SWICs for the segment with severity level = 4.
SWIC, Severity 5, PDO	Number of SWICs for the segment with severity level = 5.

Once the crash data from the RI files were incorporated with the RS dataset, quality control checks were conducted. The first and second checks tested the integration of the total crashes and the levels of severity associated with each crash. The third check tested the complete integration of the two sets of data and guaranteed that no recorded DPS accident record was missing or double counted in the final RS dataset.

After the three checks were completed and the integrity of the RS dataset was satisfactory, the final RS compiled dataset included approximately 18,500 segments totaling 4800 miles of data. This robust dataset also includes more than 8800 crashes between 1999 and 2001.

TWO-LANE OR FOUR-LANE HIGHWAY PERFORMANCE

The RS dataset can be used to determine the influence of lane width, shoulder width, and median type on crashes. Preliminary evaluation revealed that maintaining the ¼-mile increments generated poor results. Therefore, the ¼-mile increments were merged with neighboring segments to form longer segments that had the same lane width, shoulder width, and median width/class. Roadway segments that were less than 0.20 miles in length were eliminated from the dataset along with segments where the right-turn lane was longer than 15 ft (generally locations where the lane was widened due to a downstream intersection or near a mailbox).

COMPARISON OF TWO-LANE AND FOUR-LANE HIGHWAYS

The key evaluation for this research was the comparison between two-lane highways with wide shoulders and four-lane highways with narrow shoulders. The crash prediction models developed using the RS dataset could be compared to determine the crash differences between two-lane and four-lane highways. Initial reviews of the RS dataset and these models, however, generated findings that indicated additional considerations were needed to accurately determine the safety performance of the two alternatives. Geometric data were reviewed to determine the surface widths where either a two-lane with wide shoulders or a four-lane with narrow shoulders was present. The following requirements were set:

- surface width (sum of lane widths and shoulder widths) = 44 to 54 ft,
- maximum right lane width = 15 ft,
- only two- and four-lane highways (no three-lane highways), and
- segment lengths a minimum of 0.20 miles.

DESCRIPTION OF INTERSECTION DATASET

Intersections located on the roadway segments included in the RS dataset were identified from the video. In addition to the roadway geometric information that existed for each segment, the following intersection characteristics were pulled for the INTER dataset:

- type of control,
- number of legs and lanes,
- skew angle,
- number of right/left-turn lanes,
- width of right/left-turn lanes,
- lengths of right/left-turn lanes,
- offset left-turn lanes,
- median description,
- horizontal and vertical curvature, and
- location of the intersection.

Intersection information was divided into three categories: roadway approaches in the direction of travel, roadway approaches for the opposite direction, and cross-road approaches. The final intersection dataset contained several thousand intersections located throughout six districts.

Location of the Intersection

Video mile values were calculated based on the original location of the vehicle and the distance traveled as determined by the DMI located in the vehicle. The DMI provides new distances approximately every 0.05 miles (260 ft) and these distances are recorded on the video. Unlike roadway segments, where there may be several miles of geometric homogeneity, intersections are spot locations, with the potential for several intersections to be within 1000 feet of each other. Intersections located using the distances generated by the DMI needed to be checked using other sources to accurately connect the intersection visible on the video with the crash data available in the database.

To improve the overall accuracy for the placement of intersections, additional intersection-related data were obtained. In addition to the RhiNO database, the Texas Reference Marker

System includes the P-HiNI intersection database. In the P-HiNI database, intersections are located using control section/mile point and reference markers. The P-HiNI database control section/mile points were used to locate intersection and intersection-related crashes for the intersections. In addition to locating intersections, the P-HiNI database includes descriptions about the location, type, number of legs, and other intersection characteristics.

Integration of P-HiNI Data

With several thousand intersections, the final merge between the P-HiNI intersection control section/mile points in conjunction with the video mile values from the DMI was very time intensive. During the data analysis, there were several occasions when the location for an intersection was not exact between the P-HiNI database and the INTER dataset. The most prominent explanation is the result of the cumulative effects from the correct beginning position of the vehicle and the lag period associated with the DMI updates on the video. In this study the difference between the measurements was generally less than 0.15 mi.

Quality Control Integration

Several stages of quality control were used to create the final intersection dataset. Initially, an attempt was made to match all intersections observed from the video to intersections found in the Texas Reference Marker P-HiNI database. Unfortunately not all observed intersections matched intersections found in P-HiNI. In order to use these intersections, their video mile value had to be adjusted to a mile point equivalent value. This adjusted value was then compared to the P-HiNI mile point.

Data from a roadway sample can show the impact of the different quality control stages on the final outcome of the INTER dataset. It is important to mention that the tables used in the following example are abbreviated. There are additional columns and rows that are not shown. These columns and rows are not important to the overall trends discussed below.

- **Stage 1.** Stage 1 includes the initial merge between the P-HiNI intersection mile points and video mile values. This stage was completed by hand. Intersections were shifted to achieve the best match between adjusted video mile points (MPs) and P-HiNI mile

points. For the example shown in [Table 4-5](#), the P-HiNI intersection is missing between P-HiNI mile points 5.421 and 11.302, and two intersections were originally missed from the video. In total for the first stage of cleaning the information, intersection information is missing from three of the eight intersections (three intersections are not shown in abbreviated [Table 4-5](#)).

Table 4-5. Abbreviated Control Section Milepoint Check for Stage 1.

P-HiNI Mile Point	Adjusted Video MP	Video Mile Values	Check
5.421	5.564	7.12	-0.143
	5.563	7.121	-
11.302			
12.364	12.481	14.043	-0.117
13.327			

- **Stage 2.** With the help of TxDOT straight-line diagrams, Stage 2 further increased the accuracy of the merge between P-HiNI and the INTER dataset. Straight-line diagrams were consistent with the P-HiNI data, and using key characteristics such as highway number, intersection skew, and numbers of legs, researchers were able to increase the accuracy of merging P-HiNI and Stage 1 data.
- **Stage 3.** In addition to the differences between the two measurements, there were some initial problems associated with missing intersections. Missing intersections were present in both the video collection analysis and the P-HiNI database. In the video collection the most common errors were intersections that were labeled as driveways. In the P-HiNI database, the majority of the errors were a result of new intersections that were added after the P-HiNI database was created. If data were not present, a code of “N/R” for no record was placed in the mile point cell (see [Table 4-6](#)).

Table 4-6. Abbreviated Control Section Milepoint Check for Stage 4.

P-HiNI Mile Point	Adjusted Video MP	Video Mile Values	Check
5.421	5.564	7.12	-0.143
N/R	5.563	7.121	-
11.302			
12.364	12.481	14.043	-0.117
13.327			

- **Stage 4.** Researchers reviewed the video once again to check for the existence of “N/R” intersections at the mile points provided and to resolve any issues with other intersections missing data. Shown in [Table 4-7](#), two additional intersections were found and located at video MPs 12.967 and 15.054. For many of the missed intersections, the intersecting roadway was a ranch/farm road that was relatively hard to find and easy to miss on the video.
- **Stage 5.** In Stage 5, the video was rewatched and missing N/R values were replaced. The replacement of the N/R values was calculated with the average check value shown in [Table 4-7](#). The check value is the P-HiNI value minus the adjusted video MP. The average check value was calculated for each control section. The N/R value was replaced by the adjusted video MP minus 0.130. In this case the new adjusted video MP value was 5.433.

Table 4-7. Abbreviated Control Section Milepoint Check for Stage 5.

P-HiNI Mile Point	Adjusted Video MP	Video Mile Values	Check
5.421	5.564	7.12	-0.143
5.433	5.563	7.121	-
11.302	11.406	12.967	-0.103
12.364	12.481	14.043	-0.117
13.327	13.492	15.054	-0.165
		Average Value	-0.130

- **Stage 6.** When the data for INTER reaches Stage 6, the final quality control check is done. During this stage, random lines are checked to make sure the intersection merge has been completed. In the example, there were five different pieces of information that were originally missing from the analysis. At the end of Stage 6, all of this information has been updated (see [Table 4-8](#)).

Table 4-8. Abbreviated Control Section Milepoint Check for Stage 6.

P-HiNI Mile Point	Adjusted Video MP	Video Mile Values	Check
5.421	5.564	7.12	-0.143
5.433	5.563	7.121	-
11.302	11.406	12.967	-0.103
12.364	12.481	14.043	-0.117
13.327	13.492	15.054	-0.165

- **Stage 7.** In some cases, however, the final dataset still contained some missing information. In these cases, the intersections with missing information were not included in the final analysis. Upon the completion of Stage 6, the researchers felt the intersection database achieved a high level of integrity. After the completion of Stage 6, incorrect data from other areas relating to the geometric characteristics of the roadway were reviewed. The most common errors included typos or missing turn lane length or width values when the presence of a turn lane was indicated. Typos found in the INTER dataset were corrected. Isolated intersections with errors requiring reviewing video were deleted. This deletion was mainly due to limited returns on the time spent correcting isolated errors. For clustered errors located on the same roadway and control section, original videos were rewatched and corrections made accordingly.

ADDITION OF CRASH RECORDS TO INTERSECTION DATASET

For the final analysis, the researchers obtained a 3-year crash history (1999-2001) for each intersection from the DPS RI accident file. In this study, the influence of the intersection was considered to be 250 ft in each direction, or 500 ft total. The mile point values representing the intersection influence area were determined as being 250 ft prior to the intersection mile point and 250 ft after the intersection mile point. In areas where intersections were in close proximity, the distance between the two intersections was split. Under these conditions the 250-ft intersection influence length was not able to be maintained due to the overlapping of the two intersections.

Similar to the crashes associated with the roadway segments, the DPS RI file was merged to the INTER dataset. In this case, the control sections were set equal to each other and the mile point of the crash was greater or equal to the beginning mile point and less than the ending mile point associated with the intersection.

CHAPTER 5

CRASH PREDICTION FOR RURAL TWO-LANE HIGHWAYS

OVERVIEW

The objective of this effort was to determine the relationship between crashes on rural two-lane highways and lane and shoulder widths.

CRASHES

A subset of Texas on-system crashes for the years 1999 to 2001 was used in the analysis.

Crashes associated with surface width should be affected by variability in shoulder width and lane width. In previous research, this type of crash has been referred to as “related crashes” (10, 18). Related crashes are defined as single-vehicle run-off-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe.

The codes in the Texas crash database do not permit using the exact same descriptor to generate “related crashes” as used in previous research; however, similar types of crashes can be identified. The following TxDOT codes were used to identify surface width influenced crashes:

- nonintersection crashes (intersection related code = 4)
- collision code, vehicle movement/manner:
 - two motor vehicles going same direction,
 - two motor vehicles going opposite directions, and
 - single vehicles.

DATA

The roadway segments in the rural two-lane highway dataset represent 3944 miles. On those 3944 miles, a total of 4117 crashes (0.35 annual crashes per mile) occurred, with 3099 crashes meeting SWIC criteria (0.26 annual SWICs per mile). SWICs represented 75 percent of the crashes on the rural two-lane highways included in the dataset.

Roadway characteristic variables examined included:

- lane width (RT Lane),
- shoulder width (RT Shou),
- segment length (Seg Len), and/or
- ADT.

The distribution for each variable is provided in [Figure 5-1](#). Crash rate (crashes per mile) was the method selected for presentation of the number of crashes because each segment length varied. Converting to a common unit – crashes per mile – permitted the graphing of the crash rate by the total number of miles. Bins of 1 crash/mi increments were used. As can be seen in [Figure 5-1](#), the majority of the mileage represented in the dataset had less than 1 crash/mi. The average values and range for the key variables are listed in [Table 5-1](#). In such a large dataset, a few of the segments had right-lane width values that normally would be considered outside of an expected range (e.g., 24-ft right lane width). These wider widths generally reflected widening for a mailbox or the addition of a nonmarked right-turn lane. Those segments with right-lane widths greater than 15 ft were removed.

Table 5-1. Range and Average Values for Rural Two-Lane Highways Dataset.

Variable	Variable Name	Average for Dataset	Range
Average Daily Traffic	ADT	1459	16–19,333
Segment Length (mi)	Seg Len	1.50	0.20–29.37
Lane width (ft)	RT Lane	11.29	9–15
Shoulder width (ft)	RT Shou	3.59	0–13

MODELS

Generalized linear models (GLMs), specifically a negative binomial regression model and a linear regression model, were used to determine the effects of independent variables on SWIC. A negative binomial regression model is often used to model the count data when variance is much larger than the mean (this phenomenon is referred to as overdispersion). Crash frequencies can be predicted by using the mean function of the negative binomial regression. Two goodness-of-fit measures, the mean deviance and the Pearson chi-square ratio (the Pearson chi-square value divided by degrees of freedom), were used to assess the fit of the model. Generally, if the Pearson chi-square ratio is between 0.8 and 1.2, this is an indication that the model can be assumed to be appropriate in modeling the data.

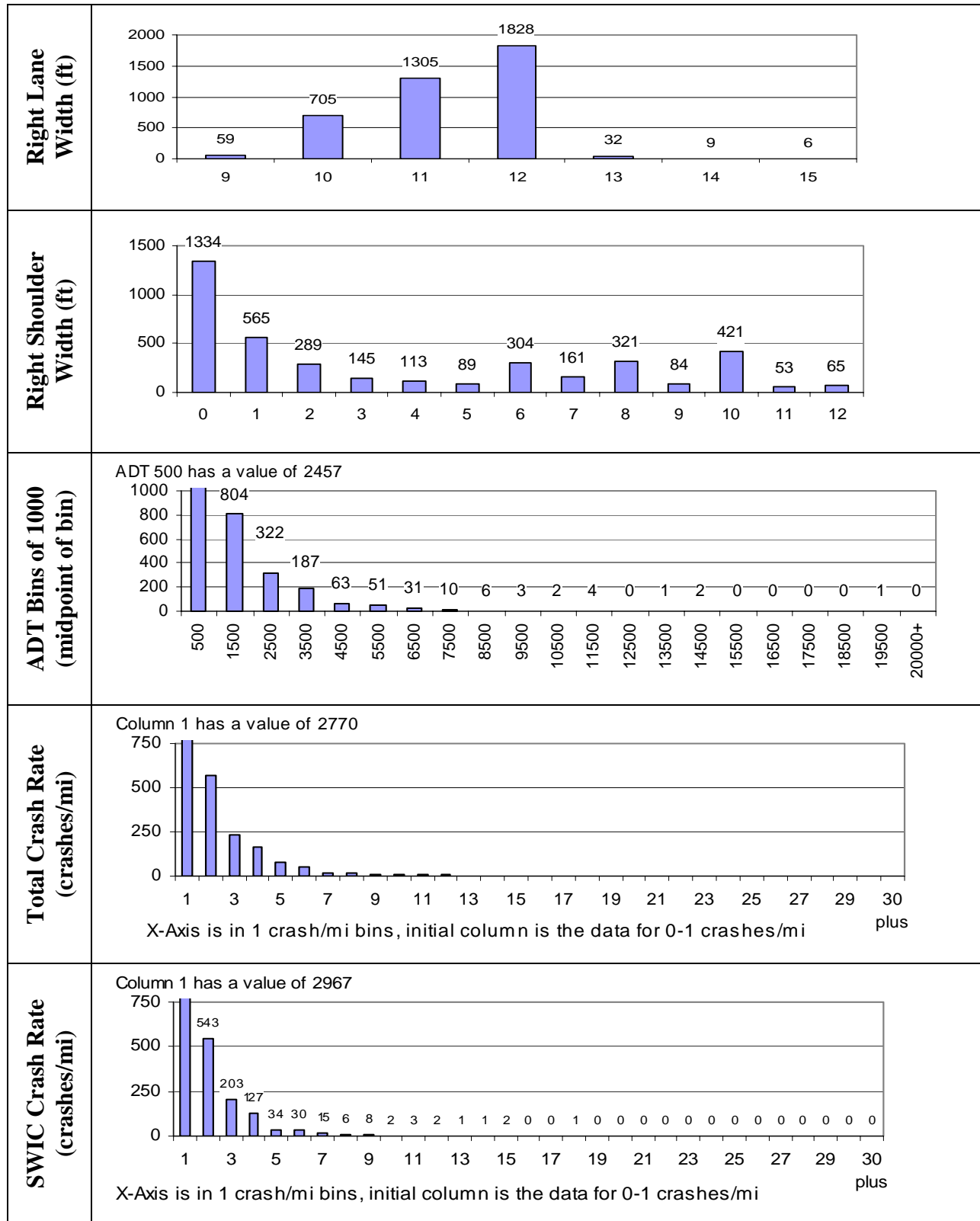


Figure 5-1. Distribution of Variables per Number of Miles for Rural Two-Lane Highway Dataset.

Alternatively, a linear regression model can be applied to the transformed counts. Note that crash frequencies such as SWICs do not follow a normal distribution as they are, and the variance usually increases as the crash frequency increases, which violates the usual assumptions in a linear regression. The purpose of transformation is to make the distribution of the transformed variable close to a normal distribution and to stabilize the variance. It needs to be remembered, however, that in some cases, the problem of nonconstant variance and/or nonnormality may still not be completely corrected even after the transformation is applied. For the count data, the square-root transformation of the form given in the following equation is used conventionally.

$$\text{Transformed Count} = (\text{Count} + 3/8)^{0.5} \quad (1)$$

A linear regression model with a normal error distribution can be employed to develop a prediction equation based on the transformed count. Once the coefficients of the equation are estimated, prediction can also be made for the original untransformed crash frequency by back-transforming transformed crash frequency.

When a variable was not significant at the preestablished alpha level (typically 5 percent), the regression was performed again excluding those variables that did not meet the alpha level.

Negative Binomial Regression Model

Three types of negative binomial regression models were employed:

- Model 1A) Segment Length (Seg Len) and the log of ADT (LogADT) are included as the independent variables in addition to other roadway characteristic variables, RT Lane and RT Shou.
- Model 1B) The log of Segment Length (LogLen) and the log of ADT (LogADT) are included as the independent variables in addition to other roadway characteristic variables, RT Lane and RT Shou.
- Model 1C) Exposure is defined as a function of Seg Len, and ADT is included as an offset variable in addition to RT Lane and RT Shou.

The functional form for the mean of each negative binomial regression model is given below:

$$1A) E(3 \text{ yr SWIC}) = \exp(\beta_0 + \beta_1 \text{ RT Lane} + \beta_2 \text{ RT Shou} + \beta_3 \text{ Seg Len} + \beta_4 \text{ LogADT}) \quad (2)$$

$$1B) E(3 \text{ yr SWIC}) = \exp(\beta_0 + \beta_1 \text{ RT Lane} + \beta_2 \text{ RT Shou} + \beta_3 \text{ LogLen} + \beta_4 \text{ LogADT}) \quad (3)$$

$$1C) E(3 \text{ yr SWIC}) = \text{EXPO}_3 \exp(\beta_0 + \beta_1 \text{ RT Lane} + \beta_2 \text{ RT Shou}) \quad (4)$$

Where:

E(3 yr SWIC)	=	the expected number of SWICs for 3 years,
RT Lane	=	width of right lane (ft),
RT Shou	=	width of right shoulder (ft),
Seg Len	=	length of segment (mi),
ADT	=	average daily traffic for the segment, and
EXPO ₃	=	exposure in million vehicle-miles of travel for 3 years (MVM)
	=	(ADT) (365) (3) (length of segment in miles) (10 ⁻⁶).

Once the predicted values for the 3-year SWICs, E(3 yr SWIC), are obtained, the predicted SWICs per year can be obtained simply by dividing E(3 yr SWIC) by 3.

Tables 5-2, 5-3, and 5-4 contain the SAS outputs for Models 1A, 1B, and 1C, obtained by using SAS PROC GENMOD. Table 5-2 shows that under Model 1A both RT Lane and RT Shou have statistically significant effects at $\alpha = 0.05$ as well as Seg Len and LogADT. The estimated equation for the expected SWICs for two-lane roadways is as follows:

$$E(3 \text{ yr SWIC}) = \exp(-5.1891 - 0.1280 \text{ RT Lane} - 0.0519 \text{ RT Shou} + 0.3935 \text{ Seg Len} + 0.8785 \text{ LogADT}) \quad (5)$$

Table 5-2. Model 1A Information for 3 yr SWIC Data with Negative Binomial Regression.

The GENMOD Procedure							
Model Information							
Data Set	LIB4618.TWO_LANE_GROUP_EXP03						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	SWIC						
Observations Used	2627						
Criteria For Assessing Goodness Of Fit							
Criterion	DF	Value	Value/DF				
Deviance	2622	2299.7970	0.8771				
Scaled Deviance	2622	2299.7970	0.8771				
Pearson Chi-Square	2622	2560.1230	0.9764				
Scaled Pearson X2	2622	2560.1230	0.9764				
Log Likelihood		-805.2984					
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-5.1891	0.4726	-6.1154	-4.2628	120.55	<.0001
RT_Lane	1	-0.1280	0.0387	-0.2039	-0.0520	10.91	0.0010
RT_Shou	1	-0.0519	0.0089	-0.0693	-0.0344	33.99	<.0001
Length	1	0.3935	0.0174	0.3594	0.4277	510.14	<.0001
LogADT	1	0.8785	0.0333	0.8132	0.9437	695.70	<.0001
Dispersion	1	0.7894	0.0551	0.6884	0.9052		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							

Table 5-3 shows that under Model 1B a similar conclusion is drawn; the effect of RT Shou and RT Lane are statistically significant at $\alpha = 0.05$. The estimated equation for the expected 3-year SWICs for two-lane roadways is given as follows:

$$E(3 \text{ yr SWIC}) = \exp(-5.0189 - 0.1126 \text{ RT Lane} - 0.0509 \text{ RT Shou} + 0.9091 \text{ LogLen} + 0.9085 \text{ LogADT}) \quad (6)$$

Table 5-3. Model 1B Information for 3 yr SWIC Data with Negative Binomial Regression.

The GENMOD Procedure							
Model Information							
Data Set	LIB4618.TWO_LANE_GROUP_EXPO3						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	SWIC						
Observations Used	2627						
Criteria For Assessing Goodness Of Fit							
Criterion	DF	Value	Value/DF				
Deviance	2622	2400.5660	0.9155				
Scaled Deviance	2622	2400.5660	0.9155				
Pearson Chi-Square	2622	3120.4959	1.1901				
Scaled Pearson X2	2622	3120.4959	1.1901				
Log Likelihood		-619.1623					
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-5.0189	0.4313	-5.8643	-4.1735	135.40	<.0001
RT_Lane	1	-0.1126	0.0359	-0.1829	-0.0422	9.83	0.0017
RT_Shou	1	-0.0509	0.0080	-0.0665	-0.0352	40.67	<.0001
LogLength	1	0.9091	0.0266	0.8569	0.9614	1164.38	<.0001
LogADT	1	0.9085	0.0299	0.8498	0.9672	920.49	<.0001
Dispersion	1	0.3946	0.0405	0.3227	0.4826		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							

Table 5-4 shows that under Model 1C the effect of RT Lane and RT Shou are significant at $\alpha = 0.05$. The estimated equation for the expected 3-year SWICs for two-lane roadways is given as follows:

$$E(3 \text{ yr SWIC}) = \text{EXPO}_3 \exp(1.2305 - 0.1196 \text{ RT Lane} - 0.0617 \text{ RT Shou}) \quad (7)$$

Table 5-4. Model 1C Information for 3 yr SWIC Data with Negative Binomial Regression.

The GENMOD Procedure							
Model Information							
Data Set	LIB4618.TWO_LANE_GROUP_EXP03						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	SWIC						
Offset Variable	LogEXP03						
Observations Used	2627						
Criteria For Assessing Goodness Of Fit							
Criterion	DF	Value	Value/DF				
Deviance	2624	2405.1687	0.9166				
Scaled Deviance	2624	2405.1687	0.9166				
Pearson Chi-Square	2624	3484.2932	1.3279				
Scaled Pearson X2	2624	3484.2932	1.3279				
Log Likelihood		-626.6774					
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	1.2305	0.4011	0.4443	2.0167	9.41	0.0022
RT_Lane	1	-0.1196	0.0369	-0.1919	-0.0474	10.53	0.0012
RT_Shou	1	-0.0617	0.0074	-0.0762	-0.0473	70.03	<.0001
Dispersion	1	0.4020	0.0410	0.3291	0.4910		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							

From the “Criteria for Assessing Goodness of Fit” table (see Tables 5-2 to 5-4), it can be seen that the negative binomial Models 1A, 1B, and 1C fit the data fairly well. Both deviance and Pearson chi-square divided by degrees of freedom are close to 1 for all three models.

Linear Regression Model for Transformed SWIC (TSWIC)

The SWICs were transformed using the following equation:

$$3 \text{ yr TSWIC} = (3 \text{ yr SWIC} + 3/8)^{0.5} \quad (8)$$

Initially, two types of linear regression models were fitted on the transformed SWIC data:

- Model 2A) Segment Length (Seg Len) and the log of ADT (LogADT) are included as the independent variables in addition to RT Lane and RT Shou.
- Model 2B) The log of Segment Length (LogLen) and the log of ADT (LogADT) are included as the independent variables in addition to RT Lane and RT Shou.

Reviews of the findings and the desire to match the variable format with the greatest promise from the negative binominal regression resulted in an emphasis of the Model 2B form. [Table 5-5](#) contains the result of the fit for TSWIC for Model 2B. In the initial model, RT Lane was not significant. The bottom half of [Table 5-5](#) shows the output when RT Shou, LogLen, and LogADT are included. This model has an adjusted r-square of 0.38.

The prediction equations for TSWIC (the estimated equations for the expected TSWIC) can be written as follows:

Prediction equations for TSWIC under Model 2B:

$$E(3 \text{ yr TSWIC}) = -0.6498 - 0.0108 \text{ RT Shou} + 0.3158 \text{ LogLen} + 0.2684 \text{ LogADT} \quad (9)$$

The prediction equations for SWICs (the estimated equation for the expected SWIC) can be obtained by back-transforming TSWIC using the relationship shown above. The predicted values are for 3-year SWIC. The predicted SWIC per year can be obtained simply by dividing E(3 yr SWIC) by 3.

Prediction equations for SWIC under Model 2B:

$$E(\text{SWIC}) = [(-0.6498 - 0.0108 \text{ RT Shou} + 0.3158 \text{ LogLen} + 0.2684 \text{ LogADT})^2 - 3/8]/3 \quad (10)$$

Table 5-5. Information for 3 yr TSWIC with Least-Squares Fit.

(A) Linear with RT Lane, RT Shou, LogLen, and LogADT				
Response TSWIC (Transformed SWIC)				
Summary of Fit				
RSquare		0.381356		
RSquare Adj		0.380413		
Root Mean Square Error		0.507087		
Mean of Response		1.067622		
Observations (or Sum Wgts)		2627		
Analysis of Variance				
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	415.6129	103.903	404.0763
Error	2622	674.2150	0.257	Prob > F
C. Total	2626	1089.8280		<.0001
Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	-0.626177	0.144022	-4.35	<.0001
RT Lane	-0.002135	0.011708	-0.18	0.8553
RT Shou	-0.010584	0.003145	-3.37	0.0008
LogLen	0.3156523	0.009828	32.12	<.0001
LogADT	0.2683329	0.010001	26.83	<.0001
(B) Linear with RT Shou, LogLen, and LogADT				
Response TSWIC (Transformed SWIC)				
Summary of Fit				
RSquare		0.381349		
RSquare Adj		0.380641		
Root Mean Square Error		0.506994		
Mean of Response		1.067622		
Observations (or Sum Wgts)		2627		
Analysis of Variance				
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	415.6044	138.535	538.9559
Error	2623	674.2236	0.257	Prob > F
C. Total	2626	1089.8280		<.0001
Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	-0.649782	0.063129	-10.29	<.0001
RT Shou	-0.010786	0.002942	-3.67	0.0003
LogLen	0.3157638	0.009808	32.20	<.0001
LogADT	0.2683679	0.009997	26.84	<.0001

Selection of Model

All of the models developed and presented within this chapter fit the data well. Models 1A and 1B were preferred over Model 1C (where exposure is considered as an offset variable) and the linear regression models (negative binomial is a better match with the distribution of the data). Model 1B is preferred over 1A and 1C because experimenting with the models revealed questionable results for model 1A (which included segment length) and model 1C (which included segment length as part of an offset variable) for longer segment lengths (on the order of 7 miles and more). Experimenting with the linear regression models also revealed that the negative binomial equations provided more reasonable results for the range of segment lengths reviewed (1 to 10 miles). Therefore, the following evaluations are performed using the negative binomial regression model where LogLen and LogADT are included as independent variables in addition to RT Lane and RT Shou. The selected regression equation for two-lane highways is:

$$E(\text{SWIC}) = [\exp(-5.0189 - 0.1126 \text{ RT Lane} - 0.0509 \text{ RT Shou} + 0.9091 \text{ LogLen} + 0.9085 \text{ LogADT})]/3 \quad (11)$$

COMPARISON BETWEEN ACTUAL DATA AND PREDICTED VALUES

While the statistical evaluation results indicate that the developed models are a good fit with the data, a visual review of the actual data with the results from the prediction equation shows the variability in the data. [Figure 5-2](#) shows the number of SWICs on a per-year and per-mile basis for segments with 12-ft lanes and ADTs greater than 2000. [Figure 5-3](#) shows similar data for segments with ADTs less than or equal to 2000. Also on these figures is a plot of the results from using the regression model for ADT of 4000 and 1000, respectively. The plot of the regression equation results represents the mean value over roadway segments of similar conditions.

As can be seen in [Figures 5-2 and 5-3](#), there are segments with annual SWICs/mile much greater (and less) than that predicted using the regression equation. This is important to consider, as the regression equation is used in selecting a lane width or a shoulder width. While on average using a wider shoulder should result in fewer crashes than using a narrow shoulder (as demonstrated by the downward slope of the regression equation), not all situations will have that result.

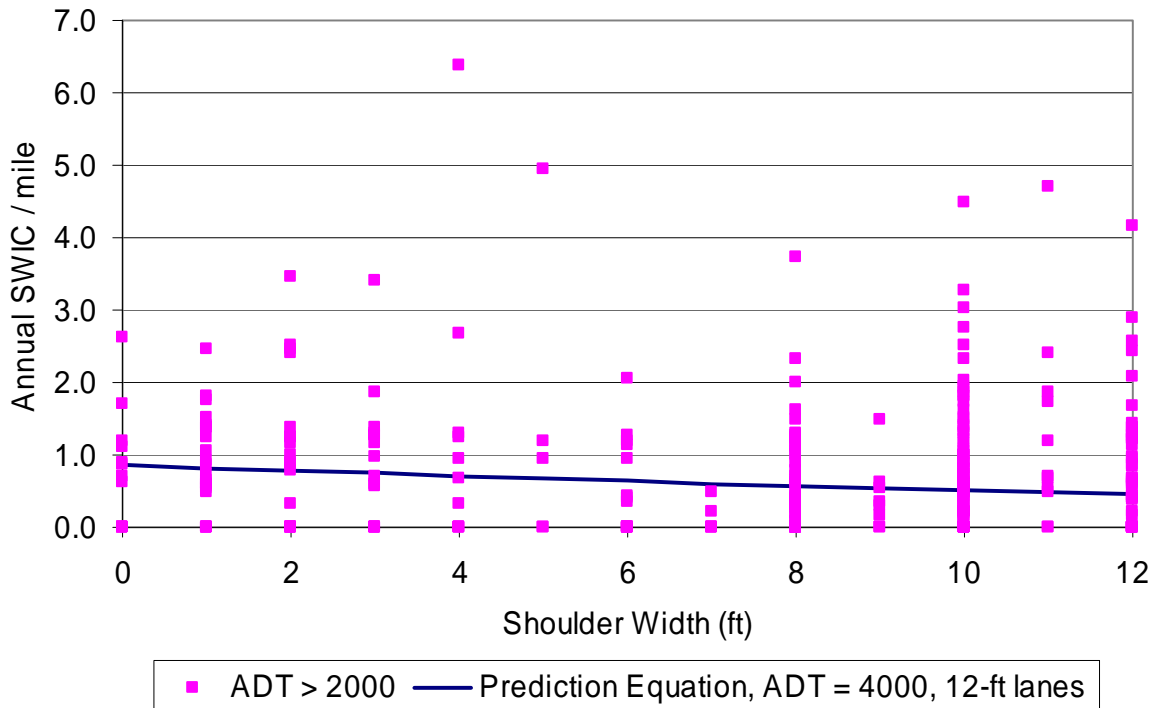


Figure 5-2. Comparison of Results from Prediction Equation to Actual Data for Roadway Segments with ADT Greater Than 2000.

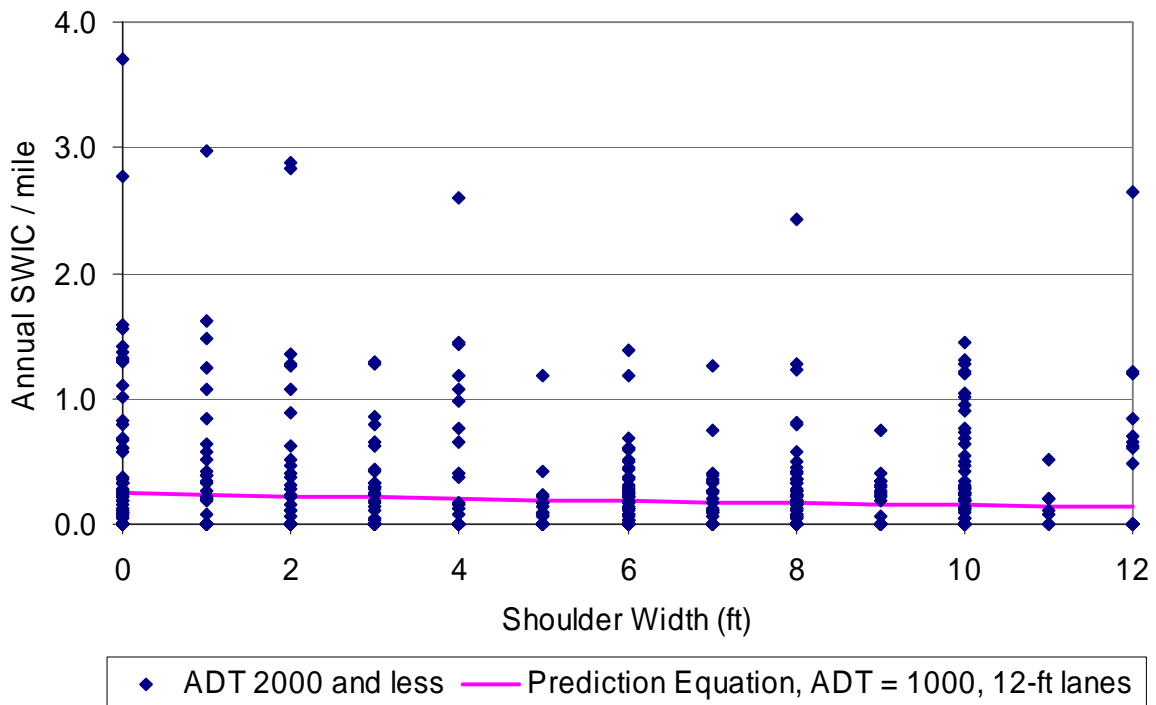


Figure 5-3. Comparison of Results from Prediction Equation to Actual Data for Roadway Segments with ADT 2000 or Less.

EFFECTS OF VARIABLES

The regression evaluation found the following variables to affect the crash prediction: ADT, lane width, shoulder width, and segment length. Figures 5-4 and 5-5 illustrate the effect that some of the variables have on crash prediction for rural two-lane highways by shoulder width and lane width, respectively.

As ADT increases, the number of SWICs also increases. For example, the number of crashes on a roadway segment with 4000 ADT is about 8.1 times the number of crashes on a roadway segment with only 400 ADT. Figure 5-4 provides a plot of the predictions by ADT and shoulder width, while Figure 5-5 shows the plot by ADT and lane width. These plots were developed assuming a 10 mile segment and then converted to a per-mile increment.

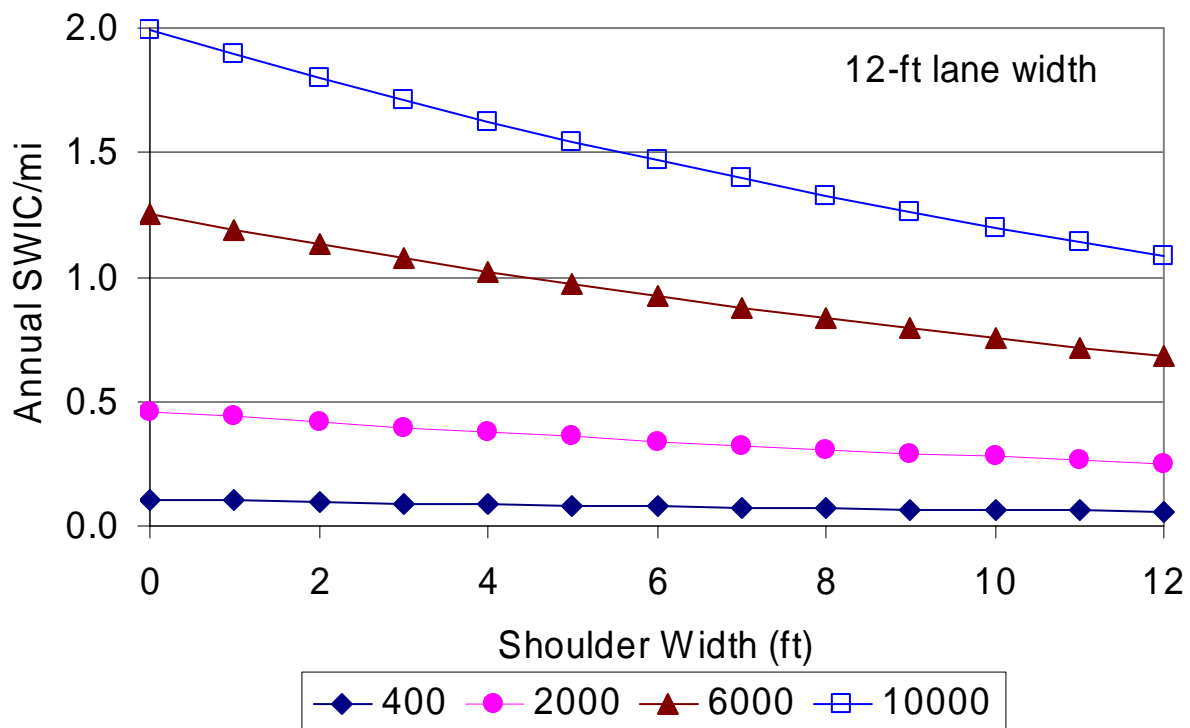


Figure 5-4. Comparison of Results from Prediction Equation by Shoulder Width for a Range of ADT Values.

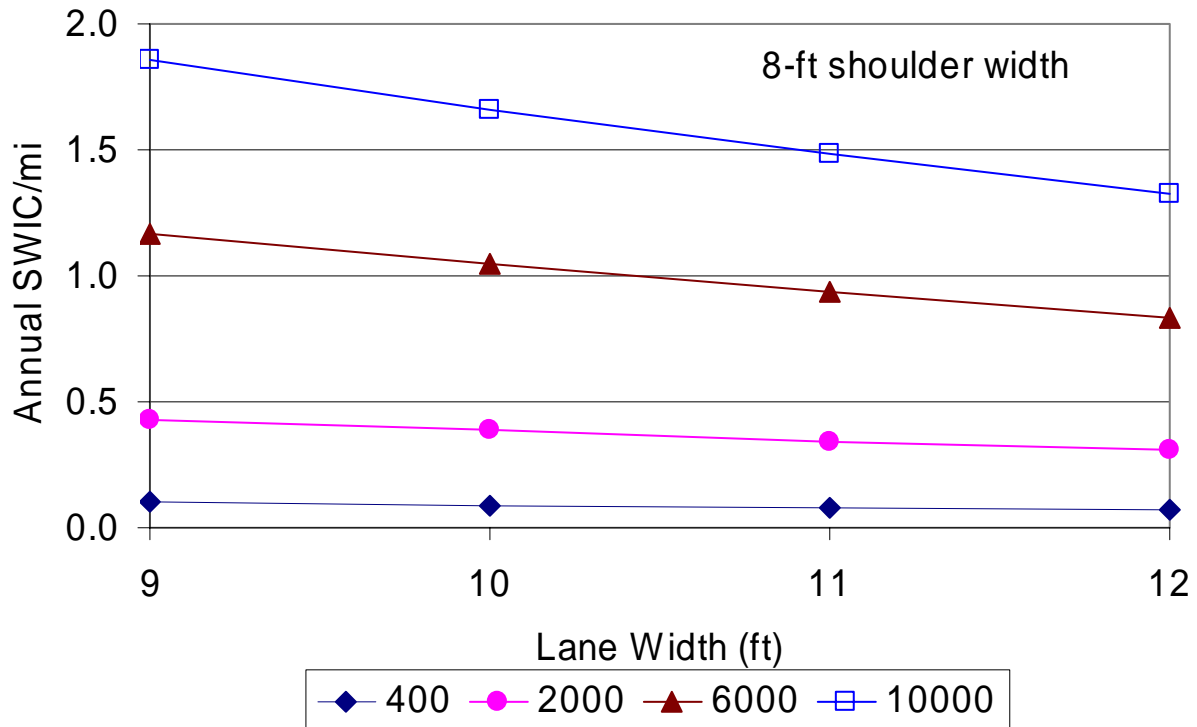


Figure 5-5. Comparison of Results from Prediction Equation by Lane Width for a Range of ADT Values.

RATIO

The ratio between the numbers of crashes at different lane width or shoulder width values can provide an appreciation for the potential benefit of widening a lane or shoulder. The ratio of crashes to a 12-ft lane and an 8-ft shoulder width is listed in [Table 5-6](#) and shown in [Figure 5-6](#).

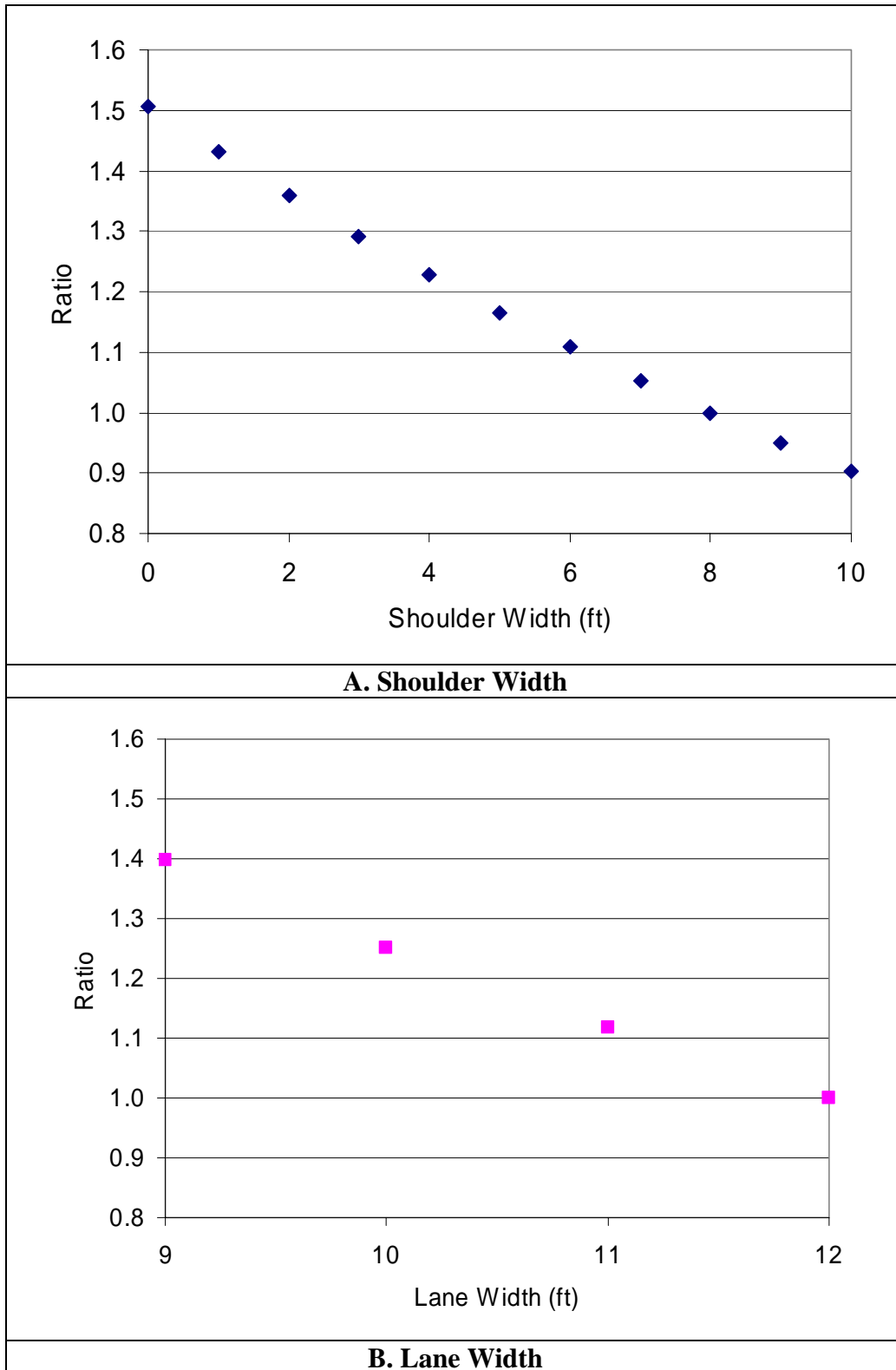


Figure 5-6. Plot of Ratios for Lane Width and Shoulder Widths for Rural Two-Lane Highways.

Table 5-6. List of Ratios for Lane Width and Shoulder Widths for Rural Two-Lane Highways Based on Predictions of SWICs.

Lane Width (ft)	Ratio to 12-ft lane
12	1.00
11	1.12
10	1.25
9	1.40
Shoulder Width (ft)	Ratio to 8-ft lane
10	0.90
9	0.95
8	1.00
7	1.05
6	1.11
5	1.16
4	1.23
3	1.29
2	1.36
1	1.43
0	1.50

Other researchers have examined the benefits of widening lanes and shoulders. The most current knowledge on the topic is represented in the *Draft Prototype Chapter (2)* developed for consideration of the forthcoming *Highway Safety Manual*. Background material on the *Draft Prototype Chapter* is included in [Chapter 2](#) of this TxDOT report. A comparison of the findings from this project with the *Draft Prototype Chapter* can provide an appreciation of whether similar trends are present for Texas as assumed for the nation. The *DPC* uses accident modification factors to describe the relationship between crashes and roadway or roadside variables. The AMF is applied to the crash prediction for the base condition. The two AMFs of interest to this project are lane width and shoulder width AMFs. The AMF is adjusted to reflect the proportion of the ‘related’ crashes to total crashes. The base condition assumes 12-ft lanes and 6-ft shoulders.

The *Draft Prototype Chapter* assumes smaller AMFs for lane and shoulder widths with ADTs of less than 2000. The data available in this study were reviewed to determine if different ratios would be present within different ADT groups. The roadway segments were subdivided into three ADT groups: less than 400, between 400 and 2000, and greater than 2000. These groups represent the divisions assumed in the *DPC*. [Table 5-7](#) lists the general statistics for each group.

Different variables were significant in the individual ADT groups as compared to the entire dataset. The SAS output is in [Table 5-8](#) (<400 ADT), [Table 5-9](#) (400 to 2000 ADT) and [Table 5-10](#) (>2000 ADT). The regression analysis of those roadway segments with ADT of less than 400 found RT Lane and RT Shou not significant. The middle ADT range found all four variables significant, similar to the evaluation using all data. The high ADT range found lane width not to be significant, which is not very surprising given that 70 percent of those roadways had 12-ft lanes.

Table 5-7. Range and Average Values for Rural Two-Lane Highways Roadway Characteristics by ADT Group.

Variable	Average (Range) or Total for Dataset		
	<400	400 to 2000	>2000
ADT	216 (16–396)	1002 (403–1983)	3795 (2000–19,333)
Seg Len (mi)	1.83 (0.20–24.16)	1.52 (0.20–29.37)	1.08 (0.20–10.50)
RT Lane (ft)	11.08 (9–15)	11.20 (9–15)	11.55 (9–15)
RT Shou (ft)	1.27 (0–12)	3.67 (0–12)	6.06 (0–13)
Total Crashes (3 yr)	275	1828	2014
3 yr SWICs	235	1450	1414
Total Miles	1317	1944	683

Table 5-8. SAS Output for Analysis by ADT Group, ADT<400.

```

The GENMOD Procedure

Model Information

Data Set          LIB4618.TWO_LN_8_29_ADT_LESS_400
Distribution      Negative Binomial
Link Function     Log
Dependent Variable SWIC
Observations Used 720

Criteria For Assessing Goodness Of Fit

Criterion          DF          Value          Value/DF
-----
Deviance           717          449.9283        0.6275
Scaled Deviance   717          449.9283        0.6275
Pearson Chi-Square 717          770.5960        1.0748
Scaled Pearson X2  717          770.5960        1.0748
Log Likelihood    -392.3273

Algorithm converged.

Analysis Of Parameter Estimates

Parameter    DF    Estimate    Standard Error    Wald 95% Confidence Limits    Chi-Square    Pr > Chi Sq
-----
Intercept   1    -6.3470    0.8893    -8.0899    -4.6041    50.94    <.0001
LogLength   1     0.8678    0.0836     0.7040     1.0316    107.83    <.0001
LogADT      1     0.8977    0.1616     0.5809     1.2145     30.84    <.0001
Dispersion  1     0.6528    0.2154     0.3418     1.2465
    
```

NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood

Table 5-9. SAS Output for Analysis by ADT Group, ADT between 400 and 2000.

```

The GENMOD Procedure

Model Information

Data Set          LIB4618.TWO_LN_8_29_ADT_BT_400_AND_2000
Distribution      Negative Binomial
Link Function     Log
Dependent Variable SWI C
Observations Used 1284

Criteria For Assessing Goodness Of Fit

Criterion          DF          Value          Value/DF
Deviance           1279         1233.4829         0.9644
Scaled Deviance    1279         1233.4829         0.9644
Pearson Chi-Square 1279         1497.4227         1.1708
Scaled Pearson X2  1279         1497.4227         1.1708
Log Likelihood     -612.8638

Algorithm converged.

Analysis Of Parameter Estimates

Parameter    DF    Estimate    Standard Error    Wald 95% Confidence Limits    Chi-Square    Pr > Chi Sq
Intercept    1     -3.2045     0.8045            -4.7814    -1.6277         15.87         <.0001
RT_Lane      1     -0.1760     0.0520            -0.2780    -0.0741         11.46         0.0007
RT_Shoulder  1     -0.0471     0.0121            -0.0708    -0.0234         15.19         <.0001
LogLength    1     0.8644     0.0369            0.7921     0.9367         549.48        <.0001
LogADT       1     0.7568     0.0833            0.5936     0.9200         82.60         <.0001
Dispersion   1     0.4463     0.0619            0.3401     0.5857

NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.
    
```

Table 5-10. SAS Output for Analysis by ADT Group, ADT>2000.

```

The GENMOD Procedure

Model Information

Data Set          LIB4618.TWO_LN_8_29_ADT_GT_2000
Distribution      Negative Binomial
Link Function     Log
Dependent Variable SWI C
Observations Used 623

Criteria For Assessing Goodness Of Fit

Criterion          DF          Value          Value/DF
Deviance           619         671.7937         1.0853
Scaled Deviance    619         671.7937         1.0853
Pearson Chi-Square 619         689.4237         1.1138
Scaled Pearson X2  619         689.4237         1.1138
Log Likelihood     400.2629

Algorithm converged.

Analysis Of Parameter Estimates

Parameter    DF    Estimate    Standard Error    Wald 95% Confidence Limits    Chi-Square    Pr > Chi Sq
Intercept    1     -6.4971     0.8022            -8.0695    -4.9247         65.59         <.0001
RT_Shoulder  1     -0.0616     0.0103            -0.0818    -0.0414         35.80         <.0001
LogLength    1     0.9956     0.0430            0.9114     1.0798         536.86        <.0001
LogADT       1     0.9348     0.1009            0.7370     1.1325         85.80         <.0001
Dispersion   1     0.2979     0.0486            0.2164     0.4101

NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.
    
```


Figure 5-7 shows the ratio using Texas data to the AMFs presented in the *Highway Safety Manual*. Table 5-11 lists the values. The *DPC* AMF assumes that 6 ft represents the desirable minimum shoulder width and that shoulder widths in excess of 8 ft provide no additional benefits. The *DPC* AMFs were adjusted to reflect an 8-ft desirable shoulder width to provide a better comparison with the Texas findings. The Texas data revealed a similar trend as that being assumed on the national level for shoulder widths less than 8 ft. The Texas data did show benefits of 10-ft shoulders over 8-ft shoulders, while the *DPC* assumes no additional benefits. The amount of increases in crashes at very low shoulder widths is assumed to be slightly greater at the national level than found using Texas data. For example, for no shoulders, the *DPC* assumes that related crashes will be 1.72 times the crash value if 8-ft shoulders were present. The Texas data found that crashes will be 1.50 times the crash value if 8-ft shoulders were present.

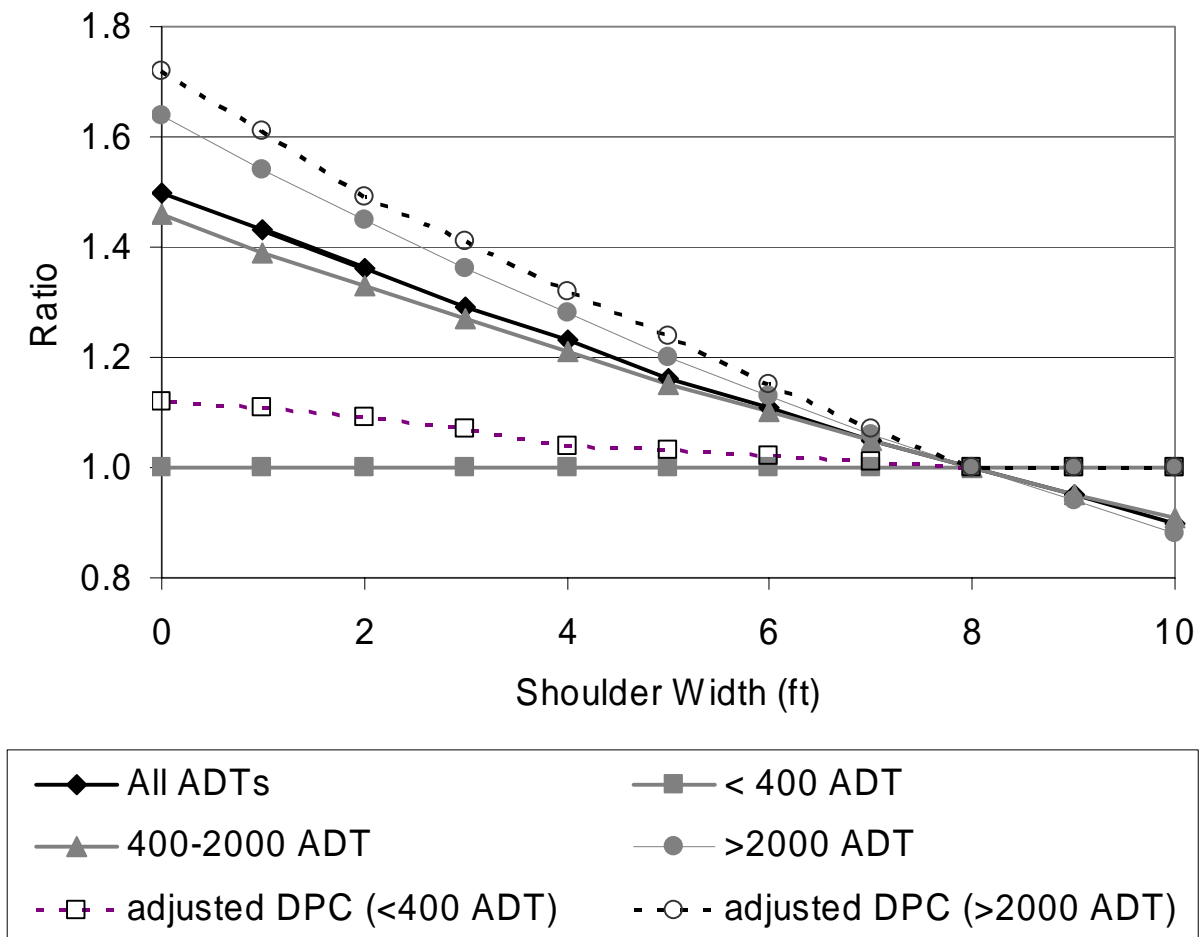


Figure 5-7. Comparison of Texas Findings to *Draft Prototype Chapter* for Shoulder Width.

Table 5-11. Ratios for Shoulder Widths for Rural Two-Lane Highways by ADT Groups for Texas Data and DPC Values.

Shoulder Width (ft)	Ratio of Number of Crashes for Given Shoulder Width to Number of Crashes on a Roadway with an 8-ft Shoulder					
	Roadway Segments with Following ADT Values:					
	Texas Data				DPC (adjusted)	
	All ADTs	<400	400 to 2000	>2000	<400	>2000
10	0.90	1.00	0.91	0.88	1.00	1.00
9	0.95	1.00	0.95	0.94	1.00	1.00
8	1.00	1.00	1.00	1.00	1.00	1.00
7	1.05	1.00	1.05	1.06	1.01	1.07
6	1.11	1.00	1.10	1.13	1.02	1.15
5	1.16	1.00	1.15	1.20	1.03	1.24
4	1.23	1.00	1.21	1.28	1.04	1.32
3	1.29	1.00	1.27	1.36	1.07	1.41
2	1.36	1.00	1.33	1.45	1.09	1.49
1	1.43	1.00	1.39	1.54	1.11	1.61
0	1.50	1.00	1.46	1.64	1.12	1.72

Similar relationships are present when comparing the AMF for lane widths to the ratios developed in this project as shown in [Figure 5-8](#) and [Table 5-12](#). A trend showing increased crashes as lane width decreases is present with the extreme values (i.e., at 9-ft lanes) being less for the Texas data (when all roadways are considered) than currently being assumed for the national data. Lane width effect on crashes for roadways greater than 2000 ADT was found to be not significant. This finding is influenced by the large number of segments with 12-ft lanes (over 70 percent). Therefore, using the findings for all ADTs would better represent the influence of lane width if a mix of ADTs is present.

Table 5-12. Ratios for Lane Widths for Rural Two-Lane Highways by ADT Groups for Texas Data and DPC Values.

Lane Width (ft)	Ratio of Number of Crashes for Given Lane Width to Number of Crashes on a Roadway with a 12-ft Lane Width					
	Roadway Segments with Following ADT Values:					
	Texas Data				DPC (adjusted)	
	All ADTs	<400	400 to 2000	>2000	<400	>2000
12	1.00	1.00	1.00	1.00	1.00	1.00
11	1.12	1.00	1.19	1.00	1.01	1.05
10	1.25	1.00	1.42	1.00	1.02	1.30
9	1.40	1.00	1.70	1.00	1.05	1.50

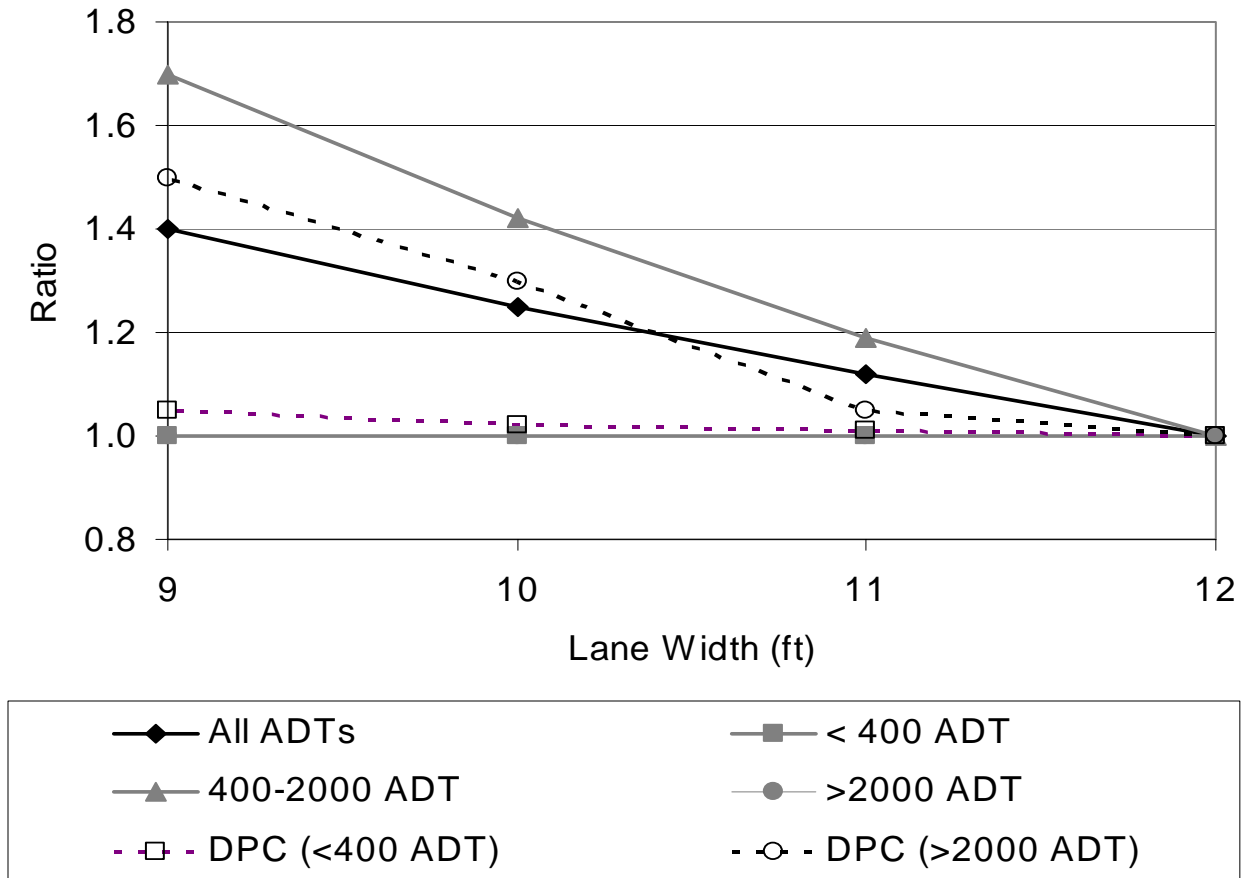


Figure 5-8. Comparison of Texas Findings to Draft Prototype Chapter for Lane Width.

COMPARISON WITH TOTAL CRASHES AND KAB CRASHES

A review of the literature indicates that selected types of crashes are affected by changes in lane width and shoulder width. Zegeer and Council (9) state "...since lane and shoulder width logically affect some crash types (e.g., run-off-road, head-on) but not necessarily other crash types (e.g., angle, rear-end), there is a need to express crash effects as a function of those crash types affected by lane and shoulder width." While a subset of crashes (called surface width influence crashes, SWICs) was used in this Texas analysis, a check was made to see if the relationship between crash prediction using total crashes and lane or shoulder width is different. The available width of a shoulder may not be a direct influence on the cause of certain types of crashes (e.g., rear-end or angle) because it does not contribute to the reason for the slowing or stopping vehicle (e.g., a turning vehicle to an intersection). The available width of a shoulder does affect the opportunity for evasive actions by the following vehicle. For example, the

following vehicle may be able to avoid the stopped vehicle by moving onto a sufficient width shoulder. Therefore, shoulder width could affect all types of crashes.

Negative binomial regression was performed using total crashes. Similar model forms were tested as used with the SWICs. The SAS output for the preferred model is shown in [Table 5-13](#). [Figure 5-9](#) compares the ratio of number of crashes at different shoulder widths to number of crashes at an 8-ft shoulder width. [Figure 5-10](#) shows the ratio of number of crashes at different lane widths to number of crashes at a 12-ft lane width. These plots indicate that total crashes have similar trends as SWICs; hence, all crashes may be just as affected by the width of the lane or the shoulder as SWICs are. The values are listed in [Table 5-14](#).

The *Draft Prototype Chapter* assumes that the lane width and shoulder width AMFs (similar to the “ratio” being used in this study) are only applied to “related accidents.” Additional, more focused research may be needed to determine if the AMFs assumed in the *Draft Prototype Chapter* should continue to be applied only to related accidents or if they should be applied to all crashes.

A check was also performed using KAB crashes. KAB crashes are defined as those crashes involving a fatality (K), an incapacitating injury (A), or a nonincapacitating injury (B). Concerns have been expressed with the quality of noninjury and PDO crash data, especially their high nonreporting rates. Because of those concerns, KAB crashes were also reviewed to determine if different patterns exist between KAB crashes and shoulder width or lane width. Negative binomial regression was performed using similar model forms as tested for SWICs. [Table 5-15](#) lists the SAS output. For SWIC KABs, RT Lane was not significant. For total crash KABs, all variables were significant. [Figure 5-11](#) shows the shoulder width ratio and [Figure 5-12](#) shows the lane width ratio. KAB crashes have a similar trend to that found for SWICs for shoulder width. The KAB total crashes have a similar trend (higher ratio with decrease in lane width) to that found for total crashes for lane width although the ratio value is smaller for KAB crashes than total crashes.

Table 5-13. Model Information for 3 yr Total Crash Data with Negative Binomial Regression.

The GENMOD Procedure

Model Information

Dataset LIB4618.TWO_LANE_GROUP_EXP03
 Distribution Negative Binomial
 Link Function Log
 Dependent Variable Total_Accident Total Accident
 Observations Used 2627

Criteria for Assessing Goodness of Fit

Criterion	DF	Value	Value/DF
Deviance	2622	2504.2498	0.9551
Scaled Deviance	2622	2504.2498	0.9551
Pearson Chi-Square	2622	3110.7341	1.1864
Scaled Pearson X2	2622	3110.7341	1.1864
Log Likelihood		462.9171	

Algorithm converged.

Analysis of Parameter Estimates

Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-5.0981	0.3973	-5.8767	-4.3195	164.69	<.0001
RT_Lane	1	-0.1372	0.0332	-0.2022	-0.0722	17.12	<.0001
RT_Shou	1	-0.0601	0.0074	-0.0746	-0.0456	66.39	<.0001
LogLen	1	0.8514	0.0246	0.8031	0.8997	1193.35	<.0001
LogADT	1	1.0045	0.0281	0.9495	1.0596	1280.92	<.0001
Dispersion	1	0.4213	0.0361	0.3561	0.4983		

NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.

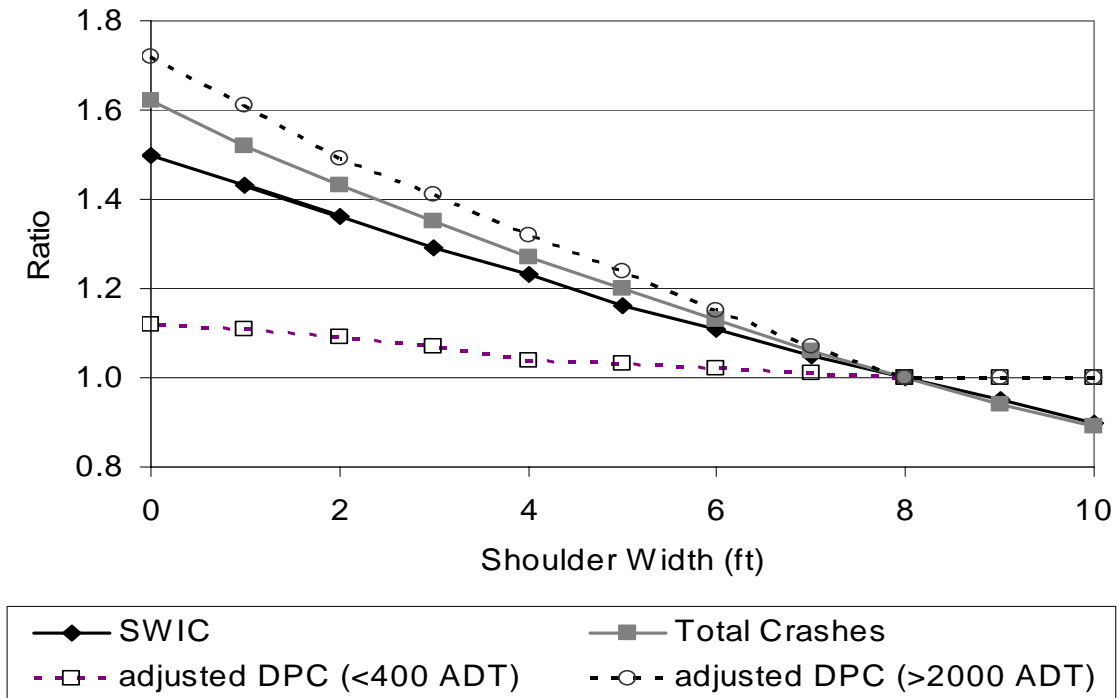


Figure 5-9. Comparison of Total Crash to SWIC for Shoulder Width.

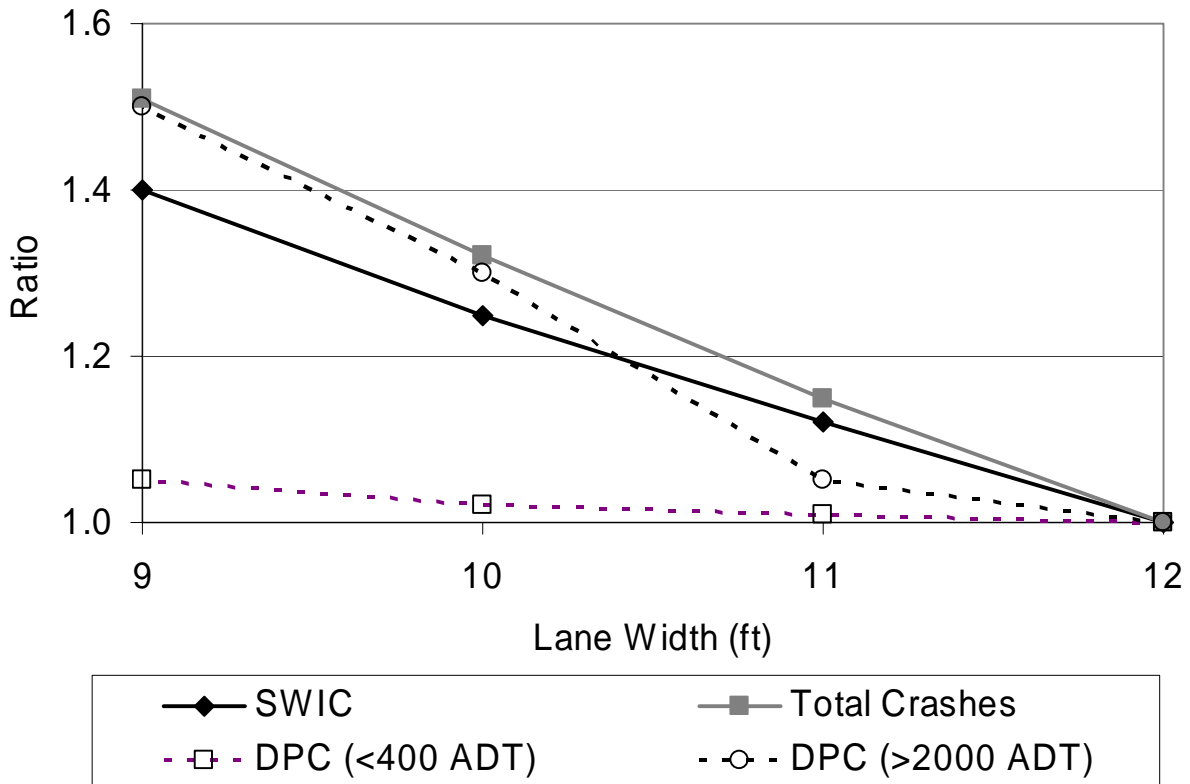


Figure 5-10. Comparison of Total Crash to SWIC for Lane Width.

Table 5-14. List of Ratios for Lane Width and Shoulder Widths for Rural Two-Lane Highways Based on Predictions of Total Crashes.

Lane Width (ft)	Ratio to 12-ft lane
12	1.00
11	1.15
10	1.32
9	1.51
Shoulder Width (ft)	Ratio to 8-ft lane
10	0.89
9	0.94
8	1.00
7	1.06
6	1.13
5	1.20
4	1.27
3	1.35
2	1.43
1	1.52
0	1.62

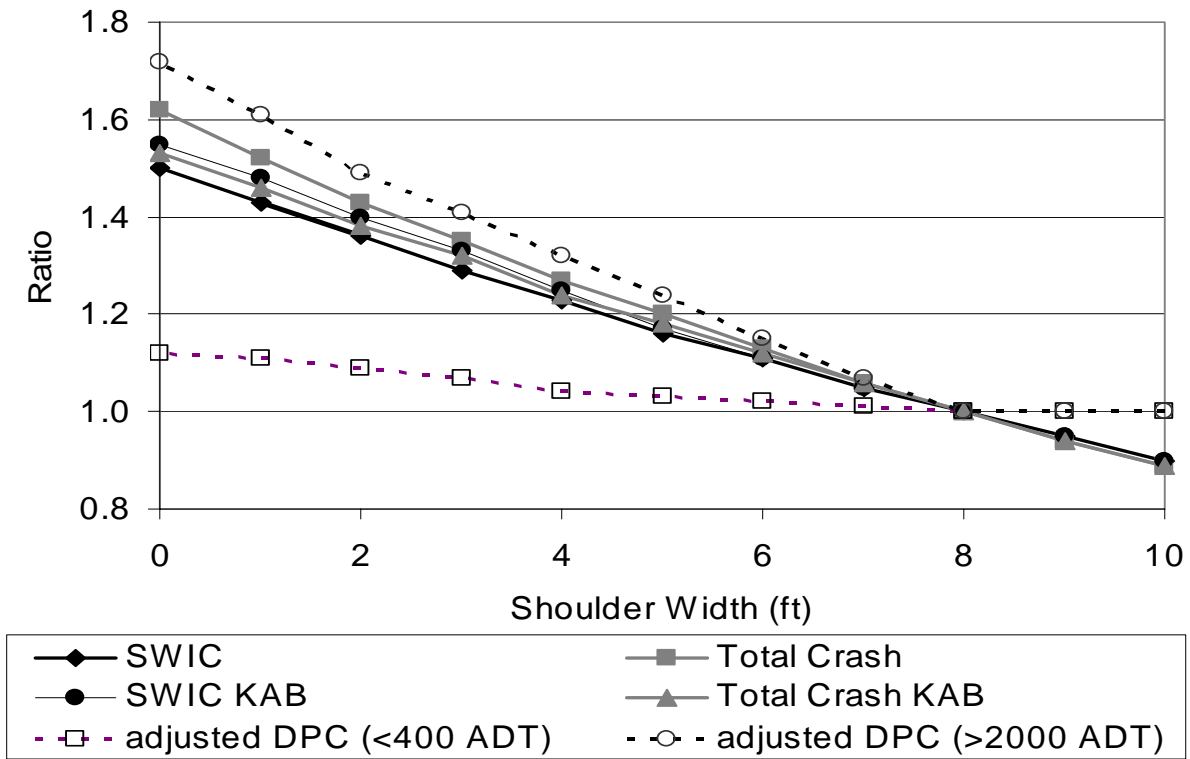


Figure 5-11. Comparison of Total Crash KABs and SWIC KABs to Total Crashes and SWICs for Shoulder Width.

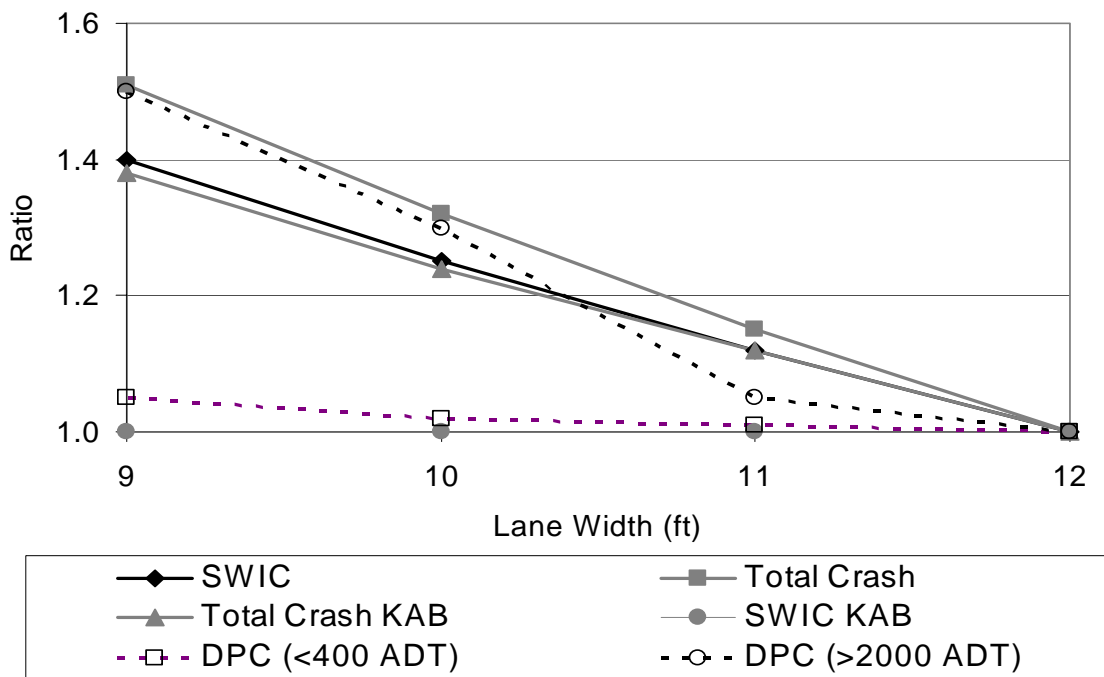


Figure 5-12. Comparison of Total Crash KABs and SWIC KABs to Total Crashes and SWICs for Lane Width.

Table 5-15. Model Information for 3 yr Crash KAB and 3 yr SWIC KAB Data with Negative Binomial Regression.

The GENMOD Procedure							
Model Information							
Dataset	LIB4618. TWO_LANE_GROUP_EXPO3						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	SWIC_KAB			SWIC KAB			
Observations Used	2627						
Criteria For Assessing Goodness Of Fit							
Criterion	DF	Value	Value/DF				
Deviance	2622	1871.7388	0.7139				
Scaled Deviance	2622	1871.7388	0.7139				
Pearson Chi-Square	2622	2935.0363	1.1194				
Scaled Pearson X2	2622	2935.0363	1.1194				
Log Likelihood		-1419.2520					
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > Chi Sq
Intercept	1	-6.2274	0.5971	-7.3977	-5.0571	108.77	<.0001
RT_Lane	1	-0.0635	0.0496	-0.1607	0.0338	1.64	0.2009
RT_Shoulder	1	-0.0495	0.0107	-0.0706	-0.0285	21.33	<.0001
LogLength	1	0.9364	0.0363	0.8652	1.0075	665.33	<.0001
LogADT	1	0.8701	0.0402	0.7913	0.9490	467.93	<.0001
Dispersion	1	0.3387	0.0657	0.2315	0.4954		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							
The GENMOD Procedure							
Model Information							
Dataset	LIB4618. TWO_LANE_GROUP_EXPO3						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	Total_Accident_KAB			Total Accident KAB			
Observations Used	2627						
Criteria For Assessing Goodness Of Fit							
Criterion	DF	Value	Value/DF				
Deviance	2622	2041.0508	0.7784				
Scaled Deviance	2622	2041.0508	0.7784				
Pearson Chi-Square	2622	3065.6796	1.1692				
Scaled Pearson X2	2622	3065.6796	1.1692				
Log Likelihood		-1413.4652					
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > Chi Sq
Intercept	1	-5.9636	0.5341	-7.0105	-4.9168	124.66	<.0001
RT_Lane	1	-0.1072	0.0445	-0.1945	-0.0200	5.81	0.0160
RT_Shoulder	1	-0.0542	0.0096	-0.0731	-0.0354	31.75	<.0001
LogLength	1	0.8740	0.0325	0.8103	0.9377	723.32	<.0001
LogADT	1	0.9466	0.0367	0.8747	1.0186	664.59	<.0001
Dispersion	1	0.3569	0.0558	0.2627	0.4848		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							

WIDEN SHOULDER OR WIDEN LANE FIRST?

The ratios indicate that a 1-ft increase in pavement for a travel lane provides greater reduction in SWICs than a 1-ft increase in a shoulder. For example, if a rural two-lane highway with 2000 ADT had 9-ft lanes and 3-ft shoulders, then the predicted number of annual SWICs/mile is 0.56 crashes (value determined assuming a 10-mile section but reported as a per-mile rate for ease in comparisons). If funds are available to widen the roadway surface by 6 ft, should the striping be (a) 9-ft lanes and 6-ft shoulders or (b) 12-ft lanes and 3-ft shoulders? Using the prediction equation, the results are:

9-ft lanes, 6-ft shoulders and 2000 ADT: 0.48 SWICs

12-ft lanes, 3-ft shoulders and 2000 ADT: 0.40 SWICs

Therefore, striping the roadway as 12-ft lanes and 3-ft shoulders (rather than 9-ft lanes and 6-ft shoulders) should result in a slightly lower number of SWICs (remember, this assumes that the roadsides such as side slopes, etc., are restored to previous conditions). The predicted crash values represent the mean crash rates. Crash rates for specific locations can vary.

Again, a caution is offered with respect to the variability in the original data (see Figures 5-2 and 5-3). The prediction equation indicates that a reduction should occur; however, factors such as increases in ADT or factors not currently included in the model such as operating speed or roadside environment could influence the outcome. The outcome could especially be influenced if the wider road results in higher speeds, greater volumes, or changes in the roadside (such as steeper ditches). This caution is offered not to discourage the use of the prediction equation but to have an appreciation of their limitations. The user should not expect that an improvement will always result in a decrease in crashes at each site. Crash reductions are more apparent when a treatment is applied at several locations, such as would be present in a district-wide policy change.

CHAPTER 6

CRASH PREDICTION FOR RURAL FOUR-LANE HIGHWAYS

OVERVIEW

The objective of this effort was to find the relationship between crashes on rural four-lane highways and lane, shoulder, and median widths.

CRASHES AND DATA

Similar to the study conducted for two-lane highways (see [Chapter 5](#)), on-system crashes for the years 1999 to 2001 were used in the analysis. The roadway segments in the dataset represent 882 miles. On those 882 miles, a total of 4662 crashes (1.76 annual crashes per mile) occurred with 3276 crashes meeting SWIC criteria (1.24 annual SWICs per mile). Higher numbers of crashes per mile occur on four-lane highways than on two-lane highways because they tend to have higher ADTs. Comparing crashes per million vehicle miles provides a better method for comparing between roads with highly different ADTs. SWICs represented 70 percent of the crashes on the rural four-lane highways included in the dataset.

Roadway characteristic variables examined included:

- lane width (RT Lane),
- shoulder width (RT Shou),
- median width,
- median type,
- segment length (Seg Len), and/or
- ADT.

The crash distribution is shown in [Figure 6-1](#). Crash rate (crashes per mile) was the method selected for presentation because each segment length varied. Converting to a common unit – crashes per mile – permitted the graphing of the crash rate by the total number of miles. Bins of 1 crash/mi increments were used. As can be seen in [Figure 6-1](#), most of the mileage represented in the dataset had less than 1 crash/mi. The distribution for each geometric variable is provided

in Figure 6-2. Both of these figures provide the data by number of miles represented in the dimension (for example, there are 266 miles of 10-ft right lane widths in the dataset). The average values and range for the key variables are listed in Table 6-1. For several of the roadway segments the median width could not be determined (generally because it was wider than 16 ft and beyond the view in the video screen). Therefore, in addition to median width, the technician also recorded the median type (e.g., raised median, wide). These median types were regrouped into five classes: drivable wide median, drivable narrow median, no median, undrivable wide median, and undrivable narrow median. These groups were used in the evaluations rather than median width, which was not available for more than half of the segments.

Table 6-1. Range and Average Values for Rural Two-Lane Highways Data Set.

Variable	Average for Data Set	Range
ADT	8917	253–29,666
Seg Len (mi)	1.33	0.20–13.28
RT Lane (ft)	11.72	10–14
RT Shou (ft)	7.29	0–14
Median Width (ft)	4.39	0–40*

*Limit that was viewable on some of the video. The dataset included roadways with greater median widths than could be measured.

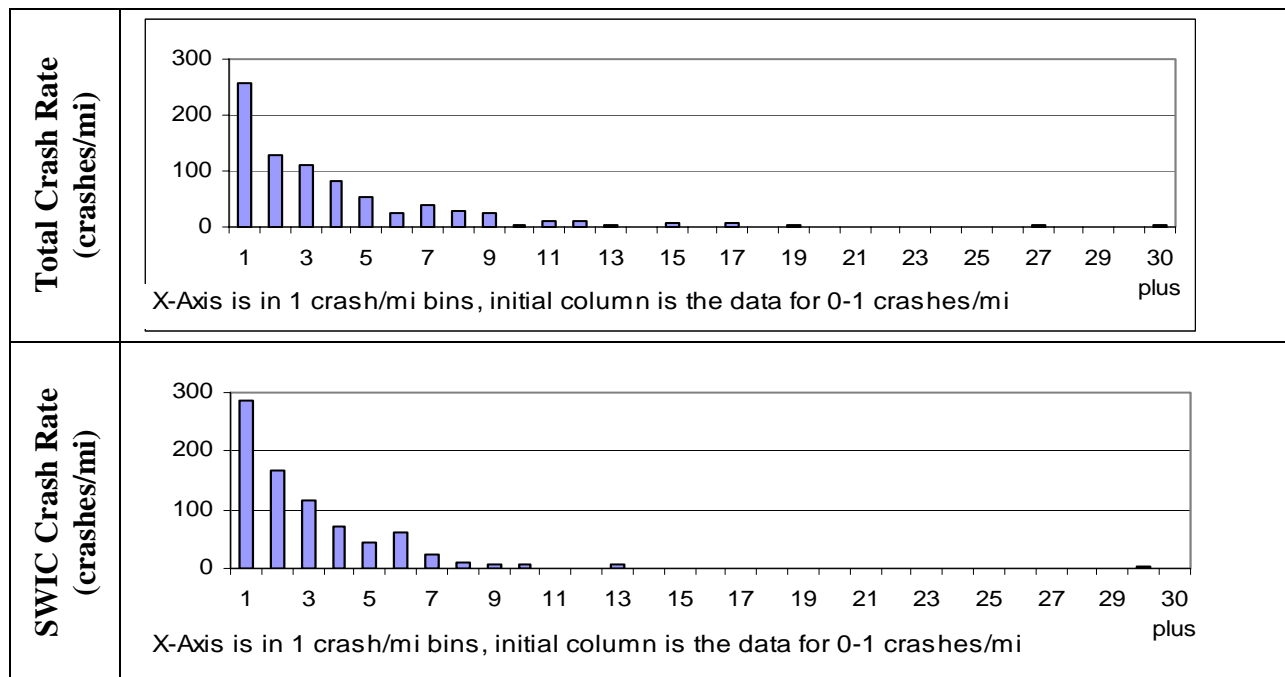


Figure 6-1. Distribution of Crashes by Mile for Rural Four-Lane Highway Dataset.

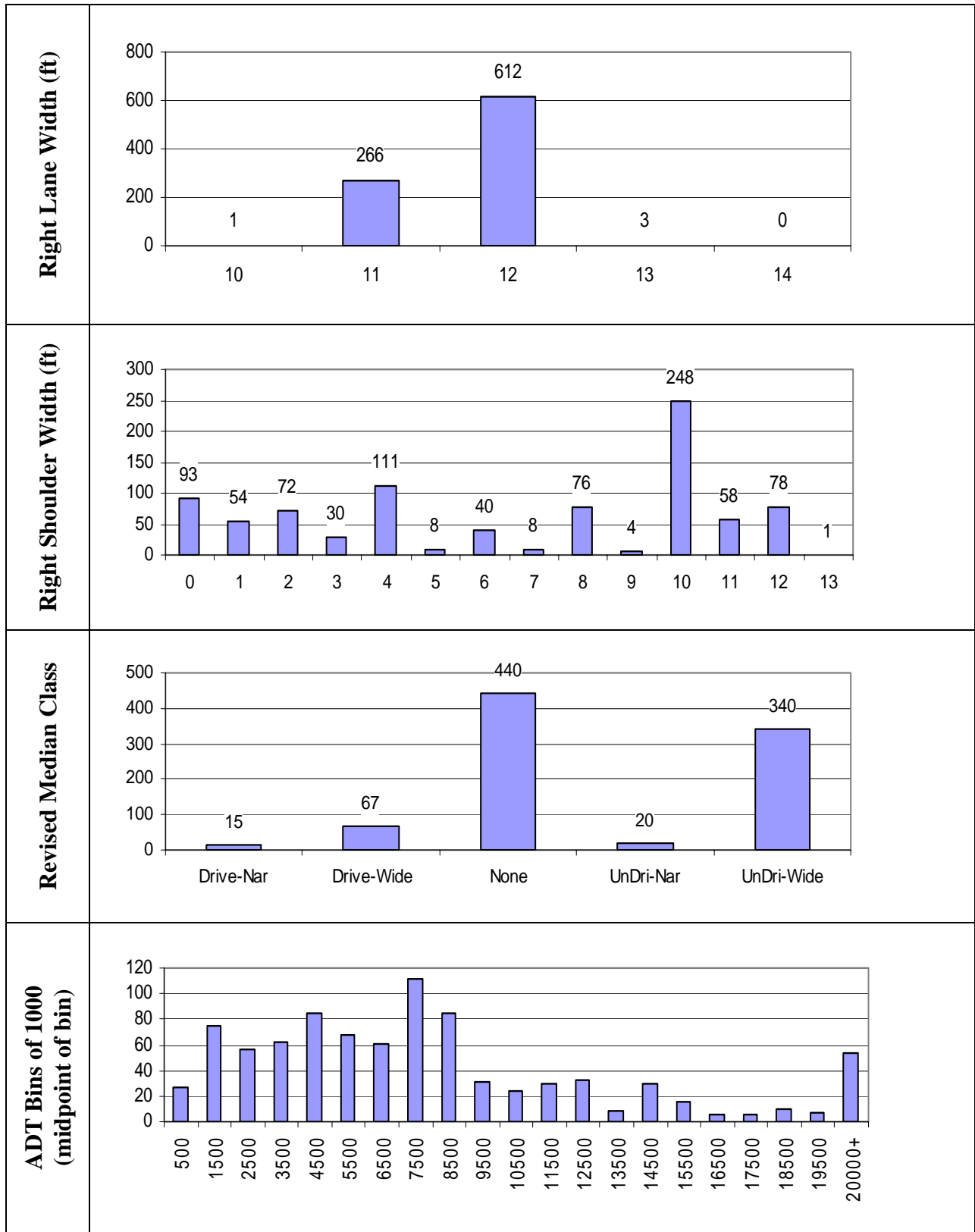


Figure 6-2. Distribution of Variables by Mile for Rural Four-Lane Highway Dataset.

MODELS

Similar to the two-lane highway analysis, GLMs, specifically a negative binomial regression model and a linear regression model, were used to determine the effects of independent variables. See [Chapter 5](#) for additional discussion and the form for the models. Several different attempts were made to determine the optimal regression equation. Only the final attempts are reported here.

Negative Binomial Regression

[Table 6-2](#) shows the SAS output when all variables are in the model and logs of segment length and ADT are used. Right lane is not significant at $\alpha = 0.05$. [Table 6-3](#) shows the SAS output when lane width is not included. The remaining variables (RT Shou, median class revised, LogLen, and LogADT) are all significant at $\alpha = 0.05$ when examining the Type 3 Analysis; however, when reviewing the individual parameters almost all of the median class revised categories are not significant. Only the “undrivable – narrow” medians were significant at 0.0489. [Table 6-4](#) shows the SAS output when median class revised is not included in the model.

Table 6-2. Model 1B Information for 3 yr SWIC Data with Negative Binomial Regression for Four-Lane Highway.

The GENMOD Procedure							
Model Information							
Data Set	LIB4618.FOUR_LANE_GROUP_EXP03						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	SWIC						
Observations Used	663						
Class Level Information							
Class	Levels	Values					
Med_Class_Revised	5	Drive-Nar Drive-Wide None UnDri -Nar UnDri -Wide					
Criteria For Assessing Goodness Of Fit							
Criterion	DF	Value		Value/DF			
Deviance	654	745.9234		1.1406			
Scaled Deviance	654	745.9234		1.1406			
Pearson Chi-Square	654	724.6305		1.1080			
Scaled Pearson X2	654	724.6305		1.1080			
Log Likelihood		3951.6241					
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-7.1462	0.9150	-8.9396	-5.3528	60.99	<.0001
RT_Lane	1	0.0489	0.0699	-0.0882	0.1860	0.49	0.4844
RT_Shou	1	-0.0589	0.0118	-0.0820	-0.0358	24.97	<.0001
Med_Class_Revised Drive-Nar	1	0.1945	0.1649	-0.1286	0.5177	1.39	0.2381
Med_Class_Revised Drive-Wide	1	-0.1069	0.1006	-0.3040	0.0902	1.13	0.2879
Med_Class_Revised None	1	-0.1537	0.1009	-0.3516	0.0441	2.32	0.1277
Med_Class_Revised UnDri -Nar	1	0.3712	0.1853	0.0080	0.7344	4.01	0.0452
Med_Class_Revised UnDri -Wide	0	0.0000	0.0000	0.0000	0.0000	.	.
LogLength	1	0.9384	0.0324	0.8750	1.0018	841.16	<.0001
LogADT	1	0.9369	0.0467	0.8454	1.0285	402.61	<.0001
Dispersion	1	0.2624	0.0324	0.2059	0.3343		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							
The GENMOD Procedure							
LR Statistics For Type 3 Analysis							
Source	DF	Chi-Square	Pr > Chi Sq				
RT_Lane	1	0.49	0.4844				
RT_Shou	1	24.81	<.0001				
Med_Class_Revised	4	10.56	0.0320				
LogLength	1	556.22	<.0001				
LogADT	1	333.90	<.0001				

Table 6-3. Model 1B Information for 3 yr SWIC Data with Negative Binomial Regression for Four-Lane Highway with Right Shoulder, Median Class Revised, LogLen, and Log ADT Included in Model.

The GENMOD Procedure							
Model Information							
Data Set	LIB4618.FOUR_LANE_GROUP_EXPO3						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	SWIC						
Observations Used	663						
Class Level Information							
Class	Levels	Values					
Med_Class_Revised	5	Drive-Nar	Drive-Wide	None	UnDri -Nar	UnDri -Wide	
Criteria For Assessing Goodness Of Fit							
Criterion	DF	Value	Value/DF				
Deviance	655	745.8952	1.1388				
Scaled Deviance	655	745.8952	1.1388				
Pearson Chi-Square	655	724.5925	1.1062				
Scaled Pearson X2	655	724.5925	1.1062				
Log Likelihood		3951.3797					
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-6.5849	0.4383	-7.4439	-5.7259	225.74	<.0001
RT_Shou	1	-0.0568	0.0114	-0.0792	-0.0345	24.84	<.0001
Med_Class_Revised Drive-Nar	1	0.1961	0.1649	-0.1272	0.5194	1.41	0.2344
Med_Class_Revised Drive-Wide	1	-0.1056	0.1005	-0.3026	0.0913	1.10	0.2932
Med_Class_Revised None	1	-0.1568	0.1008	-0.3544	0.0407	2.42	0.1197
Med_Class_Revised UnDri -Nar	1	0.3644	0.1850	0.0018	0.7271	3.88	0.0489
Med_Class_Revised UnDri -Wide	0	0.0000	0.0000	0.0000	0.0000	.	.
LogLength	1	0.9392	0.0324	0.8758	1.0027	842.77	<.0001
LogADT	1	0.9367	0.0467	0.8451	1.0283	401.73	<.0001
Dispersion	1	0.2629	0.0325	0.2064	0.3349		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							
The GENMOD Procedure							
LR Statistics For Type 3 Analysis							
Source	DF	Chi-Square	Pr > Chi Sq				
RT_Shou	1	24.67	<.0001				
Med_Class_Revised	4	10.50	0.0327				
LogLength	1	556.90	<.0001				
LogADT	1	333.52	<.0001				

Table 6-4. Model 1B Information for 3 yr SWIC Data with Negative Binomial Regression for Four-Lane Highway with Right Shoulder, LogLen, and Log ADT Included in Model.

The GENMOD Procedure							
Model Information							
Data Set	LIB4618.FOUR_LANE_GROUP_EXPO3						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	SWIC						
Observations Used	663						
Criteria For Assessing Goodness Of Fit							
Criterion	DF	Value	Value/DF				
Deviance	659	750.1393	1.1383				
Scaled Deviance	659	750.1393	1.1383				
Pearson Chi-Square	659	738.3470	1.1204				
Scaled Pearson X2	659	738.3470	1.1204				
Log Likelihood		3946.1273					
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-6.8122	0.4075	-7.6109	-6.0135	279.44	<.0001
RT_Shou	1	-0.0427	0.0081	-0.0585	-0.0269	27.98	<.0001
LogLength	1	0.9354	0.0319	0.8730	0.9979	862.39	<.0001
LogADT	1	0.9441	0.0463	0.8535	1.0348	416.48	<.0001
Dispersion	1	0.2692	0.0330	0.2117	0.3422		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							

From “Criteria for Assessing Goodness of Fit” table (see Tables 6-2, 6-3, and 6-4), it can be seen that the negative binomial model fits the data fairly well. Both deviance and Pearson chi-square divided by degrees of freedom are close to 1 for all models.

The estimated equation for expected SWICs including median class revised for four-lane roadways is as follows:

$$\begin{aligned}
 E(3 \text{ yr SWIC}) = & \exp(-6.5849 - 0.0568 \text{ RT Shou} + 0.9392 \text{ Log Seg Len} \\
 & + 0.9367 \text{ LogADT} + 0.1961 \text{ Median-Drive-Narrow} \\
 & - 0.1056 \text{ Median-Drive-Wide} - 0.1568 \text{ Median-None} \\
 & + 0.3644 \text{ Median-Undrive-Nar})
 \end{aligned}
 \tag{12}$$

The estimated equation for expected SWICs not including median class revised for four-lane roadways is as follows:

$$E(3 \text{ yr SWIC}) = \exp(-6.8122 - 0.0427 \text{ RT Shou} + 0.9354 \text{ LogLen} + 0.9441 \text{ LogADT}) \quad (13)$$

Linear Regression Model for Transformed SWIC (TSWIC)

SWICs were transformed and evaluated using the same approach as documented in [Chapter 5](#). [Table 6-5](#) contains the result of the fit for TSWIC for Model 2B. In the initial model, right lane and revised median class were not significant. The bottom half of [Table 6-5](#) shows the output when RT Shou, LogLen, and LogADT are included. This model has an adjusted r-square of 0.61.

The prediction equations for TSWIC (the estimated equations for the expected TSWIC) can be written as follows:

Prediction equations for TSWIC under Model 2B:

$$E(3 \text{ yr TSWIC}) = -3.2880 - 0.0373 \text{ RT Shou} + 0.8510 \text{ LogLen} + 0.6475 \text{ LogADT} \quad (14)$$

The prediction equations for SWICs (the estimated equations for the expected SWICs) can be obtained by back-transforming TSWIC. As before, these predicted values are for 3 yr SWICs. The predicted SWICs per year can be obtained simply by dividing E(3 yr SWIC) by 3.

Prediction equations for SWIC under Model 2B:

$$E(\text{SWIC}) = [(-3.2880 - 0.0373 \text{ RT Shou} + 0.8510 \text{ LogLen} + 0.6475 \text{ LogADT})^2 - 3/8]/3 \quad (15)$$

Table 6-5. Information for 3 yr TSWIC with Least-Squares Fit for Four-Lane Highway.

A. Linear with RT Lane, RT Shou, Revised Median Class LogLen, and LogADT					
RSquare			0.614034		
RSquare Adj			0.609312		
Root Mean Square Error			0.799247		
Mean of Response			1.919267		
Observations (or Sum Wgts)			663		
Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Ratio	
Model	8	664.6350	83.0794	130.0561	
Error	654	417.7729	0.6388	Prob > F	
C. Total	662	1082.4078		<.0001	
Parameter Estimates					
Term		Estimate	Std Error	t Ratio	Prob> t
Intercept		-3.627544	0.855958	-4.24	<.0001
RT lane		0.0335452	0.065353	0.51	0.6079
RT Shou		-0.038482	0.010787	-3.57	0.0004
Med Class Revised[Drive-Nar]		0.0176468	0.127932	0.14	0.8903
Med Class Revised[Drive-Wide]		-0.175457	0.08563	-2.05	0.0409
Med Class Revised[None]		-0.090979	0.077132	-1.18	0.2386
Med Class Revised[UnDri-Nar]		0.3487174	0.155526	2.24	0.0253
LogLength		0.850863	0.031695	26.84	<.0001
LogADT		0.6523928	0.038411	16.98	<.0001
Effect Tests					
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
RT lane	1	1	0.16830	0.2635	0.6079
RT Shou	1	1	8.13019	12.7274	0.0004
Med Class Revised	4	4	4.45579	1.7438	0.1386
LogLength	1	1	460.34874	720.6502	<.0001
LogADT	1	1	184.27722	288.4757	<.0001
B. Linear with RT Shou, LogLen, and LogADT					
RSquare			0.609806		
RSquare Adj			0.608029		
Root Mean Square Error			0.800559		
Mean of Response			1.919267		
Observations (or Sum Wgts)			663		
Parameter Estimates					
Term	Estimate	Std Error	t Ratio	Prob> t	
Intercept	-3.288018	0.315766	-10.41	<.0001	
RT Shou	-0.037358	0.008237	-4.54	<.0001	
LogLength	0.8510065	0.031043	27.41	<.0001	
LogADT	0.6474653	0.036835	17.58	<.0001	

Selection of Model

Similar to the two-lane highway analysis, all of the models developed and presented within this chapter fit the data well. Model 1B was preferred over Models 1A (not including the log of segment length resulted in illogical findings at long segment lengths), 1C (where exposure is considered an offset variable), and the linear regression models (negative binomial is a better match with the distribution of the data). Therefore, the following evaluations are performed using the negative binomial regression model where LogLen and LogADT are included as independent variables in addition to RT Lane, and RT Shou. The selected regression equation for four-lane highways is:

$$E(\text{SWIC}) = [\exp(-6.8122 - 0.0427 \text{ RT Shou} + 0.9354 \text{ LogLen} + 0.9441 \text{ LogADT})]/3 \quad (16)$$

COMPARISON BETWEEN ACTUAL DATA AND PREDICTED VALUES

Similar to the two-lane scenario, while the statistical evaluation results indicate that the developed models are a good fit with the data, a visual review of the actual data with the results from the prediction equation can show the variability in the data. [Figure 6-2](#) shows the number of SWICs on a per-year and per-mile basis for segments with 12-ft lanes and ADTs less than 5000. [Figure 6-3](#) shows similar data for segments with ADTs equal to or greater than 5000. Also on these figures is a plot of the results from using the regression model for ADT of 4000 and 8000, respectively.

As can be seen in [Figures 6-3](#) and [6-4](#), there are segments with annual SWICs/mile much greater (and less) than what is predicted using the regression equation. This is important to consider, as the regression equation is used in selecting a lane width or a shoulder width. While on average using a wider shoulder should result in fewer crashes than using a narrow shoulder (as demonstrated by the downward slope of the regression equation), not all situations will have that result.

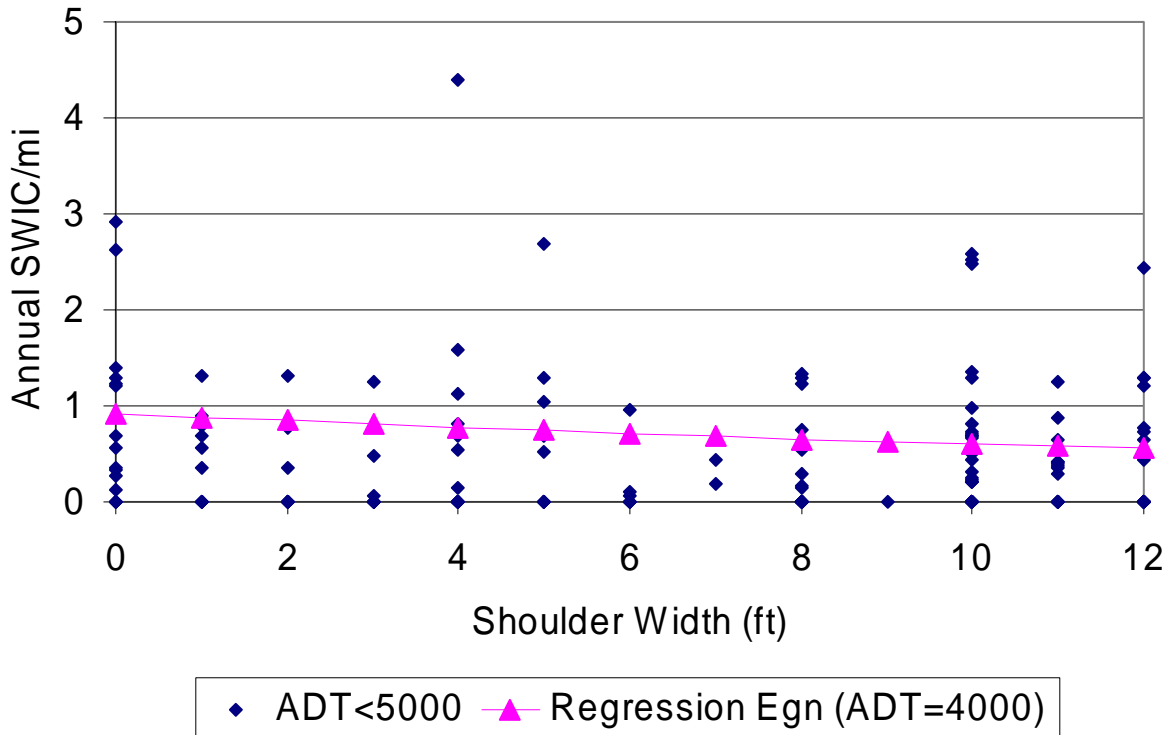


Figure 6-3. Comparison of Results from Prediction Equation to Actual Data for Roadway Segments with ADT Less Than 5000.

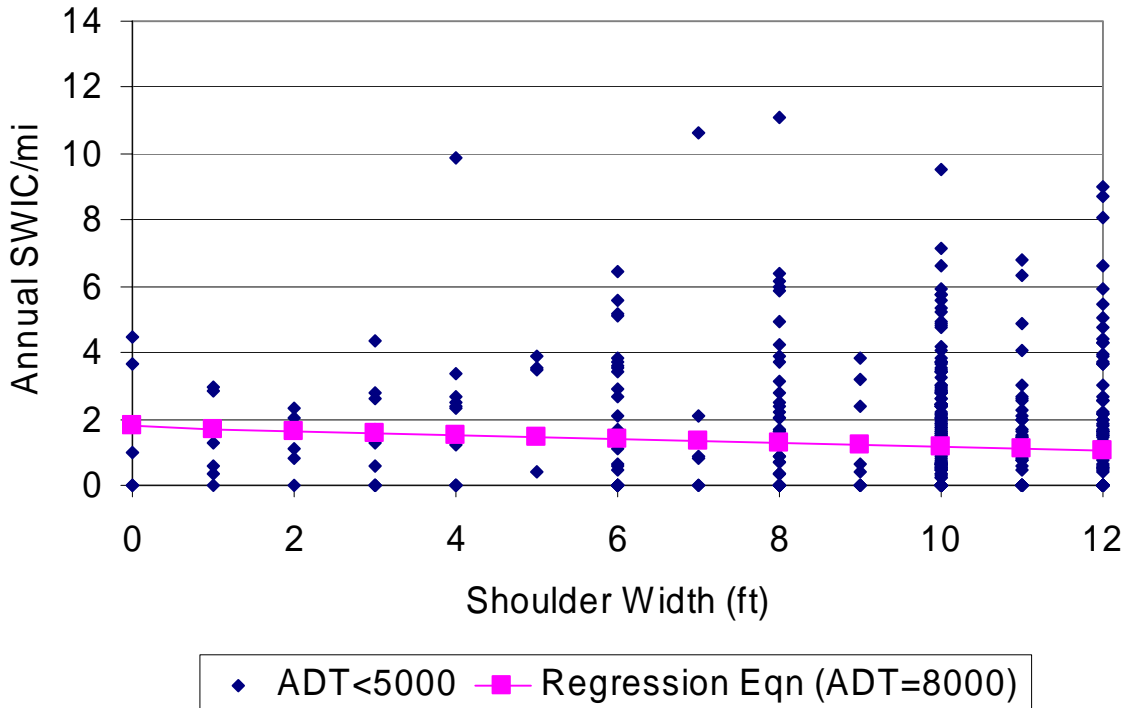


Figure 6-4. Comparison of Results from Prediction Equation to Actual Data for Roadway Segments with ADT Greater than 5000.

EFFECTS OF VARIABLES

The regression evaluation found the following variables to affect the crash prediction: ADT, shoulder width and segment length. Figure 6-5 illustrates the effect that these variables have on crash prediction for rural four-lane highways by shoulder width. As ADT increases, the number of SWICs also increases. For example, the number of crashes on a roadway segment with 10,000 ADT is about 4.7 times the number of crashes on a roadway segment with only 2000 ADT. This plot was developed assuming a 10-mile segment and then converted to a per-mile increment.

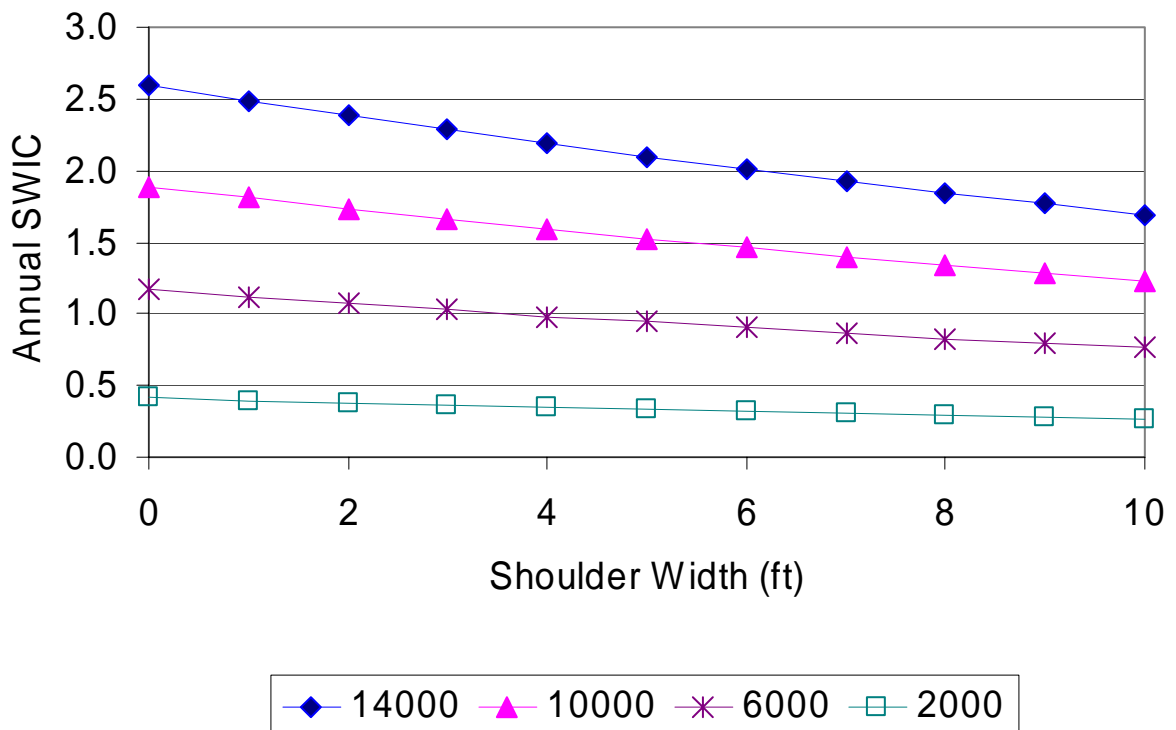


Figure 6-5. Comparison of Results From Prediction Equation by Shoulder Width for a Range of ADT Values.

RATIO

The ratio between the numbers of crashes at different shoulder width values can provide an appreciation for the potential benefit of widening a shoulder on a four-lane rural highway. The ratio of crashes to an 8-ft shoulder width is listed in Table 6-6 and shown in Figure 6-6.

Since lane width was found to be not significant, one interpretation could be that there are no benefits to widening a lane. This conclusion should not be made because most of the segments within this dataset had either 11- or 12-ft lanes – a too small range to identify a relationship.

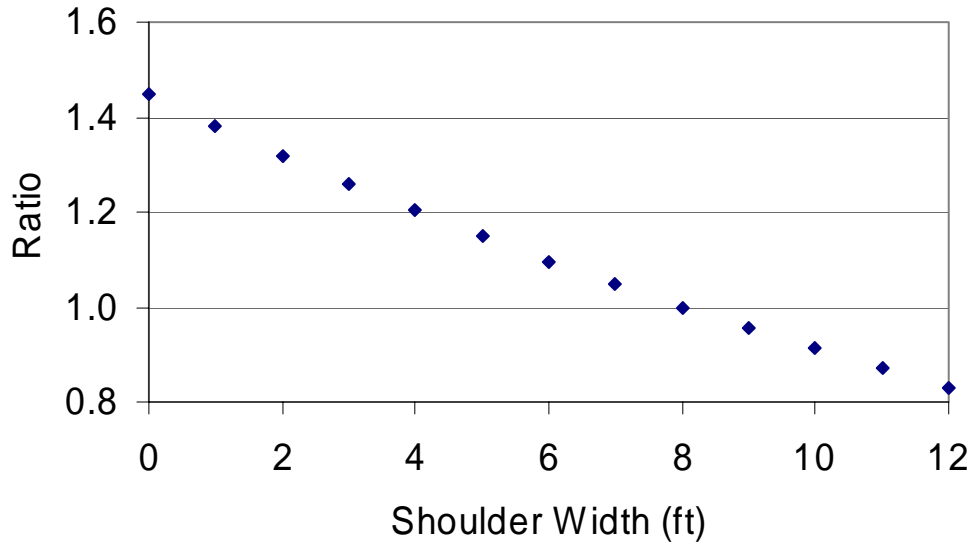


Figure 6-6. Plot of Ratios for Shoulder Widths for Rural Four-Lane Highways Based on SWICs.

Table 6-6. List of Ratios for Shoulder Widths for Rural Four-Lane Highways Based on Predictions of SWICs.

Shoulder Width (ft)	Ratio to 8-ft lane
12	0.84
11	0.88
10	0.92
9	0.96
8	1.00
7	1.04
6	1.09
5	1.14
4	1.19
3	1.24
2	1.29
1	1.35
0	1.41

Other researchers have examined the benefits of widening lanes and shoulders on two-lane rural highways, however research on rural four-lane highways was not identified. The most current knowledge on the topic is represented in the Draft Prototype Chapter (2) developed for consideration of the *Highway Safety Manual*. Background material on the *Draft Prototype Chapter* is included in Chapter 2 and Chapter 5 of this TxDOT report. A comparison of the findings from this project with the *Draft Prototype Chapter* can provide an appreciation of whether similar trends are present for four-lane highways as two-lane highways. Figure 6-7 compares the findings for the four-lane highways to those of two-lane highways (see Chapter 5) and the *Draft Prototype Chapter* two-lane shoulder width AMF. The findings for four-lane highways are similar to the findings for two-lane highways with the two-lane highways showing a slightly greater sensitivity to shoulder width (as evidenced from larger ratios).

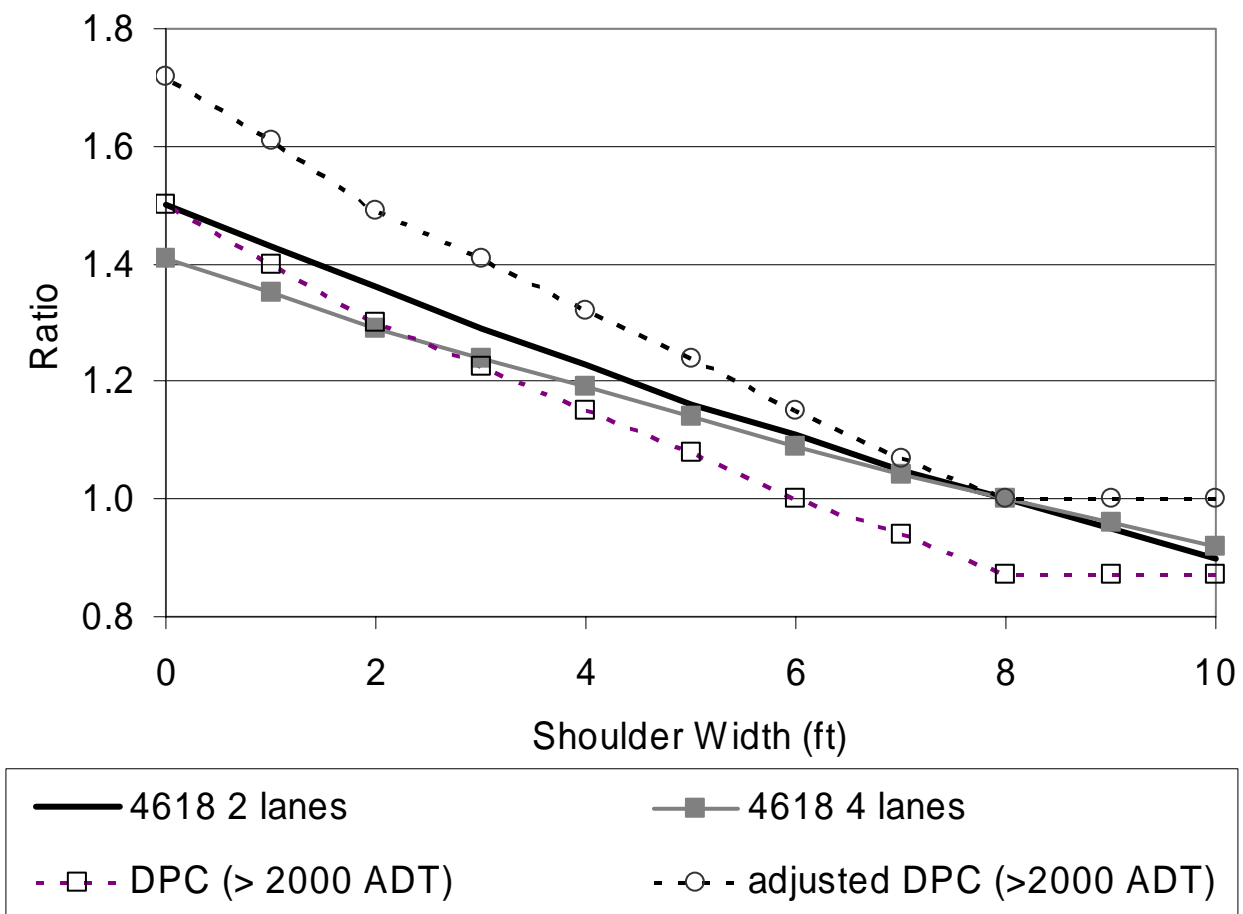


Figure 6-7. Comparison of Ratios.

The *DPC* assumes different AMF values for different ADT levels. The four-lane highway data were used to investigate whether the ratios should vary depending upon the ADT present at the site. The roadway segments were subdivided into three ADT groups: less than 4320, between 4320 and 8800, and greater than 8800. These groups represent divisions developed based on the level of service (LOS) criteria in the *Highway Capacity Manual* for multilane highways (see Exhibit 21-2 of that document). For a free-flow speed of 60 mph and LOS B, the maximum service flow rate is 1080 pc/h/ln. The 4320 ADT value represents the 1080 service flow rate multiplied by four lanes. The 8800 value was determined using LOS E and a maximum service flow rate of 2200. [Table 6-7](#) lists the general statistics for each group.

Different variables were significant in the individual ADT groups as compared to the entire dataset. The regression analysis of those roadway segments with ADT of less than 4320 (see [Table 6-8](#)) found all variables significant except revised median class. The analysis for ADTs between 4320 and 8800 (see [Table 6-9](#)) found only RT Shou and LogLen significant – LogADT was found to be not significant, a potentially surprising finding given the known importance of ADT in predicting crashes. When the LogADT limits for this group are reviewed, the difference is small, which may contribute to the variable not being significant. (Log of 4320 is 8.376, while log of 8800 is 9.0825, a difference of only 0.707.) For ADTs above 8800 (see [Table 6-10](#)), RT Shou, LogADT, and LogLen were all found to be significant, similar to the findings for the model that used all the four-lane highway data.

Table 6-7. Range and Average Values for Rural Two-Lane Highways Roadway Characteristics by ADT Group.

Variable	Average (Range) or Total for Dataset		
	<4320	4320 to 8800	>8800
ADT	2416 (253–4300)	6648 (4333–8800)	15201 (8833–29,666)
Seg Len (mi)	1.6 (0.2–13.3)	1.5 (0.2–9.8)	1.0 (0.2–6.1)
RT Lane (ft)	11.76 (10–14)	11.69 (10–13)	11.72 (11–13)
RT Shou (ft)	6.04 (0–14)	7.10 (0–13)	8.28 (0–13)
Total Crashes (3 yr)	453	1456	2753
3 yr SWICs	360	1097	1819
Total Crash KABs (3 yr)	190	571	959
3 yr SWIC KABs	149	423	612
Total Miles	264	350	269

Table 6-8. SAS Output for Analysis by ADT Group, Four-Lane Highway with ADT < 4320.

```

The GENMOD Procedure

Model Information

Data Set          LIB4618.FOUR_LN_8_29_ADT_LESS_4320
Distribution      Negative Binomial
Link Function    Log
Dependent Variable SWI C
Observations Used      166

Criteria For Assessing Goodness Of Fit

Criterion      DF      Value      Value/DF
Deviance      161      179.5160      1.1150
Scaled Deviance 161      179.5160      1.1150
Pearson Chi-Square 161      182.6236      1.1343
Scaled Pearson X2 161      182.6236      1.1343
Log Likelihood      163.5028

Algorithm converged.

Analysis Of Parameter Estimates

Parameter      DF      Estimate      Standard      Wald 95% Confidence      Chi -      Pr > Chi Sq
                DF      Estimate      Error      Limits      Square
Intercept      1      -0.5501      1.9870      -4.4445      3.3444      0.08      0.7819
RT_lane        1      -0.3416      0.1395      -0.6151      -0.0681      5.99      0.0144
RT_Shou        1      -0.0679      0.0164      -0.1000      -0.0358      17.16      <.0001
LogLength      1      0.8982      0.0623      0.7762      1.0203      208.17      <.0001
LogADT         1      0.6819      0.1141      0.4582      0.9055      35.72      <.0001
Di spersi on   1      0.1020      0.0612      0.0315      0.3305

NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.
    
```

Table 6-9. SAS Output for Analysis by ADT Group, Four-Lane Highway with ADT Between 4320 and 8800.

```

The GENMOD Procedure

Model Information

Data Set          LIB4618.FOUR_LN_8_29_ADT_4320_8800
Distribution      Negative Binomial
Link Function    Log
Dependent Variable SWI C
Observations Used      239

Criteria For Assessing Goodness Of Fit

Criterion      DF      Value      Value/DF
Deviance      236      275.6775      1.1681
Scaled Deviance 236      275.6775      1.1681
Pearson Chi-Square 236      292.5176      1.2395
Scaled Pearson X2 236      292.5176      1.2395
Log Likelihood      1183.8023

Algorithm converged.

Analysis Of Parameter Estimates

Parameter      DF      Estimate      Standard      Wald 95% Confidence      Chi -      Pr > Chi Sq
                DF      Estimate      Error      Limits      Square
Intercept      1      1.3698      0.1047      1.1647      1.5750      171.33      <.0001
RT_Shou        1      -0.0388      0.0130      -0.0643      -0.0133      8.87      0.0029
LogLength      1      1.0130      0.0565      0.9022      1.1237      321.16      <.0001
Di spersi on   1      0.3117      0.0621      0.2109      0.4606

NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.
    
```

Table 6-10. SAS Output for Analysis by ADT Group, Four-Lane Highway with ADT > 8800.

The GENMOD Procedure							
Model Information							
Data Set	LIB4618.FOUR_LN_8_29_ADT_GT_8800						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	SWIC						
Observations Used	258						
Criteria For Assessing Goodness Of Fit							
Criterion	DF	Value	Value/DF				
Deviance	254	301.0559	1.1853				
Scaled Deviance	254	301.0559	1.1853				
Pearson Chi-Square	254	280.2730	1.1034				
Scaled Pearson X2	254	280.2730	1.1034				
Log Likelihood		2609.4886					
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-9.0957	1.3281	-11.6987	-6.4927	46.90	<.0001
RT_Shou	1	-0.0303	0.0127	-0.0552	-0.0055	5.72	0.0167
LogLength	1	0.9370	0.0469	0.8451	1.0290	398.85	<.0001
LogADT	1	1.1742	0.1417	0.8966	1.4519	68.71	<.0001
Dispersion	1	0.2476	0.0427	0.1767	0.3471		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							

Figure 6-8 shows the ratio using Texas data to the AMFs presented in the *Draft Prototype Chapter* for rural two-lane highways. Table 6-11 lists the values. The *DPC* AMF assumes that 6 ft represents the desirable minimum shoulder width and that shoulder widths in excess of 8 ft provide no additional benefits. The *DPC* AMF was adjusted to reflect an 8-ft desirable shoulder width to provide a better comparison with the Texas findings. The Texas data revealed a similar trend as that assumed on the national level for shoulder widths less than 8 ft on two-lane highways. The Texas data did show benefits for 10-ft shoulders over 8-ft shoulders, while the *DPC* assumes no additional benefits. The increase in crash prediction at minimal shoulder widths is greater for the national values on two-lane highways than found using Texas four-lane highway data. For example, for no shoulders, the *DPC* assumes that related crashes will be 1.72 times the crash value if 8-ft shoulders were present. The Texas data found that crashes will be 1.41 times the crash value if 8-ft shoulders were present when using all the data. For lower

volume four-lane highways, the Texas data found that 0-ft shoulders would have 64 percent more crashes than segments with 8-ft shoulders.

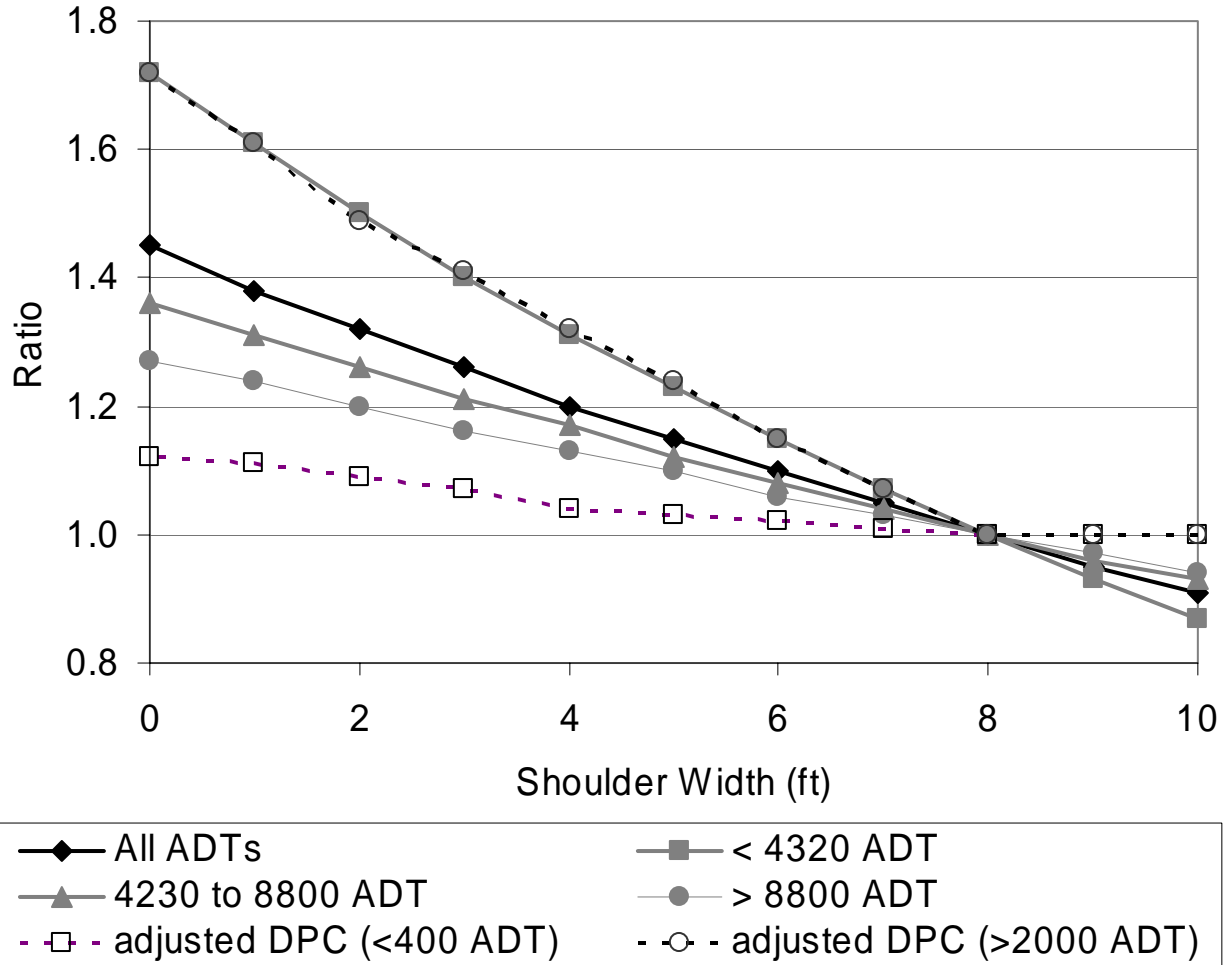


Figure 6-8. Comparison of Texas Findings to *Draft Prototype Chapter* for Shoulder Width.

Table 6-11. Ratios for Shoulder Widths for SWICs on Rural Four-Lane Highways by ADT Groups for Texas Data and Two-Lane Highway DPC Values.

Shoulder Width (ft)	Ratio of Number of Crashes for Given Shoulder Width to Number of Crashes on a Roadway with an 8-ft Shoulder					
	Roadway Segments with Following ADT Values:					
	Texas Data				DPC (adjusted) Two-lane highway	
	All ADTs	<4320	4320 to 8800	>8800	<400	>2000
10	0.91	0.87	0.93	0.94	1.00	1.00
9	0.95	0.93	0.96	0.97	1.00	1.00
8	1.00	1.00	1.00	1.00	1.00	1.00
7	1.05	1.07	1.04	1.03	1.01	1.07
6	1.10	1.15	1.08	1.06	1.02	1.15
5	1.15	1.23	1.12	1.10	1.03	1.24
4	1.20	1.31	1.17	1.13	1.04	1.32
3	1.26	1.40	1.21	1.16	1.07	1.41
2	1.32	1.50	1.26	1.20	1.09	1.49
1	1.38	1.61	1.31	1.24	1.11	1.61
0	1.45	1.72	1.36	1.27	1.12	1.72

COMPARISON WITH TOTAL CRASHES AND KAB CRASHES

As in the two-lane highway analysis, negative binomial regression was performed using total crashes. Similar model forms were tested as used with the SWICs. The SAS output for the preferred model is shown in [Table 6-12](#). [Figure 6-9](#) compares the ratio of number of crashes at different shoulder widths to number of crashes at an 8-ft shoulder width. This plot indicates that total crashes are also sensitive to shoulder width. [Table 6-13](#) lists the lane width and shoulder width ratios generated based on predictions of total crashes. The *Draft Prototype Chapter* assumes that the lane width and shoulder width AMFs (similar to the “ratio” being used in this study) are only applied to “related accidents” on rural two-lane highways. Similar to the observation made in the two-lane highway chapter, additional, more focused research may be needed to determine if AMFs should be applied only to related accidents or if they should be applied to all crashes.

Table 6-12. Model Information for 3yr Total Crash data with Negative Binomial Regression.

The GENMOD Procedure

Model Information

Dataset LIB4618.FOUR_LANE_GROUP_EXP03
 Distribution Negative Binomial
 Link Function Log
 Dependent Variable Total_Accident
 Observations Used 663

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	658	764.6679	1.1621
Scaled Deviance	658	764.6679	1.1621
Pearson Chi-Square	658	754.4177	1.1465
Scaled Pearson X2	658	754.4177	1.1465
Log Likelihood		7142.9145	

Algorithm converged.

Analysis Of Parameter Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-5.1437	0.8647	-6.8385	-3.4489	35.38	<.0001
RT_Lane	1	-0.1392	0.0677	-0.2718	-0.0066	4.23	0.0397
RT_Shou	1	-0.0618	0.0087	-0.0788	-0.0448	50.85	<.0001
LogLength	1	0.7956	0.0311	0.7347	0.8565	655.14	<.0001
LogADT	1	0.9990	0.0454	0.9101	1.0879	485.21	<.0001
Dispersion	1	0.3583	0.0356	0.2949	0.4354		

NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.

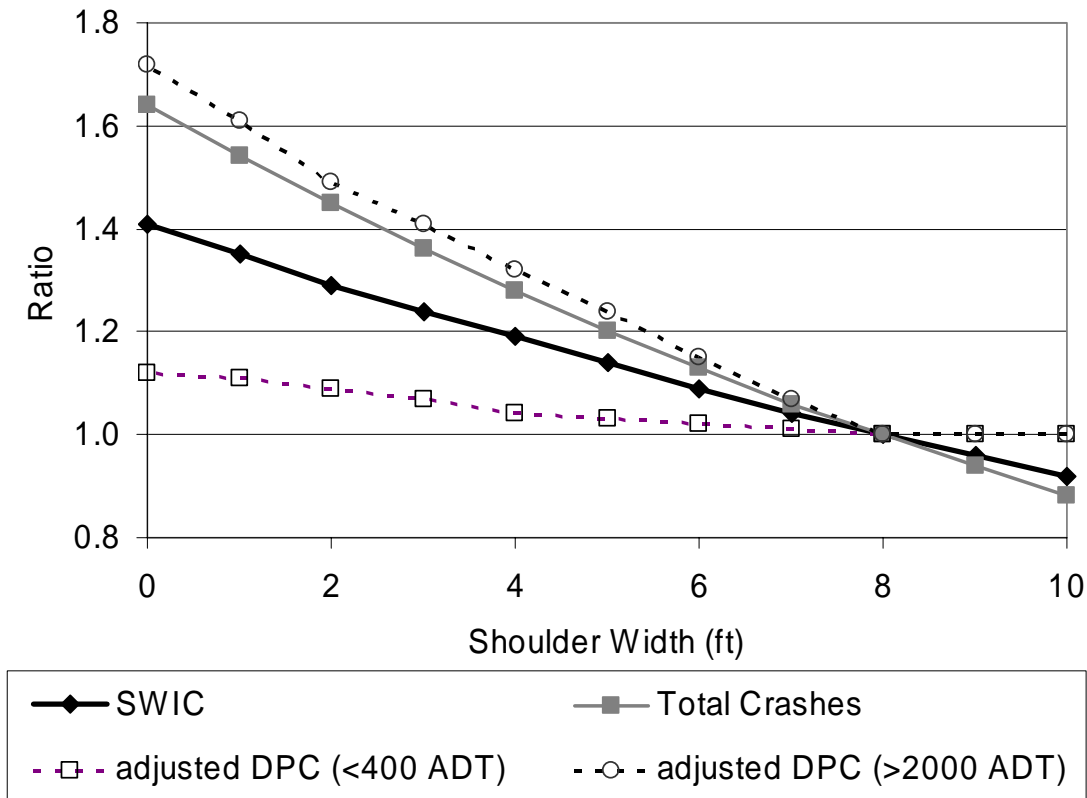


Figure 6-9. Comparison of Total Crash to SWIC for Shoulder Width.

Table 6-13. Ratios for Lane Width and Shoulder Widths for Rural Four-Lane Highways Based on Predictions of Total Crashes.

Lane Width (ft)	Ratio to 12-ft lane
12	1.00
11	1.15
10	1.32
9	1.52
Shoulder Width (ft)	Ratio to 8-ft lane
10	0.88
9	0.94
8	1.00
7	1.06
6	1.13
5	1.20
4	1.28
3	1.36
2	1.45
1	1.54
0	1.64

A check was also performed using KAB crashes. KAB crashes are defined as those crashes involving a fatality (K), an incapacitating injury (A), or a nonincapacitating injury (B). Concerns have been expressed with the quality of noninjury and PDO crash data, especially their high nonreporting rates. Because of those concerns, KAB crashes were also reviewed to determine if different patterns exist between KAB crashes and shoulder width or lane width. Negative binomial regression was performed using similar model forms as tested for the SWICs. [Table 6-14](#) lists the SAS output. For SWIC KABs and total crash KABs, RT Lane was not significant. [Figure 6-10](#) shows the shoulder width ratio. The SWIC KAB crashes followed a similar trend as was found for SWICs. The total crash KAB trend mirrors the trend seen in [Figure 6-9](#) – shoulder width has a greater effect.

Table 6-14. Model Information for 3 yr Crash KAB and 3 yr SWIC KAB Data with Negative Binomial Regression.

The GENMOD Procedure							
Dataset		LIB4618. FOUR_LANE_GROUP_EXPO3					
Distribution		Negative Binomial					
Link Function		Log					
Dependent Variable		SWIC_KAB		SWIC KAB			
Observations Used		663					
Criteria For Assessing Goodness Of Fit							
Criterion	DF	Value		Value/DF			
Deviance	659	666.4506		1.0113			
Scaled Deviance	659	666.4506		1.0113			
Pearson Chi-Square	659	667.7077		1.0132			
Scaled Pearson X2	659	667.7077		1.0132			
Log Likelihood		231.5638					
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-6.9855	0.5581	-8.0793	-5.8916	156.67	<.0001
RT_Shou	1	-0.0506	0.0105	-0.0712	-0.0301	23.29	<.0001
LogLength	1	0.9781	0.0435	0.8928	1.0633	505.54	<.0001
LogADT	1	0.8542	0.0629	0.7310	0.9775	184.63	<.0001
Dispersion	1	0.2821	0.0542	0.1937	0.4110		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							
The GENMOD Procedure							
Dataset		LIB4618. FOUR_LANE_GROUP_EXPO3					
Distribution		Negative Binomial					
Link Function		Log					
Dependent Variable		Total_Accident_KAB		Total Accident KAB			
Observations Used		663					
Criteria for Assessing Goodness of Fit							
Criterion	DF	Value		Value/DF			
Deviance	659	713.1417		1.0822			
Scaled Deviance	659	713.1417		1.0822			
Pearson Chi-Square	659	735.3597		1.1159			
Scaled Pearson X2	659	735.3597		1.1159			
Log Likelihood		916.7683					
Algorithm converged.							
Analysis of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-7.2233	0.5039	-8.2108	-6.2357	205.52	<.0001
RT_Shou	1	-0.0677	0.0095	-0.0863	-0.0492	51.24	<.0001
LogLen	1	0.8605	0.0379	0.7863	0.9347	516.60	<.0001
LogADT	1	0.9407	0.0569	0.8291	1.0523	273.04	<.0001
Dispersion	1	0.2936	0.0459	0.2161	0.3990		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							

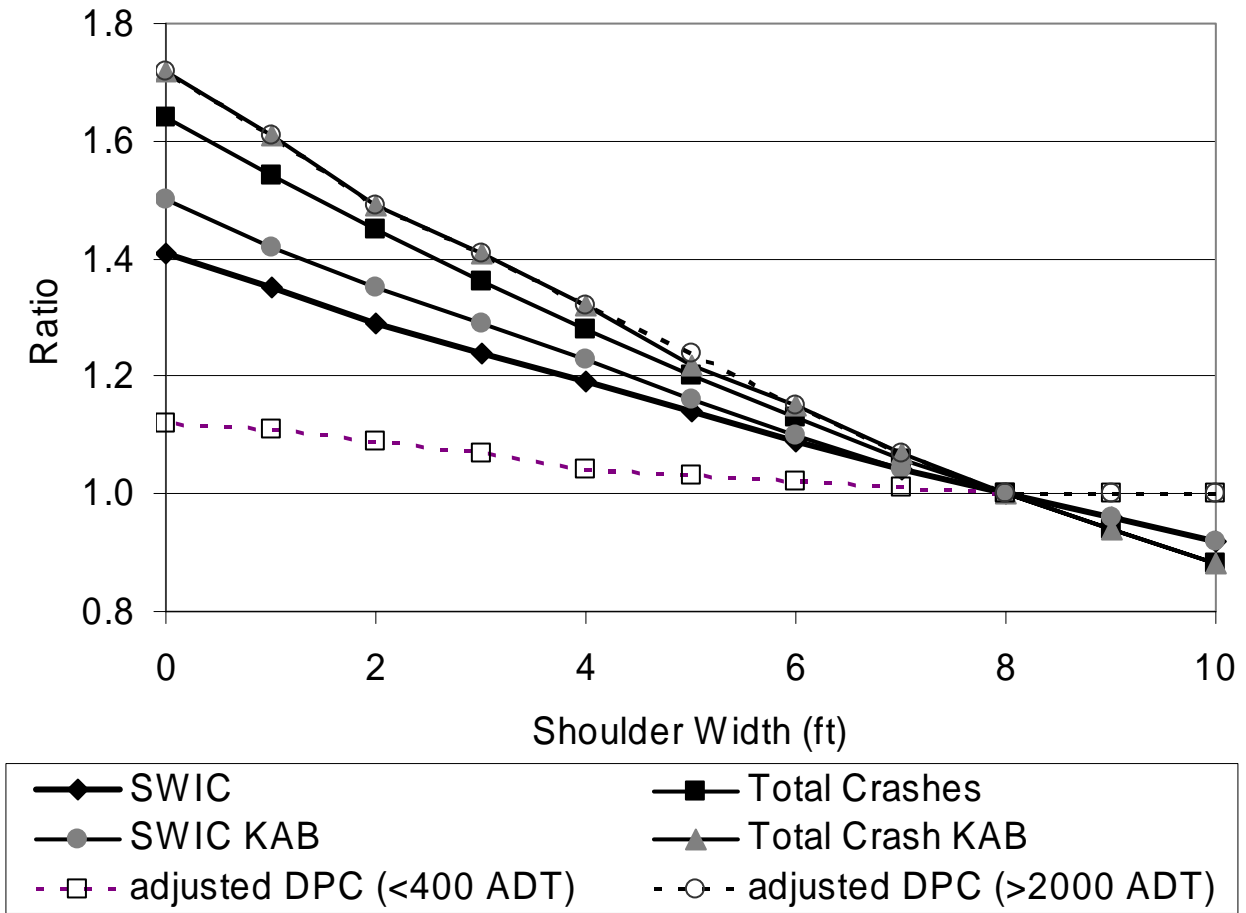


Figure 6-10. Comparison of Total Crash KABs and SWIC KABs to SWICs for Shoulder Width.

CHAPTER 7

FINDINGS FROM COMPARISON OF CRASHES ON 44- TO 54-FT SURFACE WIDTH

A low-cost method to increase capacity on rural highways is to stripe a formerly two-lane with wide shoulder highway into a four-lane with minimal shoulders. These decisions have generally been made based on capacity criteria. Information on the safety trade-offs is being sought.

OVERVIEW

The following analysis will use crash data from 1999 to 2001 to examine the safety performance on highways with a surface width of 44 to 54 ft with either two lanes and wide shoulders or four lanes with minimal shoulders. The dimensions of 44 to 54 ft were identified as being widths used for both two-lane and four-lane highways. Wider highways generally have either passing lanes, turn lanes, medians, or very wide shoulders.

At the 44-ft widths for two-lane highways, the cross sections generally consist of two 11- or 12-ft lanes and 11- or 10-ft shoulders. For four-lane highways, a 44-ft cross section would typically include four 11-ft lanes with no shoulders. For the 54-ft widths, the two-lane highways generally had 12-ft and sometimes 13- or 14-ft lanes with the remaining width allocated to the shoulders or to a wider centerline. For a four-lane highway, the cross section of a 54-ft wide highway would typically have four 12-ft lanes and 3-ft shoulders.

CRASHES

A subset of total crashes was used in the analysis. Crashes associated with the surface width rather than intersections should be affected by the change in number of lanes or availability of shoulder width. In previous research, this type of crash has been referred to as “related crashes” (10, 18). Related crashes are defined as single vehicle run-off-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe.

The codes in the Texas accident database do not permit using the exact same descriptor to generate “related crashes” as used in previous research; however, similar types of crashes can be identified. The following TxDOT codes were used to identify SWICs:

- nonintersection crashes (intersection related code = 4),
- collision code, vehicle movement/manner:
 - two motor vehicles going same direction,
 - two motor vehicles going opposite directions, and
 - single vehicles.

SWICs occurring between 1999 and 2001 were included in the study.

DATA

The dataset included a total of 804 miles of highway segments with 44- to 54-ft surface widths. A total of 514 miles of two-lane highways and 290 miles of four-lane highways were available. [Table 7-1](#) lists the general characteristics of the highway segments.

Table 7-1. Range and Average Values for Rural Two-Lane and Four-Lane Highways with Surface Widths of 44 to 54 ft.

Variable	Average (Range) or Total for Data Set	
	Two Lane	Four Lane
ADT	3176 (170–14,033)	6546 (253–18,166)
Seg Len (mi)	1.39 (0.20–10.80)	1.88 (0.20–9.80)
RT Lane (ft)	11.97 (10–15)	11.42 (11–12)
RT Shou (ft)	10.34 (2–13)	1.68 (0–5)
SWICs	754	1135
Total Crashes	991	1745
Total Crashes KAB	378	661
SWIC KABs	286	441
Total Miles	514	290

Highway characteristics considered within the prediction equations included:

- number of Lanes (LN),
- lane width (RT Lane),
- shoulder width (RT Shou),
- median width,

- segment length (Seg Len), and/or
- ADT.

The highway characteristic variable median width was removed from the list of the independent variables because most of the highway segments in the database had zero median width. Only one of the 91 four-lane highway segments and 30 of 237 two-lane highway segments have non-zero median widths. The distribution for each of the remaining variables by lane is provided in [Figure 7-1](#). Crash rate (crashes per mile) was the method selected for presentation of the crash data because each segment length varied. Converting to a common unit – crashes per mile – permitted the graphing of the crash rate by the total number of miles. Bins of 1 crash/mi increments were used. As can be seen in [Figure 7-1](#), most of the mileage represented in the two-lane dataset had less than 1 crash/mi while the four-lane dataset had much higher number of crashes per mile.

MODELS

GLMs, specifically a negative binomial regression model and an analysis of covariance model, were used to determine the effects of independent variables on SWICs. A negative binomial regression model is often used to model the count data of which variance is much larger than the mean (this phenomenon is referred to as overdispersion). The prediction of crash frequencies can be made by using the mean function of the negative binomial regression.

Alternatively, an analysis of covariance model can be applied to the transformed counts. Note that crash frequencies such as SWICs do not follow a normal distribution as they are, and the variance usually increases as the crash frequency increases, which violates the usual assumptions in the analysis of covariance/variance. The purpose of transformation is to make the distribution of the transformed variable close to a normal distribution and to stabilize the variance. For the count data, the square-root transformation of the form given in [Chapter 5](#) is used conventionally.

An analysis of covariance model with a normal error distribution can be employed to develop a prediction equation based on the transformed count. Once the coefficients of the equation are estimated, prediction can be made for the original untransformed crash frequency by back-transforming transformed crash frequency.

Crashes on Rural Two- and Four-Lane Highways in Texas

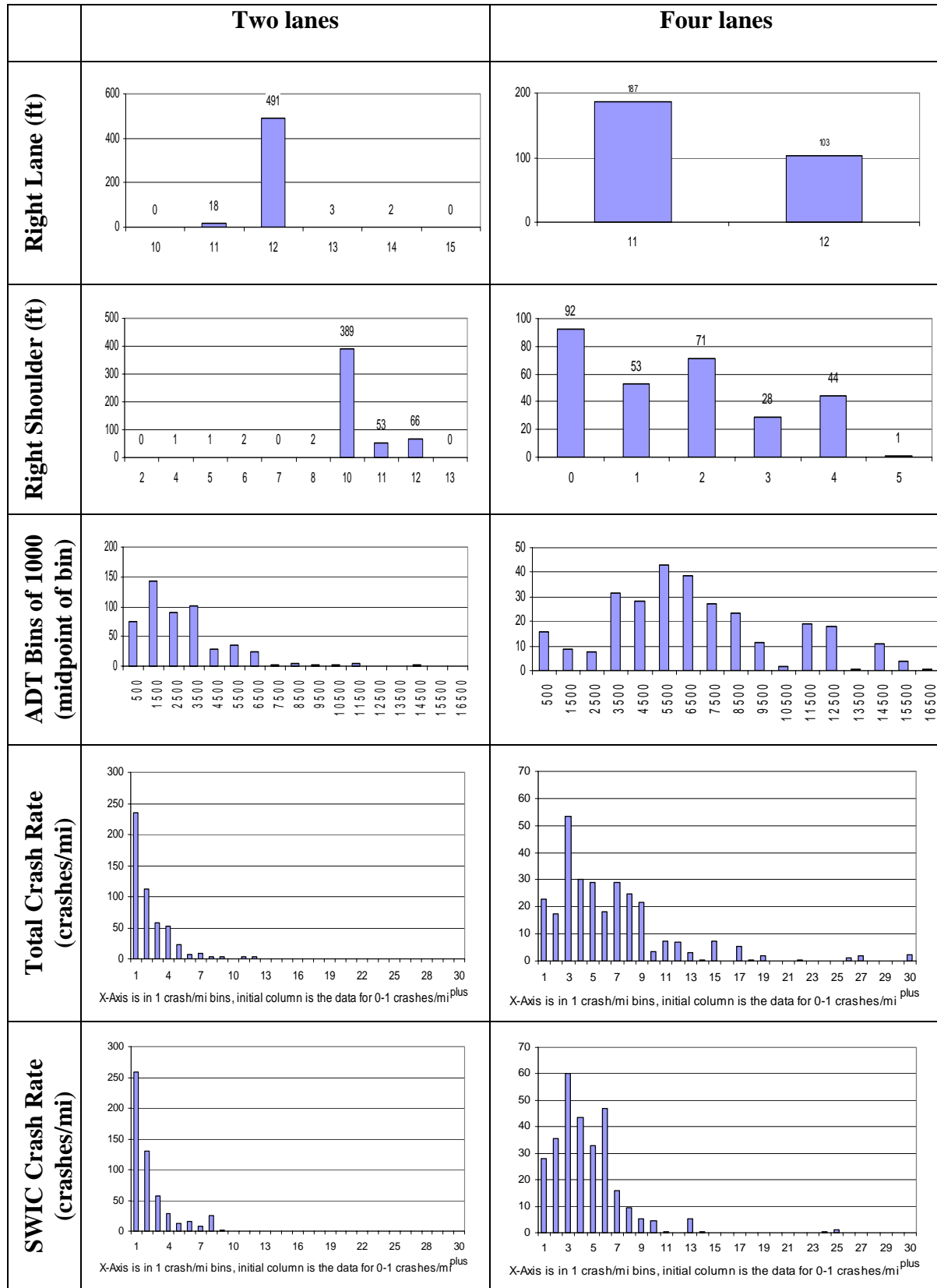


Figure 7-1. Distribution of Variables per Mile by Number of Lanes.

Negative Binomial Regression Model

Three types of negative binomial regression models were used:

- Model 1A) Segment Length (Length) and the log of ADT (LogADT) are included as the independent variables in addition to other variables (RT Lane, and RT Shou).
- Model 1B) The log of both Segment Length (LogLength) and ADT (LogADT) are included as the independent variables in addition to other highway characteristic variables (RT Lane, and RT Shou).
- Model 1C) Exposure was defined as a function of Segment Length and ADT. It is included as an offset variable in addition to RT Lane, and RT Shou.

To check if the effects of any of the highway characteristic variables change for different number of lanes, models with all possible two-way interactions between number of lanes (LN) and other highway characteristic variables were first examined. The results showed that the interactions LN * RT Shou and LN * RT Lane were significant, suggesting that the effects of RT Shou and/or RT Lane are different for different number of lanes. Therefore, a separate model was fitted for each of two-lane and four-lane highways. The functional form for the mean of each negative binomial regression model for each number of lanes is given in [Chapter 5](#).

Once the predicted values for the 3 year SWICs, E(3 yr SWIC), are obtained, the predicted SWICs per year can be obtained simply by dividing E(3 yr SWIC) by 3. Typical alpha levels used in determining whether a variable is significant range between 5 and 20 percent. An alpha of 5 percent was desired.

Initial efforts using Model 1A revealed that for two-lane highways the effects of RT Lane and RT Shou are not statistically significant. [Table 7-2](#) shows the SAS output for the revised two-lane highway Model 1A, where only Length and LogADT are retained in the model. Also shown in [Table 7-2](#) is the four-lane highway output. For the four-lane highways, all the variables (RT Lane, RT Shou, Length, and LogADT) are significant at $\alpha = 0.05$. From “Criteria for Assessing Goodness of Fit” (see [Table 7-2](#)), it can be seen that the negative binomial model fits the data very well. Note that both deviance and Pearson chi-square divided by degrees of freedom are close to 1. The ratios (Value/DF) close to 1.0 indicate that the model is adequate.

Table 7-2. Model Information for SWIC Data with Negative Binomial Regression (Model 1A: Two- and Four-Lane Highways).

Two-LANE HIGHWAY							
The GENMOD Procedure							
Model Information							
Data Set	LIB4618. NEW44T054FT_GROUP_EXPO3						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	SWIC						
Observations Used	371						
Criteria For Assessing Goodness Of Fit							
	Criterion	DF	Value	Value/DF			
	Deviance	368	367.2472	0.9980			
	Scaled Deviance	368	367.2472	0.9980			
	Pearson Chi-Square	368	350.6858	0.9530			
	Scaled Pearson X2	368	350.6858	0.9530			
	Log Likelihood		187.3481				
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-8.0391	0.7191	-9.4485	-6.6298	124.98	<.0001
Length	1	0.5066	0.0383	0.4315	0.5818	174.63	<.0001
LogADT	1	0.9662	0.0864	0.7968	1.1356	124.94	<.0001
Dispersion	1	0.4715	0.0828	0.3342	0.6651		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							
FOUR-LANE HIGHWAY							
The GENMOD Procedure							
Model Information							
Data Set	LIB4618. NEW44T054FT_GROUP_EXPO3						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	SWIC						
Observations Used	154						
Criteria For Assessing Goodness Of Fit							
	Criterion	DF	Value	Value/DF			
	Deviance	149	162.0544	1.0876			
	Scaled Deviance	149	162.0544	1.0876			
	Pearson Chi-Square	149	158.8114	1.0658			
	Scaled Pearson X2	149	158.8114	1.0658			
	Log Likelihood		1702.5624				
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-3.0750	1.7258	-6.4575	0.3075	3.17	0.0748
RT_Lane	1	-0.2688	0.1241	-0.5121	-0.0255	4.69	0.0304
RT_Shoulder	1	-0.1779	0.0409	-0.2581	-0.0977	18.89	<.0001
Length	1	0.5249	0.0370	0.4525	0.5974	201.70	<.0001
LogADT	1	0.8047	0.0913	0.6258	0.9836	77.72	<.0001
Dispersion	1	0.2597	0.0517	0.1757	0.3837		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							

Two-Lane Highway using Model 1A:

$$E(3 \text{ yr SWIC}) = \exp(-8.0391 + 0.5066 \text{ Length} + 0.9662 \text{ LogADT}) \quad (17)$$

Four-Lane Highway using Model 1A:

$$E(3 \text{ yr SWIC}) = \exp(-3.0750 - 0.2688 \text{ RT Lane} - 0.1779 \text{ RT Shou} \\ + 0.5249 \text{ Length} + 0.8047 \text{ LogADT}) \quad (18)$$

Evaluations with Model 1B also revealed that not all variables are significant. [Table 7-3](#) shows the results for two-lane highways, while the results for four-lane highways are in [Table 7-4](#). For two-lane highways, the effects of RT Lane and RT Shou are not significant. The bottom half of [Table 7-3](#) show the results when RT Lane and RT Shou are not included. For four-lane highways the effect of RT Lane is nearly significant at $\alpha = 0.1$. The bottom half of [Table 7-4](#) show the results when RT Lane is not included. From “Criteria for Assessing Goodness of Fit,” it can be seen that the negative binomial model fits the data well (both deviance and Pearson chi-square divided by degrees of freedom are less than 1.2). The estimated equations for the expected SWICs for two-lane and four-lane highways follow.

Two-Lane Highway using Model 1B:

$$E(3 \text{ yr SWIC}) = \exp(-6.8674 + 0.9691 \text{ LogLen} + 0.9139 \text{ LogADT}) \quad (19)$$

Four-Lane Highway using Model 1B:

$$E(3 \text{ yr SWIC}) = \exp(-4.4688 - 0.1338 \text{ RT Shou} + 1.0009 \text{ LogLen} \\ + 0.6895 \text{ LogADT}) \quad (20)$$

Table 7-3. Model Information for SWIC Data with Negative Binomial Regression (Model 1B: Two-Lane Highways).

The GENMOD Procedure							
Model Information							
Data Set	LIB4618. NEW44T054FT_GROUP_EXPO3						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	SWIC						SWIC
Observations Used	371						
Criteria For Assessing Goodness Of Fit							
Criterion	DF	Value	Value/DF				
Deviance	366	379.5614	1.0371				
Scaled Deviance	366	379.5614	1.0371				
Pearson Chi-Square	366	393.3684	1.0748				
Scaled Pearson X2	366	393.3684	1.0748				
Log Likelihood		227.0142					
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-8.3647	1.9881	-12.2613	-4.4680	17.70	<.0001
RT_Lane	1	0.1102	0.1423	-0.1686	0.3890	0.60	0.4385
RT_Shoulder	1	0.0159	0.0505	-0.0831	0.1150	0.10	0.7527
LogLength	1	0.9709	0.0518	0.8694	1.0723	351.89	<.0001
LogADT	1	0.9152	0.0737	0.7707	1.0597	154.07	<.0001
Dispersion	1	0.1879	0.0545	0.1064	0.3317		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							
The GENMOD Procedure							
Model Information							
Data Set	LIB4618. NEW44T054FT_GROUP_EXPO3						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	SWIC						SWIC
Observations Used	371						
Criteria For Assessing Goodness Of Fit							
Criterion	DF	Value	Value/DF				
Deviance	368	378.8006	1.0293				
Scaled Deviance	368	378.8006	1.0293				
Pearson Chi-Square	368	390.6109	1.0614				
Scaled Pearson X2	368	390.6109	1.0614				
Log Likelihood		226.7056					
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-6.8674	0.6024	-8.0481	-5.6867	129.95	<.0001
LogLength	1	0.9691	0.0517	0.8678	1.0704	351.55	<.0001
LogADT	1	0.9139	0.0735	0.7700	1.0579	154.77	<.0001
Dispersion	1	0.1913	0.0548	0.1092	0.3353		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							

Table 7-4. Model Information for SWIC Data with Negative Binomial Regression (Model 1B: Four-Lane Highways).

The GENMOD Procedure							
Model Information							
Data Set	LIB4618. NEW44T054FT_GROUP_EXPO3						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	SWIC						
Observations Used	154						
Criteria For Assessing Goodness Of Fit							
Criterion	DF	Value	Value/DF				
Deviance	149	161.6212	1.0847				
Scaled Deviance	149	161.6212	1.0847				
Pearson Chi-Square	149	171.4552	1.1507				
Scaled Pearson X2	149	171.4552	1.1507				
Log Likelihood		1718.5598					
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-2.2608	1.5259	-5.2515	0.7299	2.20	0.1384
RT_Lane	1	-0.1794	0.1109	-0.3967	0.0378	2.62	0.1055
RT_Shoulder	1	-0.1484	0.0368	-0.2205	-0.0764	16.30	<.0001
LogLength	1	0.9903	0.0580	0.8767	1.1040	291.81	<.0001
LogADT	1	0.6735	0.0805	0.5157	0.8313	70.00	<.0001
Dispersion	1	0.1647	0.0395	0.1029	0.2635		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							
The GENMOD Procedure							
Model Information							
Data Set	LIB4618. NEW44T054FT_GROUP_EXPO3						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	SWIC						
Observations Used	154						
Criteria For Assessing Goodness Of Fit							
Criterion	DF	Value	Value/DF				
Deviance	150	163.9146	1.0928				
Scaled Deviance	150	163.9146	1.0928				
Pearson Chi-Square	150	177.5134	1.1834				
Scaled Pearson X2	150	177.5134	1.1834				
Log Likelihood		1717.2417					
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-4.4688	0.7044	-5.8494	-3.0882	40.25	<.0001
RT_Shoulder	1	-0.1338	0.0356	-0.2036	-0.0641	14.14	0.0002
LogLength	1	1.0009	0.0577	0.8878	1.1140	300.69	<.0001
LogADT	1	0.6895	0.0802	0.5323	0.8467	73.91	<.0001
Dispersion	1	0.1656	0.0401	0.1030	0.2660		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							

Table 7-5 shows the SAS output for Model 1C. For two-lane highways, RT Lane and RT Shou are not significant. For four-lane highways, the effect of RT Shou is statistically significant, but not the effect of RT Lane. From “Criteria for Assessing Goodness of Fit,” it can be seen that the negative binomial model fits the data well (both deviance and Pearson chi-square divided by degrees of freedom are close to 1), but not as well as other models.

Analysis of Covariance Model for Transformed SWIC (TSWIC)

The SWIC were transformed using the equation presented in Chapter 5. To check if the effects of any of the highway characteristic variables change for different number of lanes, an analysis of covariance model having LN as a discrete factor and RT Lane, RT Shou, Seg Len, and LogADT as continuous factors along with all possible two-way interactions between LN and other factors was first examined. The results showed that the interaction effects LN * RT Shou, LN * Seg Len, and LN * LogADT are significant, suggesting that the effects of shoulder width, segment length, and LogADT might be different when the number of lanes is two and when it is four. Therefore, a separate model was fitted for each of two-lane and four-lane highways.

Table 7-6 contains the result of the fit for two-lane highways for 3 yr TSWIC. For two-lane highways, neither RT Lane nor RT Shou has a significant effect on 3 yr TSWIC. Table 7-7 contains the results of the fit for four-lane highways. For four-lane highways, the effect of RT Shou is statistically significant at $\alpha = 0.05$, while the effect of RT Lane is significant at $\alpha = 0.15$ but not at $\alpha = 0.05$. Note from the tables that the parameter estimates are quite different for two-lane highways and four-lane highways, as was expected from the significant interaction effects between LN and other variables.

The prediction equations for TSWIC (the estimated equations for the expected TSWIC) can be written as follows:

Prediction equations for TSWIC for two-lane highways:

$$E(3 \text{ yr TSWIC}) = -1.5867 + 0.4994 \text{ LogLen} + 0.3876 \text{ LogADT} \quad (21)$$

Prediction equations for TSWIC for four-lane highways:

$$E(3 \text{ yr TSWIC}) = -2.2168 - 0.1008 \text{ RT Shou} + 0.9896 \text{ LogLen} + 0.5409 \text{ LogADT} \quad (22)$$

Table 7-5. Model Information for SWIC Data with Negative Binomial Regression (Model 1C: Two- and Four-Lane Highways).

TWO-LANE HIGHWAY							
The GENMOD Procedure							
Model Information							
Data Set	LIB4618. NEW44T054FT_GROUP_EXP03						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	SWIC			SWIC			
Offset Variable	LogEXP03			LogEXP03			
Observations Used	371						
Criteria For Assessing Goodness Of Fit							
	Criterion	DF		Value		Value/DF	
	Deviance	368		381.4607		1.0366	
	Scaled Deviance	368		381.4607		1.0366	
	Pearson Chi-Square	368		416.9468		1.1330	
	Scaled Pearson X2	368		416.9468		1.1330	
	Log Likelihood			226.3186			
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-2.3171	1.8934	-6.0282	1.3940	1.50	0.2210
RT_lane	1	0.1188	0.1430	-0.1614	0.3990	0.69	0.4059
RT_Shou	1	0.0127	0.0508	-0.0868	0.1122	0.06	0.8028
Dispersion	1	0.1866	0.0547	0.1051	0.3315		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							
FOUR-LANE HIGHWAY							
The GENMOD Procedure							
Model Information							
Data Set	LIB4618. NEW44T054FT_GROUP_EXP03						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	SWIC			SWIC			
Offset Variable	LogEXP03			LogEXP03			
Observations Used	154						
Criteria For Assessing Goodness Of Fit							
	Criterion	DF		Value		Value/DF	
	Deviance	152		163.6884		1.0769	
	Scaled Deviance	152		163.6884		1.0769	
	Pearson Chi-Square	152		189.3908		1.2460	
	Scaled Pearson X2	152		189.3908		1.2460	
	Log Likelihood			1710.5477			
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-0.3437	0.0808	-0.5020	-0.1853	18.09	<.0001
RT_Shou	1	-0.1521	0.0378	-0.2262	-0.0780	16.19	<.0001
Dispersion	1	0.2036	0.0455	0.1314	0.3155		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							

Table 7-6. Least-Squares Fit for 3 yr TSWIC for Two-Lane Highways.

2-lane roadways with Rt Lane, Rt Shou, LogLength and LogADT				
LN=2				
Response TSWIC (Transformed SWIC)				
Summary of Fit				
RSquare		0.530656		
RSquare Adj		0.525526		
Root Mean Square Error		0.563427		
Mean of Response		1.319126		
Observations (or Sum Wgts)		371		
Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	-1.223415	0.887803	-1.38	0.1690
RT lane	-0.029146	0.065836	-0.44	0.6582
RT Shou	-0.002057	0.022492	-0.09	0.9272
LogLength	0.4999183	0.028215	17.72	<.0001
LogADT	0.3884623	0.037816	10.27	<.0001
2-lane roadways with LogLength and LogADT				
LN=2				
Response TSWIC				
Summary of Fit				
RSquare		0.530404		
RSquare Adj		0.527852		
Root Mean Square Error		0.562044		
Mean of Response		1.319126		
Observations (or Sum Wgts)		371		
Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	-1.586762	0.293406	-5.41	<.0001
LogLength	0.4994148	0.028119	17.76	<.0001
LogADT	0.3875847	0.037487	10.34	<.0001

Table 7-7. Least-Squares Fit for 3 yr TSWIC for Four-Lane Highways.

4-lane roadways with RT Lane, RT Shou, LogLength, and LogADT				
LN=4				
Response TSWIC				
Summary of Fit				
RSquare		0.702973		
RSquare Adj		0.694999		
Root Mean Square Error		0.810924		
Mean of Response		2.367082		
Observations (or Sum Wgts)		154		
Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	0.6644301	1.927752	0.34	0.7308
RT lane	-0.229981	0.143223	-1.61	0.1104
RT Shou	-0.122757	0.045577	-2.69	0.0079
LogLength	0.9730825	0.062309	15.62	<.0001
LogADT	0.5156751	0.083554	6.17	<.0001
4-lane roadways with RT Shou, LogLength, and LogADT				
Response TSWIC				
Summary of Fit				
RSquare		0.697833		
RSquare Adj		0.69179		
Root Mean Square Error		0.81518		
Mean of Response		2.367082		
Observations (or Sum Wgts)		154		
Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	-2.21684	0.708381	-3.13	0.0021
RT Shou	-0.100796	0.043705	-2.31	0.0225
LogLength	0.9895873	0.061778	16.02	<.0001
LogADT	0.5408748	0.082498	6.56	<.0001

The prediction equations for 3 yr SWICs (the estimated equations for the expected 3 yr SWIC) can be obtained by back-transforming 3 yr TSWIC. As before, these predicted values are for SWICs for 3 years. The predicted SWICs per year can be obtained simply by dividing E(3 yr SWIC) by 3.

Prediction equations for SWIC for two-lane highways:

$$E(\text{SWIC}) = [(-1.5867 + 0.4994 \text{ LogLen} + 0.3876 \text{ LogADT})^2 - 3/8]/3 \quad (23)$$

Prediction equations for SWIC for four-lane highways:

$$E(\text{SWIC}) = [(-2.2168 - 0.1008 \text{ RT Shou} + 0.9896 \text{ LogLen} + 0.5409 \text{ LogADT})^2 - 3/8]/3 \quad (24)$$

Selection of Model

Similar to the decisions presented in Chapters 5 and 6, Model 1B was the preferred form for the evaluation of converting the number of lanes on a 44- to 54-ft surface width. The selected regression equations are:

Two-Lane Highway for Surface Width 44- to 54-ft Evaluation:

$$E(\text{SWIC}) = [\exp(-6.8674 + 0.9691 \text{ LogLen} + 0.9139 \text{ LogADT})]/3 \quad (25)$$

Four-Lane Highway for Surface Width 44- to 54-ft Evaluation:

$$E(\text{SWIC}) = [\exp(-4.4688 - 0.1338 \text{ RT Shou} + 1.0009 \text{ LogLen} + 0.6895 \text{ LogADT})]/3 \quad (26)$$

TOTAL CRASHES AND KAB CRASHES

Previous research had indicated that selected crashes should be examined when evaluating treatments associated with the width of the pavement. Reallocating the surface width between adding a lane or retaining a wide shoulder should be associated with those crashes affected by the surface width. The previous evaluation was done with surface width influenced crashes, or SWICs, as called within this report. To verify that the results will not be different, a similar comparison was done using total crashes and KAB crashes (as described in [Chapter 5](#)).

[Table 7-8](#) shows the SAS output for the preferred models for the total crash regression analysis. Both models fit the data well, as both deviance and Pearson chi-square divided by degrees of freedom are close to 1.

COMPARISON

To investigate when a four-lane highway with minimal shoulders is preferred over a two-lane highway with wide shoulders, researchers compared the equations generated using the Model 1B form and negative binomial regression. A variety of reasonable lane widths and shoulder width values along with assumptions of segment length and ADT can be used within the equations to predict number of crashes. [Figure 7-2](#) shows such a prediction using a 10 mile segment and a 6000 ADT for SWICs. The plot uses predicted number of SWICs per million vehicle miles (MVM). Surface widths of 44 to 54 ft were included in the evaluation. Lane widths were 10, 11, or 12 ft for two-lane highways and 11 or 12 ft for four-lane highways (mimicking the lane widths present in the dataset). The shoulder widths were calculated from the surface and lane widths (for example, for a 50-ft surface width and 12-ft lanes, the shoulders would be 13 ft for the two-lane highways and 1 ft for the four-lane highways).

[Figure 7-2](#) shows that at lower surface width values, four-lane highways have higher numbers of SWICs/MVM than two-lane highways. At approximately a 53-ft surface width, the number of SWICs is similar for both the four-lane and two-lane cross sections. This figure illustrates that there could be conditions where, on a safety basis, it is logical to convert a two-lane highway with wide shoulders to a four-lane highway with minimal shoulders.

Table 7-8. Model Information for Total Crash Data with Negative Binomial Regression (Two- and Four-Lane Highways).

TWO-LANE HIGHWAY							
The GENMOD Procedure							
Model Information							
Dataset	LIB4618. NEW44T054FT_GROUP_EXP03						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	Total_Accident						
Observations Used	371						
Criteria For Assessing Goodness Of Fit							
	Criterion	DF	Value	Value/DF			
	Deviance	368	408.0642	1.1089			
	Scaled Deviance	368	408.0642	1.1089			
	Pearson Chi-Square	368	454.2176	1.2343			
	Scaled Pearson X2	368	454.2176	1.2343			
	Log Likelihood		514.5326				
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-6.7806	0.5716	-7.9009	-5.6602	140.70	<.0001
LogLength	1	0.8143	0.0474	0.7215	0.9071	295.52	<.0001
LogADT	1	0.9475	0.0702	0.8099	1.0850	182.29	<.0001
Dispersion	1	0.2729	0.0586	0.1792	0.4158		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							
FOUR-LANE HIGHWAY							
The GENMOD Procedure							
Model Information							
Dataset	LIB4618. NEW44T054FT_GROUP_EXP03						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	Total_Accident						
Observations Used	154						
Criteria For Assessing Goodness Of Fit							
	Criterion	DF	Value	Value/DF			
	Deviance	149	178.2341	1.1962			
	Scaled Deviance	149	178.2341	1.1962			
	Pearson Chi-Square	149	198.5757	1.3327			
	Scaled Pearson X2	149	198.5757	1.3327			
	Log Likelihood		3334.7202				
Algorithm converged.							
Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-1.8561	1.7524	-5.2907	1.5784	1.12	0.2895
RT_Lane	1	-0.3283	0.1284	-0.5799	-0.0768	6.54	0.0105
RT_Shoulder	1	-0.0876	0.0401	-0.1661	-0.0091	4.79	0.0287
LogLength	1	0.7577	0.0583	0.6434	0.8720	168.89	<.0001
LogADT	1	0.8800	0.0880	0.7075	1.0525	100.00	<.0001
Dispersion	1	0.3405	0.0604	0.2405	0.4821		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							

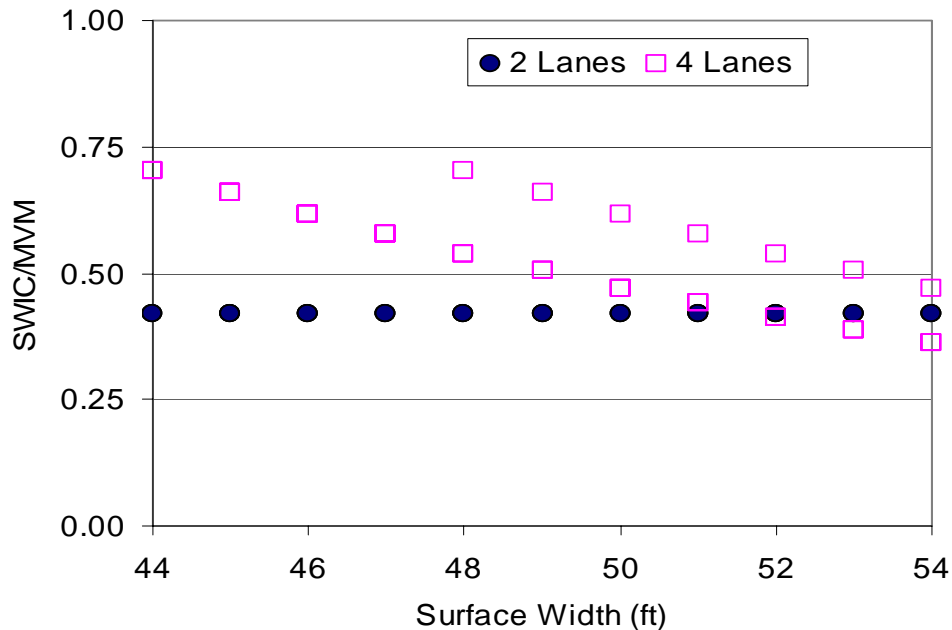


Figure 7-2. Comparison of SWIC Predictions for Two-Lane and Four-Lane Highways (10 mile Segment and ADT of 6000).

Conversions of two-lane with wide shoulder highways to a four-lane with minimal shoulder highway could occur on varying lengths of highway. Lengths of 5, 10, and 20 miles were checked as representative lengths for a project where a cross section could be changed after a resurfacing project. Figure 7-3 illustrates the predicted number of SWICs per million vehicle miles determined using an assumed 10-mile segment with ADTs ranging from 2000 to 12,000 in increments of 2000. At an ADT of 4000, a 54-ft surface width has similar predicted number of crashes for both two-lane and four-lane highways. At very high ADTs (10,000 and greater), similar SWIC values were predicted for both the four-lane and two-lane highway conditions for a 50-ft surface width. Reviewing the original data, for the 50-ft surface width, the four-lane highways had either 12-ft lanes with 1-ft shoulders or 11-ft lanes with 3-ft shoulders. The two-lane highways had 12- and 11-ft lanes with 10- to 12-ft shoulders. The balance of the surface width was allocated to a wider median (e.g., two 12-ft lanes with two 10-ft shoulders and a 6-ft median).

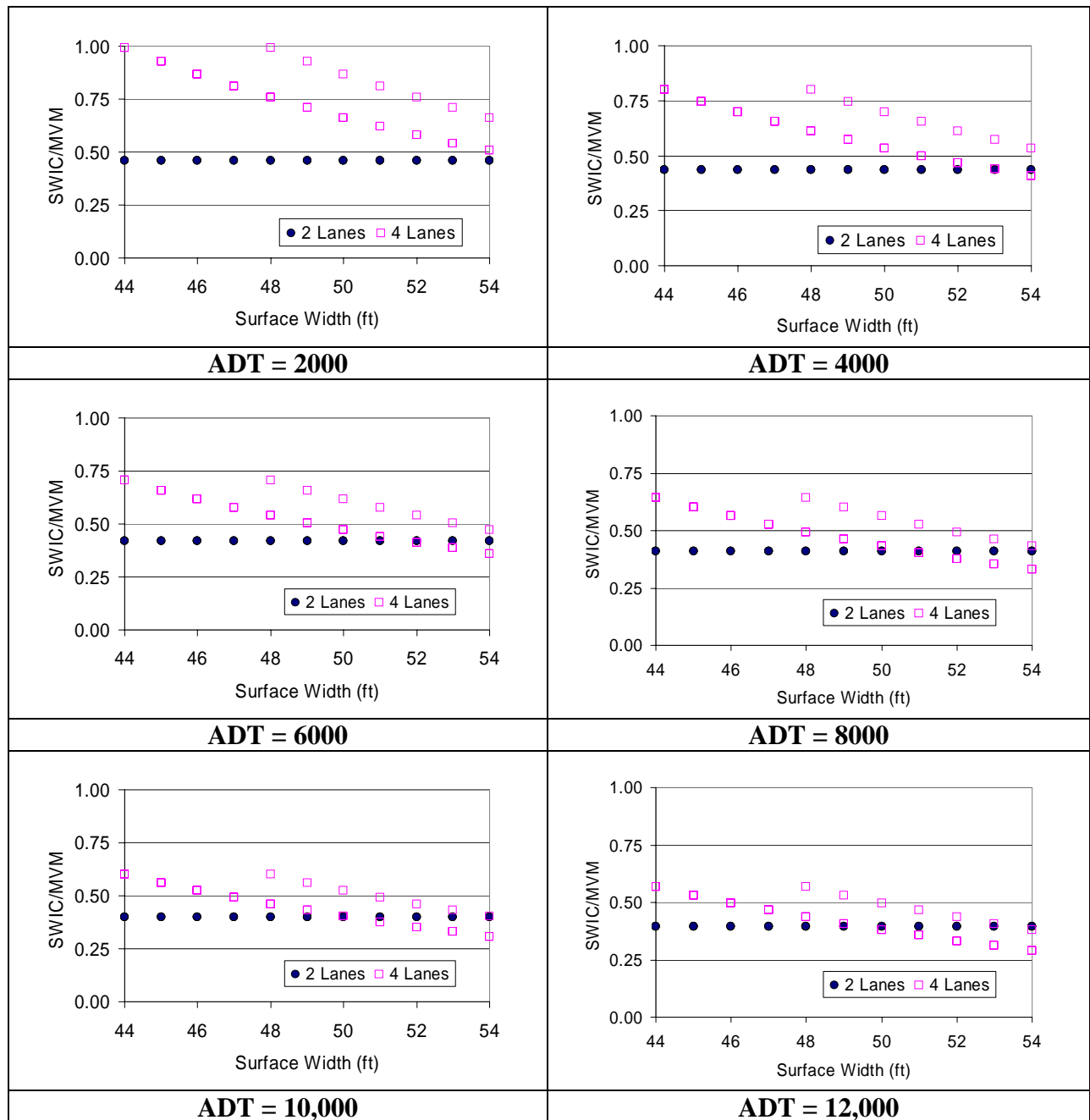


Figure 7-3. Examples of Predicted Number of Annual SWICs by Surface Width for Different ADT Levels.

For this evaluation a 10-mile segment length was assumed. If a project will have a different length, then the equations can be used to determine the surface width when the number of crashes on the two-lane cross section will be similar to the four-lane cross section. A review of other assumed lengths was conducted, and generally similar results were found (difference was on the order of only a 1-ft change in the surface width where the predicted crashes on the two-lane highway was similar to the predicted crashes on the four-lane highway).

Similar comparisons were performed using total crashes, SWIC KABs, and total crashes KAB with slightly different results. [Figure 7-4](#) shows an example of the findings when total crashes rather than SWICs are used. The total crash predictions for four-lane highways are slightly higher than the predictions for SWICs. With the higher four-lane highway predictions, the plots cross at a wider surface width. For the scenario shown in [Figure 7-4](#), a conversion from a two-lane with wide shoulders to a four-lane with minimal shoulders could possibly be considered at 54 ft (which is the limit of the data). When total crashes are compared between the four-lane and two-lane highway segments, only one ADT and surface width combination results in a situation where a four-lane cross section could be considered. Only when ADT is very high, on the order of 10,000 or more, did the four-lane cross section have similar number of total crashes.

When the SWIC KABs (see [Figure 7-5](#)) are used rather than total crashes or SWICs, an even stronger message is present. In all combinations of lane and shoulder widths, the four-lane highway predictions are higher than the two-lane highway predictions. The sensitivity to wider shoulder widths on a four-lane highway can be seen in [Figure 7-5](#). The two data points for four-lane highway for a specific surface width represent either an 11-ft lane or a 12-ft lane with the remaining surface width as the shoulder. The higher predicted crash rate generally represents only 1 ft of shoulder width, while the other data point generally represents 3 ft of shoulder width.

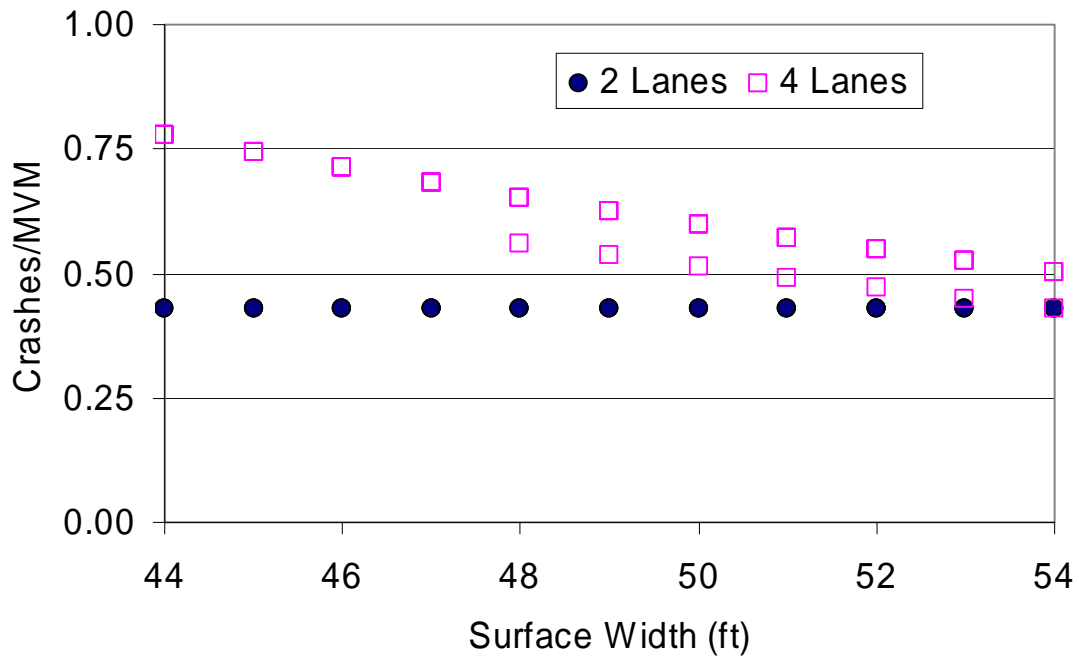


Figure 7-4. Comparison of Total Crash Predictions for Two-Lane and Four-Lane Highways (10-mile Segment and ADT of 6000).

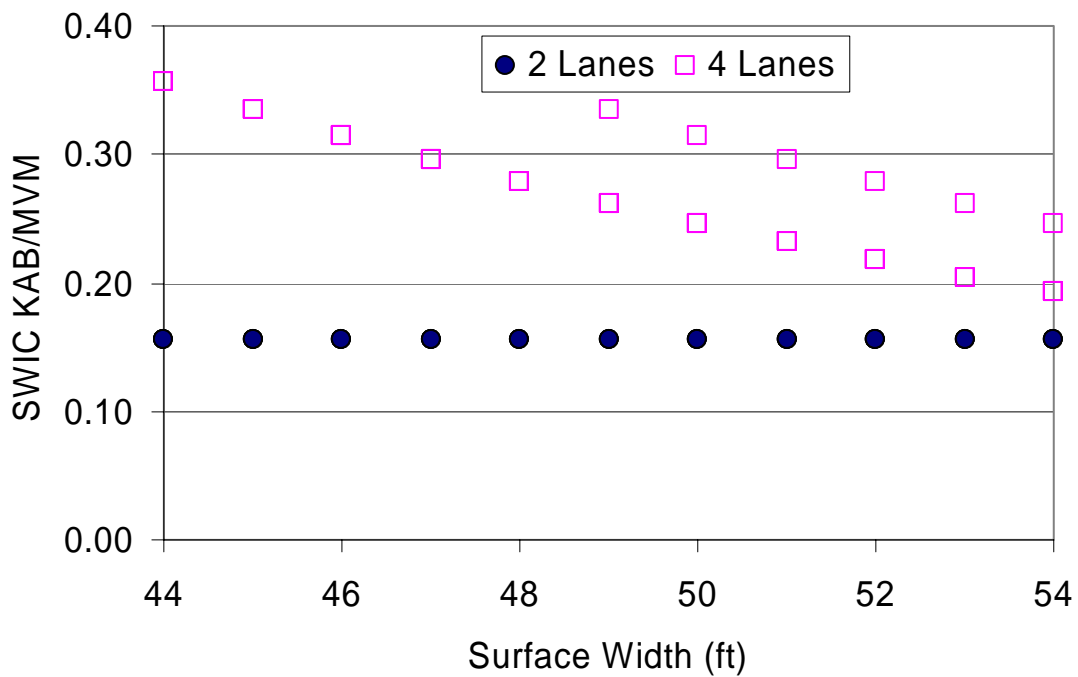


Figure 7-5. Comparison of SWIC KAB Predictions for Two-Lane and Four-Lane Highways (10-mile Segment and ADT of 6,000).

The surface width dimension when the predicted number of crashes for a four-lane highway essentially equals the predicted number of crashes for a two-lane highway was determined for each type of crash used in the evaluation: SWICs, total crashes, total crashes KAB, and SWIC KABs. Figure 7-6 shows a plot of the findings. Surface widths to the left of a curve indicate that the two-lane cross section had fewer crashes, while surface widths to the right of the curve indicate that the four-lane cross section had fewer crashes. The conclusions vary depending upon which type of crash is used in the evaluation (in other words, which of the curves in Figure 7-6 is used). Using a more conservative result (for example, the total crash curve), the recommendation would be that converting from a two-lane with wide shoulders to a four-lane with minimal shoulders only be considered at ADTs over 10,000 and a minimum 53-ft surface width (see curve with diamonds in Figure 7-6).

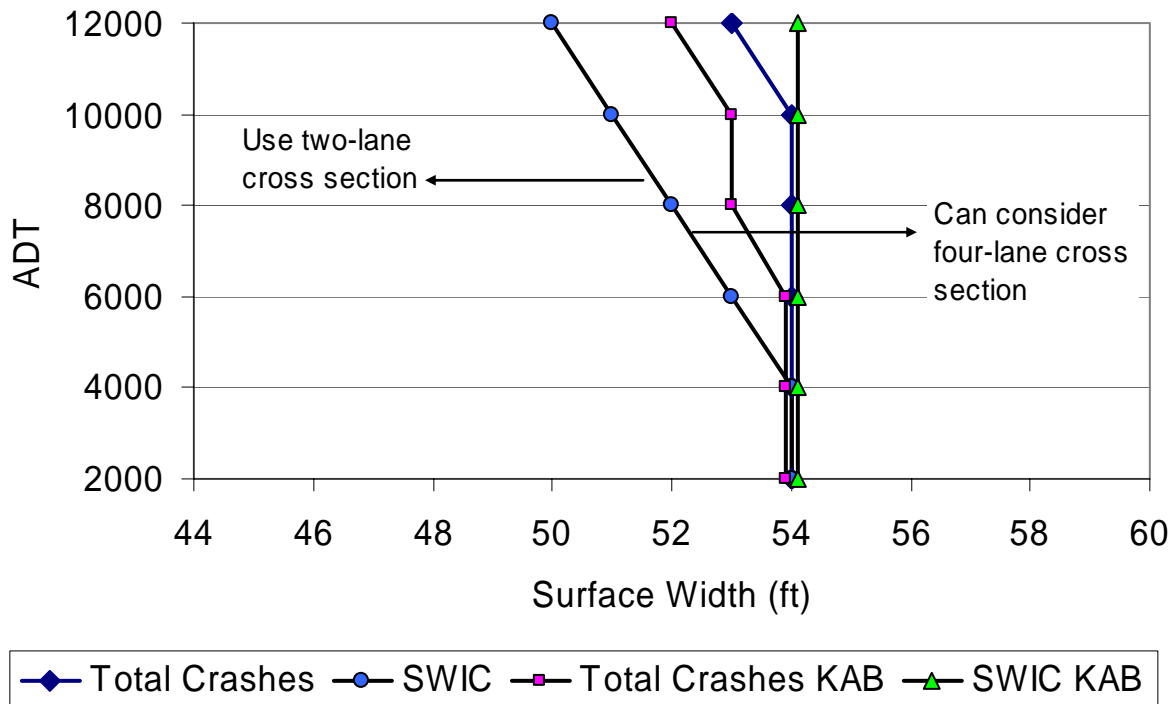


Figure 7-6. Comparison of Results Using Different Crash Types.

CHAPTER 8

CRASH PREDICTION FOR RURAL INTERSECTIONS

OVERVIEW

The objective of this study was to find the relationship between crashes at rural intersections and geometric variables available within TxDOT databases or from the field.

CRASHES AND DATA

Similar to the studies conducted for two-lane highways (see [Chapter 5](#)) and four-lane highways (see [Chapter 6](#)), on-system crashes for the years 1999 to 2001 were used in the analysis.

Intersections were identified during the data reduction efforts on the roadway segments. A total of 3739 intersections were identified, with 3109 being on two-lane highways and 630 on four-lane highways. Previous research has clearly demonstrated that ADT – both for the major road and for the cross road – is one of the strongest (if not the strongest) predictor of crashes at intersections. Cross-road ADTs were available through TxDOT maps for 265 of the 3739 intersections.

Intersection characteristic variables available from the field data reduction efforts included:

- number of lanes,
- lane width,
- shoulder width,
- median width,
- median class,
- functional class,
- number of legs,
- intersection skew,
- intersection control (e.g., signal, stop-control on minor),
- presence of left-turn lane,

- major road ADT, and/or
- cross-road ADT.

The distribution for key variable is provided in [Table 8-1](#) for the 3109 intersections located on two-lane highways, in [Table 8-2](#) for the 630 intersections located on four-lane highways, and in [Table 8-3](#) for the 265 intersections with cross-road ADT. Frequency data are plotted for total crashes and fatal/injury crashes for the different types of intersections used in the evaluation: [Figure 8-1](#) for the 3109 intersections located on two-lane highways, in [Figure 8-2](#) for the 630 intersections located on four-lane highways, and in [Figure 8-3](#) for the 265 intersections with cross-road ADT. Because almost all of the intersections were stop-controlled on the cross road, the intersection control variable was eliminated from the evaluation.

Table 8-1. Distribution of Variables for Intersections on Two-Lane Highways (3109 Intersections).

Description	%	Description	%
Functional Class		Number of Lanes	
2 – Principal Arterial	7	Two lanes	100
6 – Minor Arterial	16	Four lanes	0
7 – Major Collector	55		
8 – Minor Collector	22		
9 – Local Road	0.1		
Intersection Skew		Number of Legs	
M – approximately 90°	18	Three approaches to intersection	83
R – not quite 90°	73	Four approaches to intersection	17
S – obvious skew	9		
Median Class		Right Lane Width (ft)	
Depressed, ≥ 16 ft	0.1	9	2
Flush, >2 ft and <12 ft	1	10	24
Flush, ≥12 ft	0.3	11	36
None, <2 ft	99	12	37
Two-Way Left-Turn Lane, ≥ 12 ft	0.4	>13	1
Median Width (ft)		Right Shoulder Width (ft)	
NULL- Could not be determined	0.3	0	41
0	99	1	18
4	0.1	2	7
5	0.1	3	3
6	0.1	4	3
10	0.2	5	1
12	0.4	6	3
15	0.1	7	3
16	0.1	8	8
		9	1
		10	10
		11	1
		12	2
Presence of Left-Turn Lane		Presence of Right-Turn Lane	
Yes	1	Yes	1
No	99	No	99

Table 8-2. Distribution of Variables for Intersections on Four-Lane Highways (630 Intersections).

Description	%	Description	%
Functional Class		Number of Lanes	
Principal Arterial	75	Two lanes	0
Minor Arterial	20	Four lanes	100
Major Collector	6		
Intersection Skew		Number of Legs	
approximately 90°	11	Two approaches to intersection	2
not quite 90°	87	Three approaches to intersection	77
Obvious skew	3	Four approaches to intersection	22
Median Class		Right Lane Width (ft)	
Depressed, <16 ft	4	10	0.2
Depressed, ≥ 16 ft	55	11	19
Flush, >2 ft and <12 ft	2	12	80
Flush, ≥ 12 ft	1	13	1
None, <2 ft	20		
Two-Way Left-Turn Lane, >2 ft and <12 ft	1		
Two-Way Left-Turn Lane, ≥ 12 ft	17		
Median Width (ft)		Right Shoulder Width (ft)	
NULL- Could not be determined	53	0	5
0	20	1	3
4	1	2	2
6	0.3	3	2
8	0.3	4	2
10	1	5	1
12	10	6	3
13	0.3	7	1
14	4	8	12
16	3	9	1
18	1	10	43
20	2	11	8
24	5	12	16
		13	0.2
		14	0.3
Presence of Left-Turn Lane		Presence of Right-Turn Lane	
Yes	43	Yes	7
No	57	No	93

Table 8-3. Distribution of Variables for Intersections with Known Cross-Road ADT (265 Intersections).

Description	%	Description	%
Functional Class		Number of Lanes	
2 – Principal Arterial	27	Two lanes	80
6 – Minor Arterial	24	Four lanes	20
7 – Major Collector	42		
8 – Minor Collector	8		
Intersection Skew		Number of Legs	
M – approximately 90°	18	Three approaches to intersection	66
R – not quite 90°	74	Four approaches to intersection	34
S – Obvious skew	8		
Median Class		Right Lane Width (ft)	
Depressed, >16 ft	1	10	10
Depressed, ≥ 16 ft	11	11	28
Flush, >2 ft and <12 ft	2	12	60
Flush, ≥ 12 ft	2	13	1
None, <2 ft	78	14	1
Two-Way Left-Turn Lane, >2 ft and <12 ft	0.4	15	0.4
Two-Way Left-Turn Lane, ≥ 12 ft	6		
Median Width (ft)		Right Shoulder Width (ft)	
NULL- Could not be determined	11	0	24
0	78	1	9
6	1	2	5
10	2	3	3
12	3	4	5
14	1	5	0.4
16	1	6	3
18	1	7	5
20	2	8	11
24	1	9	2
		10	22
		11	2
		12	8
Presence of Left-Turn Lane		Presence of Right-Turn Lane	
Yes	17	Yes	9
No	83	No	91

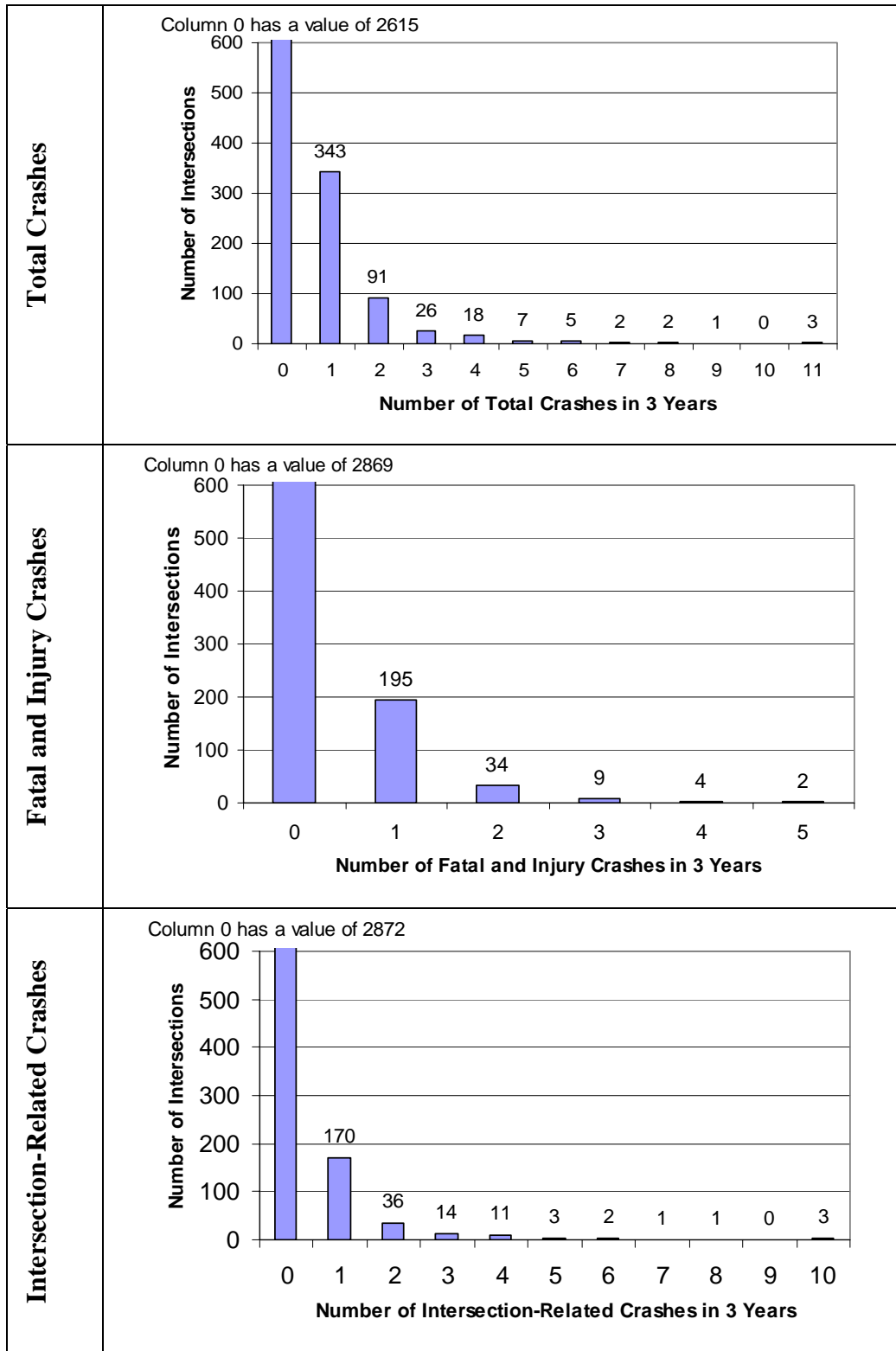


Figure 8-1. Crash Frequency Data by Number of Intersections for Intersections on Rural Two-Lane Highways (3109 Intersections).

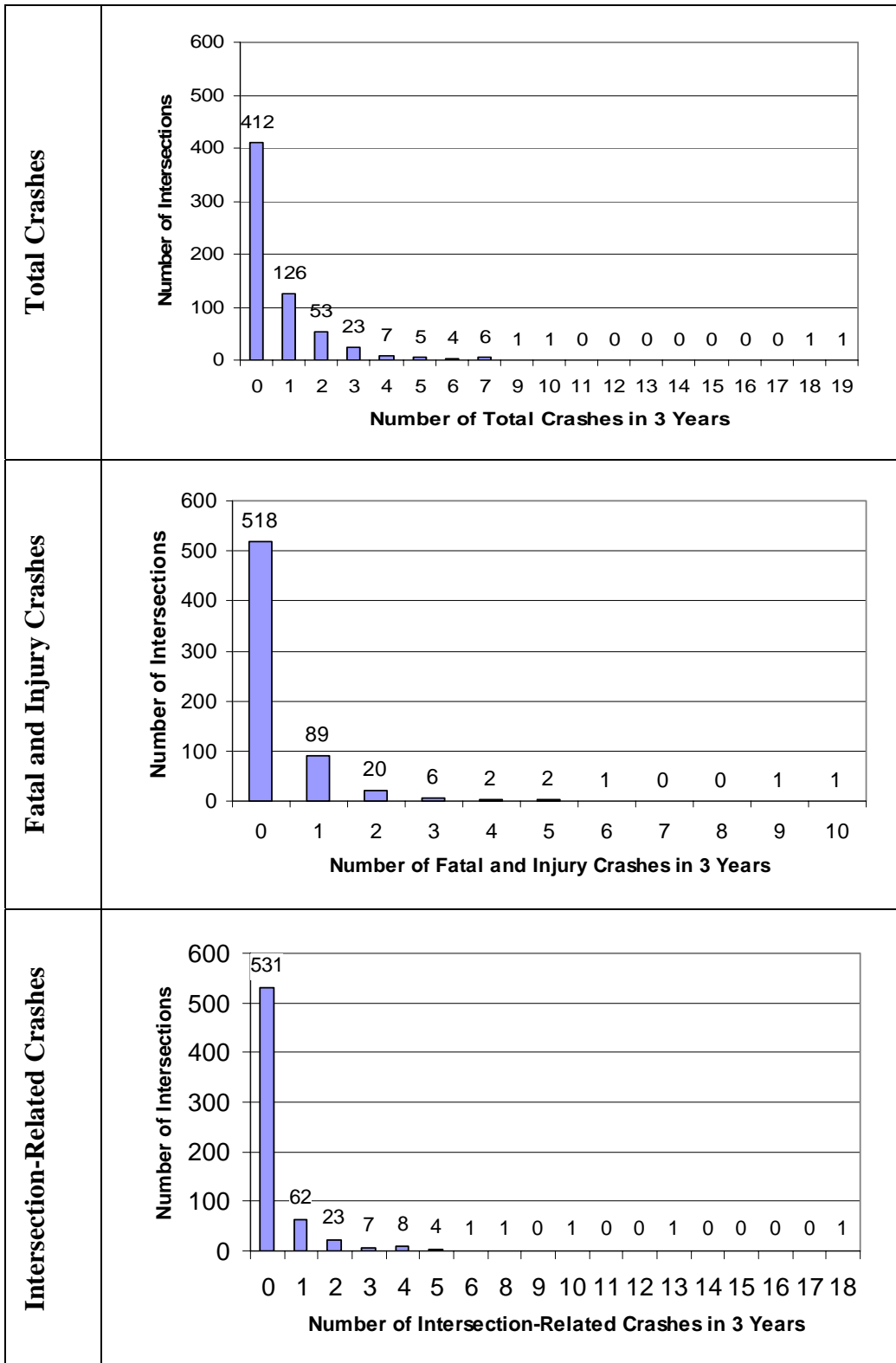


Figure 8-2. Crash Frequency Data by Number of Intersections for Intersections on Rural Four-Lane Highways (630 Intersections).

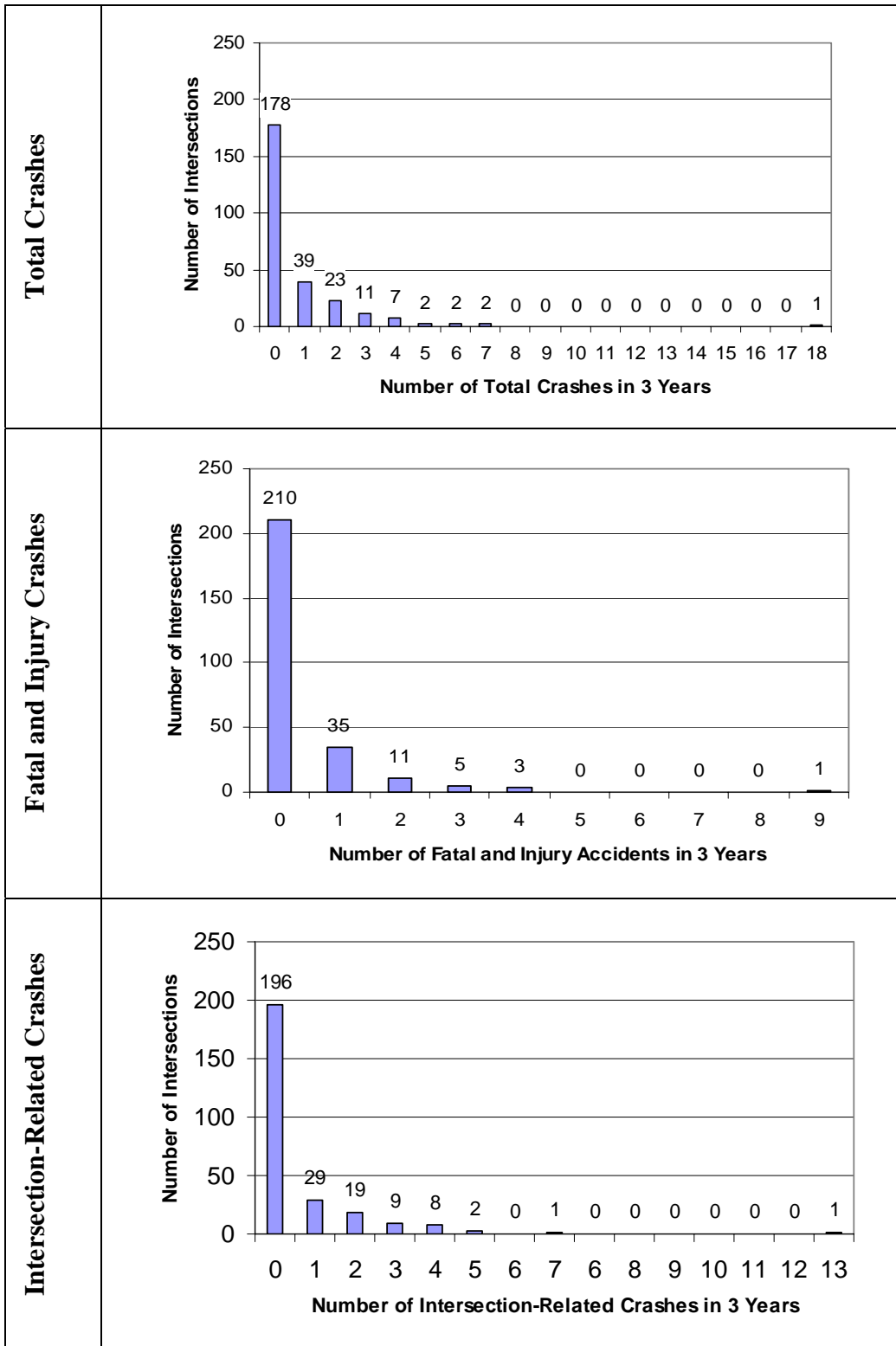


Figure 8-3. Crash Frequency Data by Number of Intersections for Intersections with Known Cross-Road ADT (265 Intersections).

MODELS

Similar to the roadway segment analysis, a negative binomial regression model is used to determine the effects of independent variables on intersection crashes. See [Chapter 5](#) for additional discussion on negative binomial regression. Several attempts were made to determine the optimal regression equation. Only the final attempts are reported here.

CRASH PREDICTION FOR INTERSECTIONS WITH CROSS-ROAD ADT

A negative binomial regression model having the following variables as independent variables was used for total crashes, total intersection-related crashes, and total fatal/injury crashes:

- right shoulder (RT Shou),
- functional class,
- number of legs (Legs),
- intersection skew (Int_Skew),
- major road approach number of lanes (Major Road Approach),
- cross-road approach number of lanes (Cross Road Approach),
- log of traffic subject ADT (LogADT_Subj), and
- log of traffic cross-road ADT (LogADT_Cross).

The results are presented in [Tables 8-4, 8-5, and 8-6](#). From [Table 8-4](#), it can be seen that for total crashes the effects of major road ADT and cross-road ADT are significant at $\alpha = 0.05$. The effects of functional class and number of legs are significant at $\alpha = 0.1$ but not at $\alpha = 0.05$.

[Table 8-5](#) shows that for total intersection crashes the effects of functional class, major road ADT, and cross-road ADT are significant at $\alpha = 0.05$. The effect of number of legs is significant at $\alpha = 0.1$ but not at $\alpha = 0.05$.

From [Table 8-6](#), it can be seen that for total crashes KAB, the effect of cross-road ADT is significant at $\alpha = 0.05$. The effect of major road ADT is significant at $\alpha = 0.1$, but not at $\alpha = 0.05$.

Table 8-4. Model Information for Total Crashes with Negative Binomial Regression for Intersections Where Cross-Road ADT is Available.

The GENMOD Procedure							
Model Information							
Dataset	LIB4618. INTERSECTION_DATA_NEW						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	Total_Accident	Total Accident					
Observations Used	265						
Class Level Information							
Class	Level	Values					
Functional_Class	4	2 6 7 8					
Legs	2	3 4					
Int_Skew	3	M R S					
Major_Road_Approach	4	1 2 3 4					
Cross_Road_Approach	3	1 2 3					
Criteria for Assessing Goodness of Fit							
Criterion	DF	Value	Value/DF				
Deviance	250	209.4325	0.8377				
Scaled Deviance	250	209.4325	0.8377				
Pearson Chi-Square	250	248.1522	0.9926				
Scaled Pearson X2	250	248.1522	0.9926				
Log Likelihood		-126.6160					
Algorithm converged.							
Analysis of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-27.9131	1.6503	-31.1476	-24.6785	286.07	<.0001
RT_Shou	1	-0.0224	0.0312	-0.0834	0.0387	0.52	0.4729
Functional_Class	2	1.2518	0.6598	-0.0414	2.5451	3.60	0.0578
Functional_Class	6	1.3037	0.5988	0.1302	2.4773	4.74	0.0295
Functional_Class	7	0.3991	0.5623	-0.7030	1.5012	0.50	0.4779
Functional_Class	8	0.0000	0.0000	0.0000	0.0000	.	.
Legs	3	-0.4339	0.2210	-0.8671	-0.0007	3.85	0.0496
Legs	4	0.0000	0.0000	0.0000	0.0000	.	.
Int_Skew	M	0.0250	0.5117	-0.9778	1.0278	0.00	0.9610
Int_Skew	R	0.2257	0.4433	-0.6432	1.0946	0.26	0.6106
Int_Skew	S	0.0000	0.0000	0.0000	0.0000	.	.
Major_Road_Approach	1	0.4189	0.5397	-0.6388	1.4767	0.60	0.4376
Major_Road_Approach	2	0.0818	0.5372	-0.9711	1.1347	0.02	0.8790
Major_Road_Approach	3	-0.0405	0.5047	-1.0297	0.9488	0.01	0.9361
Major_Road_Approach	4	0.0000	0.0000	0.0000	0.0000	.	.
Cross_Road_Approach	1	20.3848	0.2465	19.9016	20.8679	6838.81	<.0001
Cross_Road_Approach	2	20.1343	0.0000	20.1343	20.1343	.	.
Cross_Road_Approach	3	0.0000	0.0000	0.0000	0.0000	.	.
LogADT_Subj	1	0.5099	0.1783	0.1604	0.8594	8.18	0.0042
LogADT_Cross	1	0.3707	0.0981	0.1784	0.5629	14.28	0.0002
Dispersion	1	0.8445	0.2604	0.4615	1.5455		
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							
LR Statistics for Type 3 Analysis							
Source	DF	Chi-Square	Pr > Chi Sq				
RT_Shou	1	0.52	0.4716				
Functional_Class	3	7.73	0.0519				
Legs	1	3.72	0.0539				
Int_Skew	2	0.65	0.7213				
Major_Road_Approach	3	2.19	0.5336				
Cross_Road_Approach	2	1.36	0.5066				
LogADT_Subj	1	8.29	0.0040				
LogADT_Cross	1	13.80	0.0002				

Table 8-5. Model Information for Total Intersection Crashes with Negative Binomial Regression for Intersections Where Cross-Road ADT is Available.

The GENMOD Procedure									
Dataset		LIB4618.INTERSECTION_DATA_NEW							
Distribution		Negative Binomial							
Link Function		Log							
Dependent Variable		Total_Int_Accident				Total Int Accident			
Observations Used		265							
Class Level Information									
Class		Level s		Values					
Functional_Class		4		2 6 7 8					
Legs		2		3 4					
Int_Skew		3		M R S					
Major_Road_Approach		4		1 2 3 4					
Cross_Road_Approach		3		1 2 3					
Criteria for Assessing Goodness of Fit									
Criterion		DF		Value		Value/DF			
Deviance		250		180.1225		0.7205			
Scaled Deviance		250		180.1225		0.7205			
Pearson Chi-Square		250		277.9688		1.1119			
Scaled Pearson X2		250		277.9688		1.1119			
Log Likelihood				-125.6859					
Algorithm converged.									
Analysis of Parameter Estimates									
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr >	Chi Sq	
Intercept	1	-28.8984	1.9615	-32.7428	-25.0540	217.06		<.0001	
RT_Shou	1	-0.0163	0.0363	-0.0874	0.0549	0.20		0.6541	
Functional_Class	2	1.1441	0.7481	-0.3220	2.6103	2.34		0.1262	
Functional_Class	6	1.4060	0.6779	0.0773	2.7346	4.30		0.0381	
Functional_Class	7	0.2329	0.6451	-1.0315	1.4973	0.13		0.7181	
Functional_Class	8	0.0000	0.0000	0.0000	0.0000	.		.	
Legs	3	-0.4658	0.2564	-0.9683	0.0366	3.30		0.0692	
Legs	4	0.0000	0.0000	0.0000	0.0000	.		.	
Int_Skew	M	-0.0558	0.5934	-1.2189	1.1073	0.01		0.9251	
Int_Skew	R	0.2961	0.5053	-0.6943	1.2866	0.34		0.5578	
Int_Skew	S	0.0000	0.0000	0.0000	0.0000	.		.	
Major_Road_Approach	1	0.7044	0.6347	-0.5396	1.9483	1.23		0.2671	
Major_Road_Approach	2	0.2444	0.6299	-0.9901	1.4789	0.15		0.6980	
Major_Road_Approach	3	-0.0675	0.5948	-1.2333	1.0982	0.01		0.9096	
Major_Road_Approach	4	0.0000	0.0000	0.0000	0.0000	.		.	
Cross_Road_Approach	1	19.9046	0.2892	19.3378	20.4713	4737.68		<.0001	
Cross_Road_Approach	2	19.5904	0.0000	19.5904	19.5904	.		.	
Cross_Road_Approach	3	0.0000	0.0000	0.0000	0.0000	.		.	
LogADT_Subj	1	0.5984	0.2133	0.1803	1.0166	7.87		0.0050	
LogADT_Cross	1	0.4157	0.1188	0.1829	0.6486	12.25		0.0005	
Dispersion	1	1.0865	0.3615	0.5660	2.0856				
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.									
LR Statistics for Type 3 Analysis									
Source	DF	Chi-Square	Pr >	Chi Sq					
RT_Shou	1	0.20		0.6536					
Functional_Class	3	8.99		0.0295					
Legs	1	3.17		0.0749					
Int_Skew	2	1.22		0.5444					
Major_Road_Approach	3	4.12		0.2489					
Cross_Road_Approach	2	1.35		0.5085					
LogADT_Subj	1	8.02		0.0046					
LogADT_Cross	1	12.01		0.0005					

Table 8-6. Model Information for Total Crashes KAB with Negative Binomial Regression for Intersections Where Cross-Road ADT is Available.

The GENMOD Procedure							
Model Information							
Dataset	LIB4618.INTERSECTION_DATA_NEW						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	Total_Accidents_KAB	Total Accidents KAB					
Observations Used	265						
Class Level Information							
Class	Level	Values					
Functional_Class	4	2 6 7 8					
Legs	2	3 4					
Int_Skew	3	M R S					
Major_Road_Approach	4	1 2 3 4					
Cross_Road_Approach	3	1 2 3					
Criteria for Assessing Goodness of Fit							
Criterion	DF	Value				Value/DF	
Deviance	250	160.4278				0.6417	
Scaled Deviance	250	160.4278				0.6417	
Pearson Chi-Square	250	243.9522				0.9758	
Scaled Pearson X2	250	243.9522				0.9758	
Log Likelihood		-132.0088					
Algorithm converged.							
Analysis of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald Chi-Square	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-27.6099	2.1823	-31.8871	-23.3327	160.07	<.0001
RT_Shou	1	0.0431	0.0404	-0.0360	0.1223	1.14	0.2858
Functional_Class	2	1.2059	0.9765	-0.7081	3.1198	1.52	0.2169
Functional_Class	6	1.5174	0.8992	-0.2449	3.2798	2.85	0.0915
Functional_Class	7	0.8285	0.8736	-0.8837	2.5406	0.90	0.3429
Functional_Class	8	0.0000	0.0000	0.0000	0.0000	.	.
Legs	3	-0.2969	0.2818	-0.8492	0.2554	1.11	0.2921
Legs	4	0.0000	0.0000	0.0000	0.0000	.	.
Int_Skew	M	0.3205	0.7108	-1.0726	1.7136	0.20	0.6521
Int_Skew	R	0.4975	0.6263	-0.7300	1.7250	0.63	0.4270
Int_Skew	S	0.0000	0.0000	0.0000	0.0000	.	.
Major_Road_Approach	1	-0.0263	0.6376	-1.2759	1.2233	0.00	0.9671
Major_Road_Approach	2	-0.7011	0.6563	-1.9873	0.5852	1.14	0.2854
Major_Road_Approach	3	-0.4872	0.5940	-1.6515	0.6770	0.67	0.4121
Major_Road_Approach	4	0.0000	0.0000	0.0000	0.0000	.	.
Cross_Road_Approach	1	19.2563	0.3091	18.6505	19.8622	3880.89	<.0001
Cross_Road_Approach	2	0.0000	0.0000	0.0000	0.0000	.	.
Cross_Road_Approach	3	0.0000	0.0000	0.0000	0.0000	.	.
LogADT_Subj	1	0.4086	0.2333	-0.0486	0.8658	3.07	0.0799
LogADT_Cross	1	0.4266	0.1261	0.1795	0.6738	11.45	0.0007
Dispersion	1	0.9583	0.4335	0.3948	2.3259	.	.
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							
LR Statistics for Type 3 Analysis							
Source	DF	Chi-Square		Pr > Chi Sq			
RT_Shou	1	1.14		0.2866			
Functional_Class	3	4.55		0.2080			
Legs	1	1.09		0.2971			
Int_Skew	2	0.81		0.6677			
Major_Road_Approach	3	3.28		0.3502			
Cross_Road_Approach	2	0.32		0.8541			
LogADT_Subj	1	3.09		0.0785			
LogADT_Cross	1	11.28		0.0008			

CRASH PREDICTION FOR ALL INTERSECTIONS

Previous research has clearly demonstrated the importance of cross-road ADT in predicting crashes at intersections. Many intersections could be identified from the video due to the data needs for the roadway segment evaluations (see Chapters 5 and 6). Unfortunately, the cross-road ADT values could not be as easily determined for these intersections. The [previous section](#) presents the findings from the statistical modeling efforts for the 265 intersections where cross-road ADT was available. This section will present the findings from all intersections available within the database, recognizing that the evaluations will not be as strong due to the missing information.

A negative binomial regression model having the following variables as independent variables was used for total crashes and total intersection-related crashes:

- right shoulder (RT Shou),
- functional class,
- number of legs (Legs),
- intersection skew (Int_Skew),
- presence of left-turn lane on major road (Major_Lf), and
- log of major road traffic ADT (LogADT_Subj).

The results are presented in Tables [8-7](#), [8-8](#), [8-9](#), and [8-10](#). From [Table 8-7](#), it can be seen that for total crashes at intersections on two-lane highways, the effects of major road ADT, presence of left-turn lane on the major road, the number of legs, and the right shoulder width are significant at $\alpha = 0.05$. The effect of intersection skew is significant at $\alpha = 0.15$ but not at $\alpha = 0.05$.

[Table 8-8](#) shows that for total intersection-related crashes at intersections on two-lane highways, the effects of major road ADT, presence of left-turn lane on the major road, and the number of legs are significant at $\alpha = 0.05$. The effect of right shoulder width is significant at $\alpha = 0.1$ but not at $\alpha = 0.05$.

Table 8-7. Model Information for Total Crashes with Negative Binomial Regression for Intersections on Two-Lane Highways.

The GENMOD Procedure							
Model Information							
Dataset	LIB4618.INTERSECTION_DATA_BIG_2LN						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	Total_Accident						
Observations Used	3109						
Class Level Information							
Class	Levels	Values					
Functional_Class	5	2 6 7 8 9					
Legs	2	3 4					
Int_Skew	3	M R S					
Major_LF	2	0 1					
Criteria for Assessing Goodness of Fit							
Criterion	DF	Value				Value/DF	
Deviance	3098	1487.4113				0.4801	
Scaled Deviance	3098	1487.4113				0.4801	
Pearson Chi-Square	3098	3281.8576				1.0593	
Scaled Pearson X2	3098	3281.8576				1.0593	
Log Likelihood		-1339.0728					
Algorithm converged.							
Analysis of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > Chi Sq
Intercept	1	-27.1906	0.5862	-28.3396	-26.0416	2151.23	<.0001
RT_Shou	1	-0.0723	0.0164	-0.1044	-0.0401	19.42	<.0001
Functional_Class	2	19.0445	0.2395	18.5751	19.5140	6321.29	<.0001
Functional_Class	6	19.1448	0.1825	18.7872	19.5024	11010.2	<.0001
Functional_Class	7	19.1493	0.1419	18.8712	19.4275	18207.5	<.0001
Functional_Class	8	19.1634	0.0000	19.1634	19.1634	.	.
Functional_Class	9	0.0000	0.0000	0.0000	0.0000	.	.
Legs	3	-0.3358	0.1227	-0.5764	-0.0953	7.49	0.0062
Legs	4	0.0000	0.0000	0.0000	0.0000	.	.
Int_Skew	M	-0.1264	0.1986	-0.5157	0.2629	0.40	0.5246
Int_Skew	R	-0.2936	0.1740	-0.6346	0.0475	2.85	0.0916
The SAS System 16:59 Monday, August 22, 2005 129							
The GENMOD Procedure							
Analysis of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > Chi Sq
Int_Skew	S	0.0000	0.0000	0.0000	0.0000	.	.
Major_LF	0	-0.6226	0.3199	-1.2497	0.0045	3.79	0.0516
Major_LF	1	0.0000	0.0000	0.0000	0.0000	.	.
LogADT_Subj	1	1.1273	0.0632	1.0034	1.2512	317.94	<.0001
Dispersion	1	1.8580	0.2102	1.4886	2.3192	.	.
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							
LR Statistics for Type 3 Analysis							
Source	DF	Chi-Square		Pr > Chi Sq			
RT_Shou	1	19.84		<.0001			
Functional_Class	4	0.79		0.9399			
Legs	1	7.36		0.0067			
Int_Skew	2	4.00		0.1355			
Major_LF	1	3.95		0.0468			
LogADT_Subj	1	356.14		<.0001			

Table 8-8. Model Information for Total Intersection Crashes with Negative Binomial Regression for Intersections on Two-Lane Highways.

The GENMOD Procedure							
Model Information							
Dataset	LIB4618.INTERSECTION_DATA_BIG_2LN						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	Total_Int_Accident	Total Int Accident					
Observations Used	3109						
Class Level Information							
Class	Level	Values					
Functional_Class	5	2 6 7 8 9					
Legs	2	3 4					
Int_Skew	3	M R S					
Major_LF	2	0 1					
Criteria for Assessing Goodness of Fit							
Criterion	DF	Value				Value/DF	
Deviance	3098	831.0123				0.2682	
Scaled Deviance	3098	831.0123				0.2682	
Pearson Chi-Square	3098	3411.4768				1.1012	
Scaled Pearson X2	3098	3411.4768				1.1012	
Log Likelihood		-795.1907					
Algorithm converged.							
Analysis of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-27.6943	0.8984	-29.4551	-25.9334	950.23	<.0001
RT_Shou	1	-0.0434	0.0239	-0.0903	0.0035	3.29	0.0697
Functional_Class	2	17.6419	0.3536	16.9488	18.3349	2489.22	<.0001
Functional_Class	6	18.0149	0.2714	17.4829	18.5469	4405.37	<.0001
Functional_Class	7	17.9599	0.2192	17.5302	18.3896	6711.41	<.0001
Functional_Class	8	18.0244	0.0000	18.0244	18.0244	.	.
Functional_Class	9	0.0000	0.0000	0.0000	0.0000	.	.
Legs	3	-0.6275	0.1789	-0.9781	-0.2769	12.31	0.0005
Legs	4	0.0000	0.0000	0.0000	0.0000	.	.
Int_Skew	M	-0.0240	0.3221	-0.6554	0.6073	0.01	0.9406
Int_Skew	R	0.1179	0.2790	-0.4289	0.6647	0.18	0.6727
Analysis of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Int_Skew	S	0.0000	0.0000	0.0000	0.0000	.	.
Major_LF	0	-0.9784	0.4375	-1.8360	-0.1208	5.00	0.0253
Major_LF	1	0.0000	0.0000	0.0000	0.0000	.	.
LogADT_Subj	1	1.2716	0.0977	1.0801	1.4630	169.47	<.0001
Dispersion	1	4.1230	0.5830	3.1250	5.4396	.	.
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							
LR Statistics for Type 3 Analysis							
Source	DF	Chi-Square	Pr > Chi Sq				
RT_Shou	1	3.32	0.0684				
Functional_Class	4	2.19	0.7000				
Legs	1	12.11	0.0005				
Int_Skew	2	0.62	0.7325				
Major_LF	1	5.57	0.0182				
LogADT_Subj	1	199.15	<.0001				

From [Table 8-9](#), it can be seen that for total crashes for intersections on a four-lane highway, the effect of major road ADT, number of legs, and functional class are significant at $\alpha = 0.05$. The results are slightly different when only total intersection-related crashes are considered (see

Table 8-10). At $\alpha = 0.05$ only number of legs and major road ADT are significant. When $\alpha = 0.1$ is used, then right shoulder width, functional classification, and presence of left-turn lane become significant.

Table 8-9. Model Information for Total Crashes with Negative Binomial Regression for Intersections on Four-Lane Highways.

Model Information								
Dataset	LIB4618: INTERSECTION_DATA_BIG_4LN							
Distribution	Negative Binomial							
Link Function	Log							
Dependent Variable	Total_Accident	Total Accident						
Observations Used	630							
Class Level Information								
Class	Level	Values						
Functional_Class	3	2 6 7						
Legs	2	3 4						
Int_Skew	3	M R S						
Major_Lf	2	0 1						
Criteria for Assessing Goodness of Fit								
Criterion	DF	Value	Value/DF					
Deviance	621	509.3729	0.8202					
Scaled Deviance	621	509.3729	0.8202					
Pearson Chi-Square	621	762.7149	1.2282					
Scaled Pearson X2	621	762.7149	1.2282					
Log Likelihood		-382.1373						
Algorithm converged.								
Analysis of Parameter Estimates								
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr >	Chi Sq
Intercept	1	-7.5044	1.1695	-9.7967	-5.2122	41.17	<	.0001
RT_Shou	1	-0.0188	0.0246	-0.0669	0.0294	0.58		0.4450
Functional_Class	2	-1.1855	0.4140	-1.9971	-0.3740	8.20		0.0042
Functional_Class	6	-0.8498	0.4203	-1.6737	-0.0260	4.09		0.0432
Functional_Class	7	0.0000	0.0000	0.0000	0.0000	.		.
Legs	3	-0.6130	0.1654	-0.9371	-0.2889	13.74		0.0002
Legs	4	0.0000	0.0000	0.0000	0.0000	.		.
Int_Skew	M	-0.0757	0.4911	-1.0383	0.8870	0.02		0.8775
Int_Skew	R	1	0.2485	0.4369	-0.6078	1.1048		0.32
Int_Skew	S	0	0.0000	0.0000	0.0000	0.0000		0.5695
Major_Lf	0	1	-0.0990	0.1568	-0.4063	0.2082		0.5276
				The SAS System 16:59 Monday, August 22, 2005 133				
The GENMOD Procedure								
Analysis of Parameter Estimates								
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr >	Chi Sq
Major_Lf	1	0.0000	0.0000	0.0000	0.0000	62.34	<	.0001
LogADT_Subj	1	0.9655	0.1223	0.7258	1.2052			
Dispersion	1	1.4568	0.2172	1.0875	1.9513			
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.								
LR Statistics for Type 3 Analysis								
Source	DF	Chi-Square	Pr >	Chi Sq				
RT_Shou	1	0.58		0.4458				
Functional_Class	2	9.64		0.0081				
Legs	1	13.78		0.0002				
Int_Skew	2	1.88		0.3915				
Major_Lf	1	0.40		0.5280				
LogADT_Subj	1	67.57		<.0001				

Table 8-10. Model Information for Total Intersection Crashes with Negative Binomial Regression for Intersections on Four-Lane Highways.

The GENMOD Procedure							
Model Information							
Dataset	LIB4618.INTERSECTION_DATA_BIG_4LN						
Distribution	Negative Binomial						
Link Function	Log						
Dependent Variable	Total_Int_Accident	Total Int Accident					
Observations Used	630						
Class Level Information							
Class	Level	Values					
Functional_Class	3	2 6 7					
Legs	2	3 4					
Int_Skew	3	M R S					
Major_Lf	2	0 1					
Criteria for Assessing Goodness of Fit							
Criterion	DF	Value			Value/DF		
Deviance	621	293.1068			0.4720		
Scaled Deviance	621	293.1068			0.4720		
Pearson Chi-Square	621	585.8679			0.9434		
Scaled Pearson X2	621	585.8679			0.9434		
Log Likelihood		-247.5641					
Algorithm converged.							
Analysis of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Intercept	1	-11.8270	2.0827	-15.9090	-7.7450	32.25	<.0001
RT_Shou	1	-0.0651	0.0388	-0.1412	0.0110	2.81	0.0937
Functional_Class	2	-0.8407	0.6188	-2.0536	0.3721	1.85	0.1743
Functional_Class	6	-0.1200	0.6358	-1.3661	1.1262	0.04	0.8503
Functional_Class	7	0.0000	0.0000	0.0000	0.0000	.	.
Legs	3	-0.8836	0.2624	-1.3979	-0.3693	11.34	0.0008
Legs	4	0.0000	0.0000	0.0000	0.0000	.	.
Int_Skew	M	0.3156	0.8289	-1.3091	1.9403	0.14	0.7034
Int_Skew	R	0.5755	0.7440	-0.8827	2.0336	0.60	0.4392
Int_Skew	S	0.0000	0.0000	0.0000	0.0000	.	.
Major_Lf	0	-0.4631	0.2538	-0.9606	0.0344	3.33	0.0681
The GENMOD Procedure							
Analysis of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald	95% Confidence Limits	Chi-Square	Pr > Chi Sq
Major_Lf	1	0.0000	0.0000	0.0000	0.0000	.	.
LogADT_Subj	1	1.3644	0.2179	0.9374	1.7914	39.22	<.0001
Dispersion	1	3.9441	0.6921	2.7962	5.5631	.	.
NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.							
LR Statistics for Type 3 Analysis							
Source	DF	Chi-Square	Pr > Chi Sq				
RT_Shou	1	2.82	0.0929				
Functional_Class	2	5.35	0.0688				
Legs	1	11.60	0.0007				
Int_Skew	2	0.92	0.6313				
Major_Lf	1	3.27	0.0705				
LogADT_Subj	1	44.11	<.0001				

CHAPTER 9

SUMMARY AND CONCLUSIONS

The selection of the cross section for a roadway is a critical decision in the design process. This decision substantially impacts safety, capacity, and cost. Although capacity and cost considerations are generally readily evaluated, the impact of cross section on safety is not always apparent. Previously, safety information was not available on a level similar to capacity and cost. Recent efforts, both on a national level as part of the development of the *Draft Prototype Chapter* and within the state of Texas as part of Research Project 0-4703, however, are developing guidance materials that can evaluate potential safety effects of different design alternatives.

SUMMARY OF RESEARCH

To compare the safety relationships for cross-sectional elements on rural two- and four-lane roadways, a dataset containing a range of lane widths and shoulder widths is needed. [Figure 9-1](#) illustrates examples of the types of roadway segments included in the dataset. The dataset of rural highway roadway segments developed for this project included the following:

- two- and four-lane segments,
- range of shoulder widths (between 0 and >12 ft),
- range of lane widths (between 9 and >12 ft), and
- a sample of median types and widths.

The dataset for intersections included the above information and a number of other variables such as skew of the intersection, number of legs, and presence of turn lanes.

The overall data collection procedure was to identify roadway segments of interest, to videotape those roadways while driving at or near highway speed, and then to pull geometric information such as lane width and shoulder width from the video tapes in the office. The videotapes were also used to identify intersections of interest for the intersection analysis. Supplementing the data

from the video was (a) information from straight-line diagrams provided by the districts and (b) data, such as average daily traffic values, from the Texas Reference Marker databases.

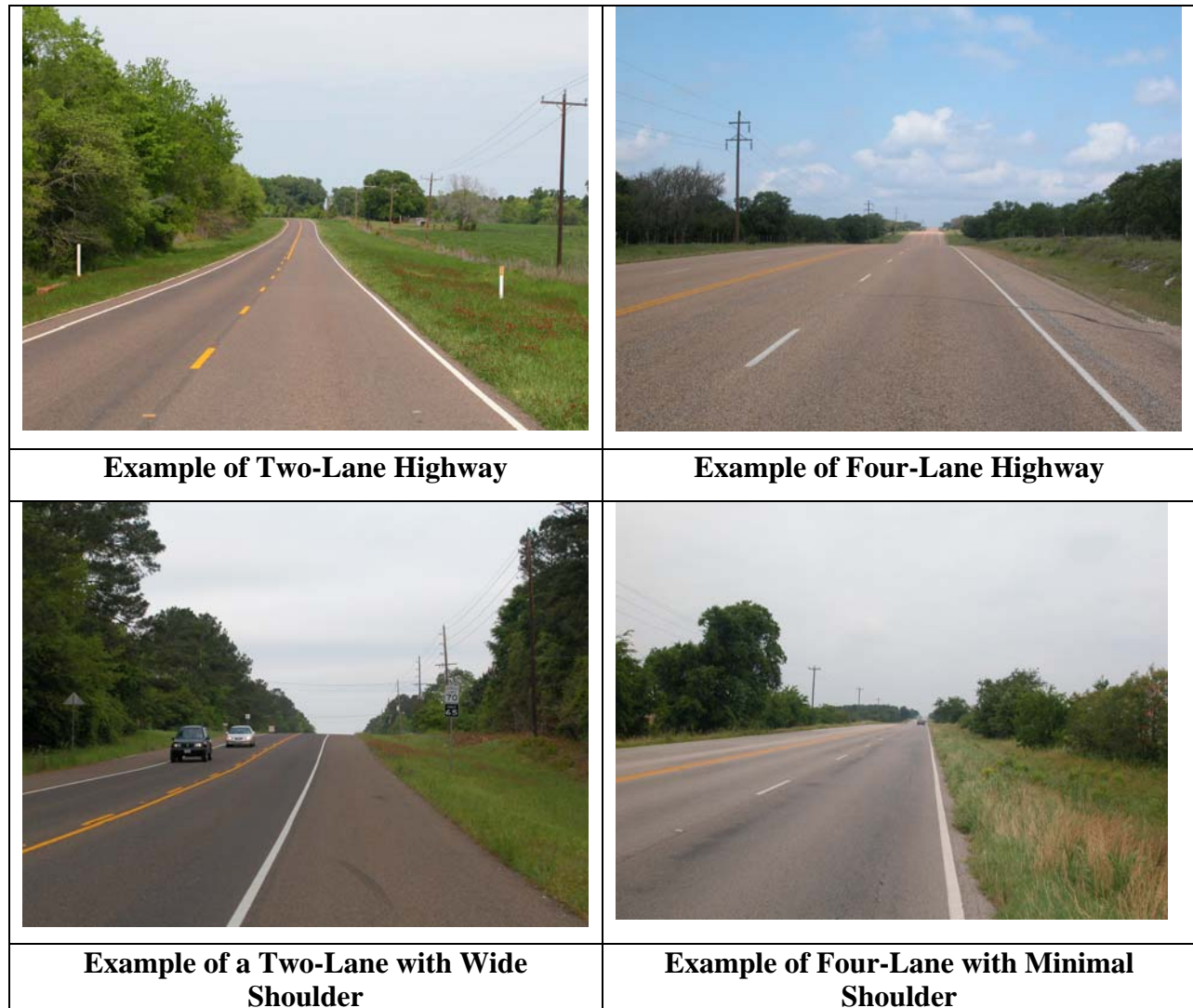


Figure 9-1. Examples of Roadway Segments Included in Dataset.

TTI researchers developed a video collection system that was used for the field data collection. This video system recorded lane/shoulder/median conditions along with distance traveled while driving. The video camera was mounted to the windshield of the vehicle for each trip. The video recording included distance traveled from a selected starting point (generally a reference marker or an intersection) as determined from a distance measuring instrument that was installed in the vehicle. These distances were related to the department’s control section/mile point system so that crash data could be matched to the geometric conditions present within a segment or at an intersection.

Two primary datasets were generated for use in the evaluations – roadway segments and intersections. Subsets of these datasets were used depending upon the evaluation, for example, only roadway segments with 44- to 54-ft surface widths were used in the comparison of converting a two-lane with wide shoulder to a four-lane with narrow shoulder cross section.

Following is a summary of the findings from the research.

Impacts of Lane Width and Shoulder Width on Crashes on Rural Two-Lane Highways

The objective of this portion of the study was to find the relationship between crashes on rural two-lane highways with lane and shoulder widths. A subset of Texas on-system crashes called SWICs, for surface width influence crashes, for the years 1999 to 2001 was analyzed. While SWICs were the crash type primarily used in the evaluations, other crash types (e.g., total crashes and KAB crashes) were also considered.

The following model was selected for predicting SWICs on a rural two-lane highway:

$$E(\text{SWIC}) = [\exp(-5.0189 - 0.1126 \text{ RT Lane} - 0.0509 \text{ RT Shou} \\ + 0.9091 \text{ LogLen} + 0.9085 \text{ LogADT})]/3 \quad (27)$$

The following model was selected for predicting total crashes on a rural two-lane highway:

$$E(\text{Total Crashes}) = [\exp(-5.0981 - 0.1372 \text{ RT Lane} - 0.0601 \text{ RT Shou} \\ + 0.8514 \text{ LogLen} + 1.0045 \text{ LogADT})]/3 \quad (28)$$

The impact of changes in lane width and shoulder width on crashes can be seen in the ratios of number of crashes for a given width to the number of crashes on a roadway with a selected width. For example, the ratio of crashes on a roadway with no shoulders compared to a roadway with an 8-ft shoulder is 1.51. In other words, the no-shoulder segment is predicted to have 51 percent more crashes. This example assumes that all other conditions for the two roadways are similar, such as lane width and roadside conditions. The ratios for shoulders and lane widths were determined and are listed in [Table 9-1](#).

Table 9-1. List of Ratios for Lane Width and Shoulder Widths for Rural Two-Lane Highways Based on Total Crashes.

Lane Width (ft)	Ratio to 12-ft lane
12	1.00
11	1.15
10	1.32
9	1.51
Shoulder Width (ft)	Ratio to 8-ft lane
10	0.89
9	0.94
8	1.00
7	1.06
6	1.13
5	1.20
4	1.27
3	1.35
2	1.43
1	1.52
0	1.62

Impacts of Lane Width and Shoulder Width on Crashes on Rural Four-Lane Highways

The relationship between crashes on rural four-lane highways with lane, shoulder, and median widths was also examined as part of this study. Again SWICs along with other crash types for the years 1999 to 2001 were analyzed. The regression evaluations using total crashes found median class to not meet the significance at the 5 percent alpha level requirement. Other research has found median width or type of median to be significant; however, the data available within this project (which included a large portion of segments with no median due to other objectives of the project) did not find a relationship between crashes and median class or width. When the evaluation was performed using SWICs, one of the median classes was found significant (undrivable narrow medians); however, the other classes were not within the 5 percent alpha level.

The following model was selected for predicting SWIC on a rural four-lane highway:

$$E(\text{SWIC}) = [\exp(-6.8122 - 0.0427 \text{ RT Shou} + 0.9354 \text{ LogLen} + 0.9441 \text{ LogADT})]/3 \tag{29}$$

The following model was selected for predicting total crashes on a rural four-lane highway:

$$E(\text{Total Crashes}) = [\exp(-5.1437 - 0.1392 \text{ RT Lane} - 0.0618 \text{ RT Shou} \\ + 0.7956 \text{ LogLen} + 0.9990 \text{ LogADT})]/3 \quad (30)$$

Similar to the two-lane highway analysis, the impact of changes in lane width and shoulder width on crashes can be seen in the ratios of number of crashes. The ratios for shoulders and lane widths were determined based on the predictions of total crashes and are listed in [Table 9-2](#).

Table 9-2. Ratios for Lane Width and Shoulder Widths for Rural Four-Lane Highways Based on Predictions of Total Crashes.

Lane Width (ft)	Ratio to 12-ft lane
12	1.00
11	1.15
10	1.32
9	1.52
Shoulder Width (ft)	Ratio to 8-ft lane
10	0.88
9	0.94
8	1.00
7	1.06
6	1.13
5	1.20
4	1.28
3	1.36
2	1.45
1	1.54
0	1.64

Conversion from a Two-Lane to a Four-Lane Highway

Previous research has clearly shown that a full-scale upgrade from a rural two-lane highway to a divided four-lane facility can result in notable crash reduction. Predicted crash reductions for conversion from a typical two-lane roadway to a four-lane divided section ranged from 40 to 60 percent. The reduction due to conversion from a two-lane roadway to a four-lane undivided configuration is much less well defined, ranging from no effect to perhaps a 20 percent reduction. Note that these conversions always involved shoulders of at least 8 ft in width; therefore, similar reductions in crashes should not be expected when converting a two-lane highway with wide shoulders to a four-lane highway with minimal shoulders.

A low-cost method to increase capacity on rural highways is to stripe a formerly two-lane with wide shoulder highway into a four-lane with minimal shoulders. These decisions have generally been made based on capacity criteria. Information on the safety trade-offs was sought. Previous research has indicated that at certain ADT levels, the four-lane highway may operate with fewer crashes than the two-lane cross section. The researchers reached this conclusion through the use of extrapolated data, and they did not qualify their findings by the amount of surface width available. Therefore, additional investigation into this question was needed. Previous research also examined the change in number of crashes from a 2-year before period to a 2-year after period at locations where the change was made from a two-lane cross section to a four-lane cross section. The before-and-after study did find a reduction in crashes; therefore, there could be locations where it is logical to consider a change in the number of lanes within the available surface width.

This analysis used crash data from 1999 to 2001 to examine the safety performance on highways with a surface width of 44 to 54 ft with either two lanes and wide shoulders or four lanes with minimal shoulders. Crashes associated with the surface width rather than intersections should be affected by the change in number of lanes or availability of wider shoulder widths. SWICs were identified from the TxDOT database as being nonintersection crashes where the vehicle movement/manner was two motor vehicles going same direction, two motor vehicles going opposite directions, or single vehicles. A negative binomial regression model determined the effects of the independent variables (lane width, shoulder width, ADT, and segment length) on SWICs. Prediction equations were developed. These equations identified if there are conditions when it would be logical, on a safety basis, to convert a two-lane with wide shoulders to a four-lane with minimal shoulders.

Additional analyses were also conducted to determine if the results would change if total crashes were examined (i.e., include intersection crashes) or if only the more severe crashes were examined (i.e., to account for differences in reporting practices for PDO crashes). A graph was developed to show the surface width (in 1-ft increments) where the predicted number of crashes on a two-lane highway essentially equals the predicted number of crashes on a four-lane highway. In summary, conversion would be considered only at very high ADTs (e.g., 10,000 and

greater) and wide surface widths (53 ft and more) based on safety. A scenario where the conversion may be considered is when a roadway section with high ADT and a wide surface width (e.g., 53 ft or more) is experiencing crashes (e.g., passing-related crashes) that would be addressed by the addition of another through lane. Evaluation of the section should include consideration of turning vehicles. For example, would reallocating the surface width to include left-turn bays be a better solution?

Intersections

Similar to the roadway segment analysis, negative binomial regression determined the effects of independent variables on intersection crashes. Previous research has clearly demonstrated the importance of cross-road ADT in predicting crashes at intersections. While many intersections could be identified within this project's roadway segment evaluations, the cross-road ADT values could not be as easily determined. Therefore, evaluations were conducted using both the entire intersection dataset (3109 intersections on two-lane highways and 630 intersections on four-lane highways) and the 265 intersections where cross-road ADTs were available.

[Table 9-3](#) summarizes the findings from this project's regression analyses. For all scenarios, major road ADT was statistically significant. Cross-road ADT was also significant when available. Other variables were significant in different situations and should be considered as appropriate when making safety decisions regarding an intersection. For example, the right shoulder width and the presence of left-turn lane were significant in certain conditions. Previous research projects ([11](#), [16](#)) have also demonstrated the value of left- and right-turn lanes and wider outside shoulders, along with the value of lighting.

Table 9-3. Alpha Level Results from Negative Binomial Regression for Intersections.

	Intersections on Two-Lane Highways (Cross-Road Data Not Available)		Intersections on Four-Lane Highways (Cross-Road Data Not Available)		Intersections Where Cross-Road Data Are Available		
Number Sites	3109		630		265		
Type of Crash	Total Crashes	Total Intersection Crashes	Total Crashes	Total Intersection Crashes	Total Crashes	Total Intersection Crashes	Total Crash KABs
Major Road ADT	5%	5%	5%	5%	5%	5%	10%
Cross-Road ADT	Not available	Not available	Not available	Not available	5%	5%	5%
Presence of Left-Turn Lane on Major	5%	5%	NS	10%	NS	NS	NS
Number of Legs	5%	5%	5%	5%	10%	10%	NS
Right Shoulder Width	5%	NS	NS	10%	NS	NS	NS
Intersection Skew	15%	NS	NS	NS	NS	NS	NS
Functional Class	NS	NS	5%	10%	10%	5%	NS

NS = not significant at an alpha level of 15% or less

CONCLUSIONS

Following are the conclusions from the research.

Impacts of Lane Width and Shoulder Width on Crashes on Rural Two-Lane Highways

- Lane width and shoulder width have a significant impact on safety of rural two-lane highways. Prediction models generated the percent change in crashes between different shoulder or lane width decisions. These values can be used when evaluating alternatives.

Impacts of Lane Width and Shoulder Width on Crashes on Rural Four-Lane Highways

- Lane width and shoulder width also have a significant impact on safety of rural four-lane highways. Prediction models generated the percent change in crashes between different shoulder or lane width decisions. These values can be used when evaluating alternatives.

Conversion from a Two-Lane with Wide Shoulders to a Four-Lane with Narrow Shoulders Highway

- With consideration for safety, conversion from a two-lane with wide shoulder cross section to a four-lane with narrow shoulder cross section should be considered only at very high ADTs and wide surface widths.

Intersections

- Several variables were found through the literature and through this research that affect crash prediction at rural intersections. Those elements that can be influenced by designers with the greatest benefits in affecting crashes include left-turn lanes, lighting, and wider right shoulders/right-turn lanes. Variables with the greatest influence on crashes are subject road ADT and the cross-road ADT.

APPENDIX

SUGGESTIONS ON MATERIAL FOR REFERENCE DOCUMENTS

Findings from this project can be incorporated into future editions of the TxDOT *Roadway Design Manual* (RDM) (13), the national *Draft Prototype Chapter* (2), or in materials being developed as part of the TxDOT Project 0-4703 (*Incorporating Safety in Design*)(3).

POTENTIAL MATERIAL FOR CHAPTER 3 ROADWAY DESIGN MANUAL

The following comments are suggestions on where findings from this project could be incorporated into the *Roadway Design Manual*. Within Chapter 3 (New Location and Reconstruction (4R) Design Criteria) they would represent isolated direct references to crashes or crash predictions. In other words, not all roadway design elements would have an associated safety discussion thus resulting in an uneven treatment on the topic. Therefore, full integration of the findings from this project (e.g., tables listing ratio of crashes at different lane widths, etc.) into Chapter 3 of the *Roadway Design Manual* is not recommended at this time. Rather, in the future, a comprehensive integration of known crash relationships could be included in the next *Roadway Design Manual* rewrite. Another option is to add a statement indicating the availability of other materials that provide information on crash relationships with geometric elements. Examples of materials that could be referenced include the forthcoming *Highway Safety Manual*, materials being developed as part of the TxDOT Project 0-4703 (*Incorporating Safety in Design*), or this report (FHWA/TX-06/0-4618-1) or its summary report (TxDOT 0-4618-S).

Rural Two-Lane Highways (*Roadway Design Manual* Chapter 3, Section 4, and Chapter 4, Section 2)

A new footnote to the *Roadway Design Manual* Table 3-8 (reproduced here as [Figure A-1](#)) or Table 4-2 (reproduced as [Figure A-2](#)) could inform the reader of the availability of material on the relationship between lane and shoulder width and crashes. The new footnote could be attached to the title of the table or to the LANES and SHOULDERS headings within Table 3-8 or Lane Width and Shoulder Outside rows within Table 4-2. The footnote could state:

An appreciation of the relationship between lane width or shoulder width and crashes is available in the TxDOT 0-4618-S report available on-line at <provide address here>.

Table 3-8: Width of Travel Lanes and Shoulders on Rural Two-lane Highways (US Customary)					
Functional Class	Design Speed (mph)	Minimum Width ^{1,2} (ft) for future ADT of:			
		< 400	400-1500	1500-2000	> 2000
Arterial	LANES (ft)				
	All	12			
	SHOULDERS (ft)				
	All	4 ³	4 ³ or 8 ³	8 ³	8 - 10 ³
Collector	LANES (ft)				
	30	10	10	11	12
	35	10	10	11	12
	40	10	10	11	12
	45	10	10	11	12
	50	10	10	12	12
	55	10	10	12	12
	60	11	11	12	12
	65	11	11	12	12
	70	11	11	12	12
	75	11	12	12	12
	80	11	12	12	12
	SHOULDERS (ft)				
	All	2 ^{4,5}	4 ⁵	8 ⁵	8 - 10 ⁵
Local ⁶	LANES (ft)				
	30	10	10	11	12
	35	10	10	11	12
	40	10	10	11	12
	45	10	10	11	12
	50	10	10	11	12
	SHOULDERS (ft)				
All	2	4	4	8	

¹ Minimum surfacing width is 24 ft for all on-system state highway routes.
² On high riprapped fills through reservoirs, a minimum of two 12 ft lanes with 8 ft shoulders should be provided for roadway sections. For arterials with 2,000 or more ADT in reservoir areas, two 12 ft lanes with 10 ft shoulders should be used.
³ On arterials, shoulders fully surfaced.
⁴ On collectors, use minimum 4 ft shoulder width at locations where roadside barrier is utilized.
⁵ For collectors, shoulders fully surfaced for 1,500 or more ADT. Shoulder surfacing not required but desirable even if partial width for collectors with lower volumes and all local roads.
⁶ Applicable only to off-system routes that are not functionally classified at a higher classification.

Figure A-1. Reproduction of Roadway Design Manual Table 3-8.

Table 4-2: 3R Design Guidelines for Rural Two-Lane Highways ^a			
(US Customary)			
Design Element	Current Average Daily Traffic		
	0 – 400	400 -1500	1500 or more
Design Speed ^b	30 mph	30 mph	40 mph
Shoulder Width	0 ft	1 ft	3 ft
Lane Width	10 ft	11 ft	11 ft
Surfaced Roadway	20 ft	24 ft	28 ft
Turn Lane Width ^c	10 ft	10 ft	10 ft
Horizontal Clearance	7 ft	7 ft	16 ft
Bridges ^d : Width to be retained	20 ft	24 ft	24 ft ^e
(Metric)			
Design Element	Current Average Daily Traffic		
	0 – 400	400 – 1500	1500 or more
Design Speed ^b	50 km/h	50 km/h	60 km/h
Shoulder Width	0 m	0.3 m	0.9 m
Lane Width	3.0 m	3.3 m	3.3 m
Surfaced Roadway	6.0 m	7.2 m	8.4 m
Turn Lane Width ^c	3.0 m	3.0 m	3.0 m
Horizontal Clearance	2.1 m	2.1 m	4.9 m
Bridges ^d : Width to be retained	6.0 m	7.2 m	7.2 m ^e

^a These values are intended for use on rehabilitation projects. However, the designer may select higher values to provide consistency with adjoining roadway sections, to provide consistency with prevailing conditions on similar roadways in the area or to provide operational improvements at specific locations.

^b Considerations in selecting design speeds for the project should include the roadway alignment characteristics as discussed in this chapter.

^c For two-way left turn lanes, 11 ft – 14 ft [3.3 m - 4.2 m] usual.

^d Where structures are to be modified, bridges should meet approach roadway width as a minimum. (Approach roadway width is the total width of the lanes and shoulders.) Greater bridge widths may be appropriate if the rehabilitation project increases roadway life significantly or if higher design values are selected for the remainder of the project. Existing structure widths less than those shown may be retained if the total lane width is not reduced across or in the vicinity of the structure.

^e For current ADT exceeding 2000, minimum width of bridge to be retained is 28 ft [8.4 m].

Figure A-2. Reproduction of Roadway Design Manual Table 4-2.

The *Roadway Design Manual* could also include information on the findings from the evaluation of a conversion from a two-lane with wide shoulders highway to a four-lane with narrow shoulders highway. A new section within [Chapter 3](#) could be added to discuss the results ([Chapter 3](#) was suggested over [Chapter 4](#) since the change in cross section would result in adding capacity). Suggestions on where to locate the material include after the Transition to Four-Lane Divided Highways section or after the Converting Existing Two-Lane Roadways to Four-Lane Divided Facilities section (reproduced as [Figure A-3](#)). The new section could state:

Conversion from a Two-Lane with Wide Shoulders to a Four-Lane with Narrow Shoulders Highway

With consideration of safety, a conversion from a two-lane with wide shoulder cross section to a four-lane with narrow shoulder

cross section should be considered only at very high ADTs and wide surface widths.

The above statement was developed to communicate the findings, yet provide some engineering judgment flexibility. There are scenarios where a conversion may be logical, for example, as an interim measure until a widening project for a roadway can be designed. If the preference is to have specific values within the statement, then the section could contain the following:

Conversion from a Two-Lane with Wide Shoulders to a Four-Lane with Narrow Shoulders Highway

With consideration of safety, a conversion from a two-lane with wide shoulder cross section to a four-lane with narrow shoulder cross section should be considered only at ADTs of 10,000 and greater and available surface widths (total of lane and shoulder widths) of a minimum of 53 ft.

Converting Existing Two-Lane Roadways to Four-Lane Divided Facilities

The Federal Highway Administration will allow the existing alignments to remain in place when existing two-lane roadways are converted to four-lane divided facilities. Specifically, the new roadbed will be constructed to full current standards. When the existing lanes are converted to one-way operations, no changes are required in the horizontal or vertical alignment of the existing road. Other features such as signing, roadside hardware, safety end treatments, etc., should meet current standards.

Existing structures with substandard width on the existing lanes may remain if that width meets minimum rehabilitation (3R) requirements for multi-lane facilities.

An accident analysis of the existing two-lane roadway should be conducted. Any specific areas involving high accident frequencies will be reviewed and corrective measures taken where appropriate.

Figure A-3. Material from *Roadway Design Manual on Conversion*.

Multi-Lane Rural Highways (*Roadway Design Manual* Chapter 3, Section 5, and Chapter 4, Section 2)

A new footnote to the *Roadway Design Manual* Table 3-12 (reproduced here as [Figure A-4](#)) or Table 4-1 (reproduced here as [Figure A-5](#)) could inform the reader of the availability of material on the relationship between lane and shoulder width and crashes. The new footnote could be attached to the title of the table or to the Lane Width and Shoulder Outside rows within the tables. The footnote could state:

An appreciation of the relationship between lane width or shoulder width and crashes is available in the TxDOT 0-4618-S report available on-line at <provide address here>.

Table 3-12: Design Criteria For Multilane Rural Highways (Non-controlled Access) (All Functional Classes) (US Customary)							
Type of Facility		Six-Lane Divided		Four-Lane Divided		Four-Lane Undivided ¹	
Design Speed (Arterials) ² (mph)		Min.		Min.		Min.	
Flat		70 ³		70 ³		70 ³	
Rolling		60 ⁴		60 ⁴		60 ⁴	
Lane Width (ft)		12					
		Des.	Min.	Des.	Min.	Des.	Min.
Median Width (ft)	Surfaced	16	4	16	4	Not Applicable	
	Depressed	76	48	76	48		
Shoulder Outside (ft)		10	8 ⁵	10	8 ⁵	10	8 ⁵
Shoulder Inside (ft) for Depressed Medians		10	4	4	4	Not applicable	
Min. Structure Widths for Bridges to Remain in place (ft)	Depressed Median	--	42	--	30	--	56

¹ Undivided section may be used on two-lane highways to improve passing opportunities. Most appropriate for use in rolling terrain and/or restricted right of way conditions.
² For multilane collectors, minimum design speed values are 10 mph less than tabulated.
³ 60 mph acceptable for heavy betterment under unusual circumstances. Otherwise, 70 mph should be minimum.
⁴ 50 mph acceptable for heavy betterment under unusual circumstances. Otherwise, 60 mph should be minimum for rural design.
⁵ Applies to collector roads only. On four-lane undivided highways, outside surfaced shoulder width may be decreased to 4 ft where flat (1V:10H), sodded front slopes are provided for a minimum distance of 4 ft from the shoulder edge.

Figure A-4. Reproduction of *Roadway Design Manual* Table 3-12.

Table 4-1: 3R Design Guidelines for Rural Multilane Highways (Nonfreeway) ^a			
(US Customary)			
Design Element	Highway Class		
	6-Lane Divided	4-Lane Divided	4-Lane Undivided
Design Speed ^b	50 mph	50 mph	50 mph
Lane Width	11 ft	11 ft	11 ft
Outside Shoulder	4 ft	4 ft	4 ft
Inside Shoulder	4 ft	2 ft	N/A
Turn Lane Width ^c	10 ft	10 ft	N/A
Horizontal Clearance	16 ft	16 ft	16 ft
Bridges ^d : Width to be retained	42 ft	28 ft	52 ft
(Metric)			
Design Element	Highway Class		
	6-Lane Divided	4-Lane Divided	4-Lane Undivided
Design Speed ^b	80 km/h	80 km/h	80 km/h
Lane Width	3.3 m	3.3 m	3.3 m
Outside Shoulder	1.2 m	1.2 m	1.2 m
Inside Shoulder	1.2 m	0.6 m	N/A
Turn Lane Width ^c	3.0 m	3.0 m	N/A
Horizontal Clearance	4.9 m	4.9 m	4.9 m
Bridges ^d : Width to be retained	12.3 m	8.4 m	15.6 m

^a These values are intended for use on rehabilitation projects. However, the designer may select higher values to provide consistency with adjoining roadway sections, to provide consistency with prevailing conditions on similar roadways in the area or to provide operational improvements at specific locations.

^b Considerations in selecting design speeds for the project should include the roadway alignment characteristics as discussed in this chapter.

^c For two-way left turn lanes, 11 ft – 14 ft [3.3 m - 4.2 m] usual.

^d Where structures are to be modified, bridges should meet approach roadway width as a minimum. (Approach roadway width is the total width of the lanes and shoulders.) Greater bridge widths may be appropriate if the rehabilitation project increases roadway life significantly or if higher design values are selected for the remainder of the project. Existing structure widths less than those shown may be retained if the total lane width is not reduced across or in the vicinity of the structure.

Figure A-5. Reproduction of *Roadway Design Manual* Table 4-1.

Intersections

The *Roadway Design Manual* discusses intersections in both Section 4 (Two-Lane Highways) and Section 5 (Multi-Lane Highways) of Chapter 3 (reproduced as Figures A-6 and A-7). The material provided is general in nature and when it covers variables included in the intersection evaluations it agrees with the project finding. For example, comments that roadways should cross at approximately a right angle is supported by research. Research has also shown the value of left-turn lanes and wide right shoulders/right-turn lanes. The RDM provides specific guidance on when to consider a left-turn lane (in RDM Table 3-11, reproduced as Figure A-8). Similar guidance on when to install a right-turn lane is not provided in the RDM. The left-turn lane guidance contained in Figure A-8 is based on conflict avoidance (as opposed to crashes) and recommendations for updating those values by updating assumptions used in the development of the original recommendations have been established in a previous project and are provided

elsewhere (19). The following comment could be added in both Section 4 and Section 5 to provide a general observation of the value of turn lanes:

Turn lanes can improve both the operations and safety of an intersection.

Intersections

The provision of adequate sight distance is of utmost importance in the design of intersections along two-lane rural highways. At intersections, consideration should be given to avoid steep profile grades as well as areas with limited horizontal or vertical sight distance. An intersection should not be situated just beyond a short crest vertical curve or a sharp horizontal curve. Where necessary, backslopes should be flattened and horizontal and vertical curves lengthened to provide additional sight distance. For more information on intersection sight distance, see Intersection Sight Distance, in Chapter 2.

Desirably, the roadways should cross at approximately right angles. Where crossroad skew is flatter than 60 degrees to the highway, the crossroad should be re-aligned to provide for a near perpendicular crossing. The higher the functional classification, the closer to right-angle the crossroad intersection should be.

Minimum Designs for Truck and Bus Turns in Chapter 7 provides information regarding the accommodation of various types of truck class vehicles in intersection design. Further information on intersection design may also be found in AASHTO's *A Policy on Geometric Design of Highways and Streets*.

Figure A-6. Reproduction of *Roadway Design Manual* Material on Intersections in Chapter 3, Section 4, Rural Two-Lane Highway Section.

Intersections

In the design of intersections, careful consideration should be given to the appearance of the intersection from the driver's perspective. In this regard, design should be rather simple to avoid driver confusion. In addition, adequate sight distance should be provided throughout, especially in maneuver or conflict areas. See Stopping Sight Distance in Chapter 2 for further information regarding sight distance.

Right angle crossings are preferred to skewed crossings, and where skew angles exceed 60 degrees, alignment modifications are generally necessary. Turn Lanes may be provided in accordance with previous discussions.

Chapter 7, Minimum Designs for Truck and Bus Turns, provides information regarding the accommodation of various types of truck class vehicles in intersection design. AASHTO's *A Policy on Geometric Design of Highways and Streets* should be consulted for further information on intersection design and intersection sight distance.

Intersections formed at by-pass and existing route junctions should be designed so as not to mislead drivers. Treatment of an old-new route connection is illustrated in Figure 3-11.

For intersections with narrow, depressed median sections, it may be necessary to effect superelevation across the entire cross section to provide for safer operation at median openings.

For more information on intersection design, see Stopping Sight Distance in Chapter 2.

For more information on border areas, see Borders.

Figure A-7. Reproduction of *Roadway Design Manual* Material on Intersections in Chapter 3, Section 5, Multi-lane Rural Highway Section.

Table 3-11: Guide for Left-Turn Lanes on Two-Lane Highways				
Opposing Volume (vph)	Advancing Volume (vph)			
	5 % Left Turns	10 % Left Turns	20 % Left Turns	30 % Left Turns
40 mph [60 km/h] Design Speed				
800	330	240	180	160
600	410	305	225	200
400	510	380	275	245
200	640	470	350	305
100	720	515	390	340
50 mph [80 km/h] Design Speed				
800	280	210	165	135
600	350	260	195	170
400	430	320	240	210
200	550	400	300	270
100	615	445	335	295
60 mph [100 km/h] Design Speed				
800	230	170	125	115
600	290	210	160	140
400	365	270	200	175
200	450	330	250	215
100	505	370	275	240

Figure A-8. Reproduction of *Roadway Design Manual* Table 3-11.

POTENTIAL MATERIAL FOR CHAPTER 4 ROADWAY DESIGN MANUAL

Within Chapter 4 of the *Roadway Design Manual*, Section 3 is dedicated to safety enhancement discussion. The Safety Design subsection within Section 3 discusses suggestions paraphrased from Transportation Research Board (TRB) Special Report 214. These suggestions include comments on horizontal curves and bridge widening. The section could be expanded to include comments regarding pavement widening on roadway segments and intersection treatments. The suggestions are shown with underlines in an excerpt of Section 3 material in [Table A-1](#).

Table A-1. Suggested New Material for *Roadway Design Manual* Chapter 4, Section 3.

Material from *Roadway Design Manual* Chapter 4, Section 3.....

Before developing construction plans and specifications, designers should document the project evaluation and give the design criteria which will be used to produce the final rehabilitation project.

Research has also supported the following suggestions:

Along roadway segments, designers should evaluate the benefits of increasing the lane or shoulder width of narrow pavements.

At intersections, designers should consider the value of lighting, and adding left- or right-turn bays.

Other methods have been successfully used to identify potential crash problems....

POTENTIAL MATERIAL FOR SAFETY REFERENCES

Rural Two-Lane Highways

The impact of changes in lane width and shoulder width on crashes can be seen in the ratios of number of crashes for a given width to the number of crashes on a roadway with a selected width. For example, the ratio of crashes on a roadway with no shoulders as compared to a roadway with an 8-ft shoulder is 1.62. In other words, the no-shoulder segment is predicted to

have 62 percent more crashes. This example assumes that all other conditions for the two roadways are similar, such as lane width and roadside conditions. The ratios for shoulders and lane widths were determined based on total crashes. The ratios are listed in [Table A-2](#).

Table A-2. List of Ratios for Lane Width and Shoulder Widths for Rural Two-Lane Highways Based on Predictions of Total Crashes.

Lane Width (ft)	Ratio to 12-ft lane
12	1.00
11	1.15
10	1.32
9	1.51
Shoulder Width (ft)	Ratio to 8-ft lane
10	0.89
9	0.94
8	1.00
7	1.06
6	1.13
5	1.20
4	1.27
3	1.35
2	1.43
1	1.52
0	1.62

Rural Four-Lane Highways

Similar to the two-lane highway analysis, the impact of changes in lane width and shoulder width on crashes can be seen in the ratios of number of crashes. The ratios for shoulders and lane widths were determined based on the predictions of total crashes and are listed in [Table A-3](#).

Table A-3. Ratios for Lane Width and Shoulder Widths for Rural Four-Lane Highways Based on Predictions of Total Crashes.

Lane Width (ft)	Ratio to 12-ft lane
12	1.00
11	1.15
10	1.32
9	1.52
Shoulder Width (ft)	Ratio to 8-ft lane
10	0.88
9	0.94
8	1.00
7	1.06
6	1.13
5	1.20
4	1.28
3	1.36
2	1.45
1	1.54
0	1.64

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