IDAHO TRANSPORTATION DEPARTMENT
RESEARCH REPORT

RP 200

Potential Safety Effects of Lane Width and Shoulder Width on Two-Lane Rural State Highways in Idaho

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Prepared for
Idaho Transportation Department
Research Program
Division of Highways, Resource Center
http://itd.idaho.gov/highways/research/

July 2012

DISCLAIMER

1. Report No. FHWA-ID-12-200	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Potential Safety Effects of Lane Width and Shoulder Width on Two-Lane Rural State Highways in Idaho		5. Report Date July 2012
		6. Performing Organization Code KLK559
7. Author(s) Ahmed Abdel-Rahim and Joseph Sonnen		8. Performing Organization Report NIATT-N11-05
9. Performing Organization Name and Address National Institute for Advanced Transportation Technology (NIATT) P.O. Box 440901 University of Idaho Moscow, Idaho 83844-0901		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. RP200
12. Sponsoring Agency Name and Address Research Program Division of Highways, Resource Center Idaho Transportation Department 3311 West State Street Boise, ID 83707-5881		13. Type of Report and Period 08/14/09-07/30/12
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This study provides a comprehensive evaluation of the relationship between crash rates and shoulder width and lane width for two-lane rural state highways in Idaho. Crash Modification Factors (CMFs) for shoulder width and lane width were developed using Idaho crash data covering the period from 1993 to 2010. The CMFs developed as part of this project will allow ITD to assess the potential safety benefits of shoulder widening projects. In addition to all crashes, models for single-vehicle and multiple-vehicle crashes were also developed. The CMFs presented in this study follow the general trends of prior knowledge and research. The results of the analysis showed that there is no significant difference between 12 ft lanes and 11 ft lanes in terms of safety for all types of crashes. The CMF for highways with 11 ft lanes was 1.02 indicating a marginal 2 percent increase in all crashes in comparison to highways with standard 12 ft lanes. The CMFs for highways with very small shoulders (less than 1 ft) were 1.16, 1.17, and 1.15 for all crashes, single-vehicle crashes, and multiple-vehicle crashes, respectively. This corresponds to an average increase in crashes of 16 percent when compared to highways with a 3-ft shoulder width. For highway sections with a shoulder width of 8 ft or more, the CMFs were 0.87, 0.90, and 0.83 for all crashes, single-vehicle crashes, and multiple-vehicle crashes, respectively, indicating an average reduction in crashes of approximately 13 percent when compared to highways with a 3-ft shoulder width. Idaho's crash data was also used to investigate the characteristics of pedestrian and bicycle crashes on two-lane rural highways. The results show that roadway sections with a right paved shoulder width of 4 ft to 6 ft had the lowest number of pedestrian and bicycle crashes. The probability for a pedestrian/bicycle crash increases significantly for roadway sections with shoulder widths less than 3 ft. The likelihood of a crash also increases for roadway sections with shoulder widths of 8 ft or more.

17. Key Word: Highway Safety Improvement Program, Crash Reduction Factor, Lane Width, Shoulder Width	18. Distribution Statement Unrestricted. http://itd.idaho.gov/highways/research/archived/closed.htm and http://www.webs1.uidaho.ed/niatt		
19. Security Classif. (of this report) Unrestricted	20. Security Classif. (of this page) Unrestricted	21. No. of Pages 52	22. Price

METRIC (SI*) CONVERSION FACTORS									
APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					LENGTH		
in	inches	25.4		mm	mm	millimeters	0.039	inches	in
ft	feet	0.3048		m	m	meters	3.28	feet	ft
yd	yards	0.914		m	m	meters	1.09	yards	yd
mi	Miles (statute)	1.61		km	km	kilometers	0.621	Miles (statute)	mi
		AREA					AREA		
in^2	square inches	645.2	millimeters squared	cm^2	mm^2	millimeters squared	0.0016	square inches	in^2
ft^2	square feet	0.0929	meters squared	m^2	m^2	meters squared	10.764	square feet	ft^2
yd^2	square yards	0.836	meters squared	m^2	km^2	kilometers squared	0.39	square miles	mi^2
mi^2	square miles	2.59	kilometers squared	km^2	ha	hectares (10,000 m^2)	2.471	acres	ac
ac	acres	0.4046	hectares	ha					
		MASS (weight)					MASS (weight)		
oz	Ounces (avdp)	28.35	grams	g	g	grams	0.0353	Ounces (avdp)	oz
lb	Pounds (avdp)	0.454	kilograms	kg	kg	kilograms	2.205	Pounds (avdp)	lb
T	Short tons (2000 lb)	0.907	megagrams	mg	mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME					VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces (US)	fl oz
gal	Gallons (liq)	3.785	liters	liters	liters	liters	0.264	Gallons (liq)	gal
ft^3	cubic feet	0.0283	meters cubed	m^3	m^3	meters cubed	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	meters cubed	m^3	m^3	meters cubed	1.308	cubic yards	yd^3
Note: Volumes greater than 1000 L shall be shown in m^3									
		TEMPERATURE (exact)					TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (°F-32)	Celsius temperature	°C	°C	Celsius temperature	9/5 °C+32	Fahrenheit temperature	°F
		ILLUMINATION					ILLUMINATION		
fc	Foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2	cd/cm^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS					FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N	N	newtons	0.225	pound-force	lbf
psi	pound-force per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	pound-force per square inch	psi

Acknowledgements

The authors would like to acknowledge the Idaho Transportation Department's Office of Highway Safety staff for their continuing support and guidance throughout this study and for providing the data used in the analysis.

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Executive Summary

This study examined the relationship between crash rates and shoulder width and lane width for two-lane rural state highways in Idaho. The study was done for the Idaho Transportation Department, which was interested in obtaining a better understanding of the relationship between the likelihood of a crash and the roadway's cross section elements such as lane width and shoulder width. Crash modification factors (CMFs) for shoulder width and lane width were developed using Idaho crash data covering the period from 1993 to 2010. The CMFs developed as part of this project will allow ITD to assess the potential safety benefits of lane and shoulder widening projects and to develop guidelines for determining appropriate lane width and shoulder width factoring in safety and cost. The research was conducted in two stages. The first stage comprised a literature review and the development of methodology for data collection and analysis. In the second stage, data were collected and analyzed to develop an understanding of the safety impacts of shoulder width and lane width.

Generalized linear negative binomial models, a well-accepted method of modeling discrete rare events such as roadway crashes, were used to develop prediction models for assessing the safety impacts of using different lane width and shoulder width values. Models were developed for all crashes, single-vehicle crashes and multiple-vehicle crashes. Models for specific crash types such as, run-off-road (ROR), opposite direction (OD), single vehicle, and/or sideswipe crashes, however, were not developed due to the limited number of crashes and the small sample size available. The model coefficients were estimated using the maximum-likelihood method. This approach is suitable for models that have predictor variables that are either continuous or categorical. Variables with coefficients that were not statistically significant at the 95 percent confidence level were removed from the model. This process was followed until a model was obtained in which all variables entered were statistically significant. The signs of the coefficients were also evaluated to ensure that they were in agreement with observed crash trends.

In general, the trends of the variables used in all models showed an agreement with rational expectations indicating reasonable trends. No significant difference was shown between 12 ft lanes and 11 ft lanes in terms of safety for all types of crashes. The CMF for highways with 11 ft lanes was 1.02 indicating a marginal 2 percent increase in all crashes when compared to highways with standard 12 ft lanes. The CMF values for single-vehicle crashes and multiple-vehicle crashes were 2 percent and 3 percent, respectively. This conclusion is also valid for low-volume highways with an Average Annual Daily Traffic (AADT) of less than 400 vehicles per day. The CMF for low-volume highways with 11 ft lanes was 1.01 for all crashes, 1.02 for single-vehicle crashes, and 1.02 for multiple-vehicle crashes.

The CMFs for highways with very small shoulders (less than 1 ft) were 1.16, 1.17, and 1.15 for all crashes, single-vehicle crashes, and multiple-vehicle crashes, respectively. This corresponds to an average increase in crashes of 16 percent when compared to highways with a 3 ft shoulder width. For low-volume highways, the average increase in crashes for highways with no shoulders was at 13 percent when compared to highways with a 3 ft shoulder width. For highway sections with a shoulder width of 8 ft or more, the CMFs were 0.87, 0.90, and 0.83 for all crashes, single-vehicle crashes, and multiple-vehicle crashes, respectively. This indicates an average reduction in crashes of approximately 13 percent when

compared to highways with a 3 ft shoulder width. Low-volume highways experienced a similar reduction of crashes with an average value of 12 percent.

Idaho's crash data was also used to investigate the characteristics of pedestrian and bicycle crashes on two-lane rural highways. Data used for this part of the study covered a 9-year period spanning from 2002 to 2010. The results show that roadway sections with a right paved shoulder width of 4 ft to 6 ft had the lowest number of pedestrian and bicycle crashes. The probability for a pedestrian/bicycle crash increases significantly for roadway sections with shoulder widths less than 3 ft. The likelihood of a crash also increases for roadway sections with shoulder widths of 8 ft or more. Potential pedestrian crash countermeasures for rural areas include improving roadway lighting, educating pedestrians and drivers, and adding sidewalks and paved shoulders. Potential bicycle crash countermeasures for rural areas include improvement of shoulders (surfacing and width), restriction of bicycle use for segments with narrow shoulders, and improving roadway lighting.

Recommendations

- When conducting cost-benefit analysis for lane and shoulder widening projects, we recommend ITD staff use the Idaho-specific CMFs presented in Table 1 and Table 2, to quantify the potential crash reduction benefits of alternative lane width and shoulder width treatments.

Table 1. Recommended CMFs for Lane Width for Idaho's Two-Lane Rural Highways

Highway	Crash Type	Lane Width (ft)		
		10	11	12
All Highways	All Crashes	1.05	1.02	1.00
	Single-Vehicle Crashes	1.07	1.02	1.00
	Multiple-Vehicle Crashes	1.04	1.03	1.00
Low-Volume Highways	All Crashes	1.04	1.01	1.00
	Single-Vehicle Crashes	1.06	1.02	1.00
	Multiple-Vehicle Crashes	1.04	1.02	1.00

Table 2. Recommended CMFs for Shoulder Width for Idaho's Two-Lane Rural Highways

Highway	Crash Type	Shoulder Width (ft)								
		0	1	2	3	4	5	6	7	8
All Highways	All Crashes	1.16	1.13	1.03	1.00	0.97	0.95	0.93	0.91	0.87
	Single-Vehicle Crashes	1.17	1.07	1.02	1.00	0.95	0.93	0.91	0.92	0.90
	Multiple-Vehicle Crashes	1.15	1.18	1.03	1.00	0.97	0.95	0.94	0.89	0.83
Low-Volume Highways	All Crashes	1.13	1.11	1.03	1.00	0.98	0.94	0.93	0.90	0.88
	Single-Vehicle Crashes	1.14	1.09	1.03	1.00	0.94	0.94	0.90	0.92	0.91
	Multiple-Vehicle Crashes	1.11	1.13	1.02	1.00	0.97	0.93	0.94	0.88	0.84

- We also suggest a number of possible pedestrian/ bicycle crash countermeasures for two-lane rural highways in Idaho that ITD could consider to improve safety. These include improvement of shoulders (surfacing and width), improving roadway lighting, restriction of use by bicycle for segments with shoulder less than 4 ft, and education program for pedestrians/bicyclists and drivers.

Chapter 1
Introduction

Overview

Safety and mobility are impacted by cross section design elements, including shoulder width and lane width. Right shoulders in two-lane rural highways provide a stable and clear recovery area for drivers who have left the travel lane and also a place for a driver to maneuver to avoid crashes. They also provide an area for law enforcement to safely pull vehicles over, space for pedestrians and bicycles, and a place for disabled vehicles to pull over. Lane width impacts vehicle maneuverability and can influence crashes related to lane departure. The American Association of State Highway and Transportation Officials' (AASHTO) Policy on Geometric Design of Highways and Streets (commonly referred to as the Green Book) provides design guidance for different highway design elements.(1) This policy has established ranges for minimum lane and shoulder widths for various types of roadways to help maximize both safety and mobility. However, the effects of cost restrictions and environmental concerns sometimes warrant deviations from the prevailing optimum value expressed in AASHTO's guidelines and policies. An understanding of the impacts of such alternative designs on both the safety and the operational characteristics of the roadway is essential to making an informed choice between design possibilities. Past studies have reached mixed conclusions as to the effect shoulder and lane widths have on safety. The evaluation of Idaho-specific data with respect to shoulder width and lane width, and their impacts on safety would be helpful in providing additional information for the determination of future projects.

This project provides a comprehensive evaluation of the relationship between crash rates and shoulder width and lane width for Idaho's two-lane rural state highways. Crash Modification Factors (CMFs) for shoulder width and lane width that were developed as part of this project will allow ITD staff to assess the potential safety benefits of proposed shoulder and lane widening projects. The project output will help ITD develop guidelines for determining appropriate lane width and shoulder width factoring in safety and cost. This will allow ITD to allocate safety funds using a data driven decision process in a manner that maximizes safety benefits and ensures the most cost-effective use of ITD resources.

Research Objectives

The objectives of this research are listed below:

1. Synthesize available research on the relationship of shoulder width and lane width to crash rates.
2. Evaluate the relationship between shoulder width and crash rates on Idaho two-lane state highways by analyzing crash data for road segments where shoulder widening projects have been completed.
3. Develop guidelines for determining appropriate lane and shoulder widths factoring in safety and cost.

The research was conducted in two main stages. The first stage comprised a literature review and the development of methodology for data collection and analysis. In the second stage, data were collected and analyzed to develop an understanding of the safety and operational impacts of shoulder width and lane width based on Idaho's crash experience. The project included seven specific tasks:

1. Conduct a thorough review of available literature evaluating the relationship between crash rates and shoulder width and lane width.
2. Work with the ITD project team to collaboratively identify road segments in Idaho where shoulder widening projects have been completed.
3. Review, collect, and document historical crash data for the identified road segments.
4. Analyze the data using the appropriate statistical methodology and develop a GIS database.
5. Develop Idaho-specific CMFs for shoulder width and lane widths based on Idaho's crash experience
6. Prepare a final report and executive summary of the work efforts, findings, conclusions, and recommendations.
7. Make an executive presentation to ITD at the conclusion of the work effort.

Report Organization

This report is organized into five chapters. After the introduction, Chapter 2 presents the literature review. Chapter 3 documents the research methodology and data collection. Chapter 4 summarizes the analysis used, the results of the lane width and shoulder width effectiveness, and CMF analysis. Chapter 5 includes the conclusions and recommendations followed by a list of references used in the analysis.

Chapter 2
Literature Review

Introduction to Literature Review

Highway road projects have many different design elements that can affect the safety of the roadway section. It is important to understand these elements and their effect on roadway safety. Several previous significant efforts have been directed towards quantifying the safety effects of two such elements on U.S. highways: lane width and shoulder width. Many times, this quantification is represented by CMFs. A CMF is a factor representing the expected change in the number of crashes when a certain design element is changed from a base value.(2) Essentially, when the factor is less than 1.0, the change in the design element is expected to reduce the number of crashes; whereas, a value greater than 1.0 is expected to increase the number of crashes. A literature review was performed to identify previously developed CMFs for lane and shoulder widths of two-lane rural highways. Only one study specific to Idaho was found in our review of the literature. This 1976 study only examined the full pavement width and did not look at the different elements separately.(3) Many studies outside of Idaho were identified and reviewed. The methods used and conclusions reached varied somewhat, but generally have indicated that as lane width and shoulder width increases, the number of crashes decrease. Studies have also shown that the reduction in crashes is dependent on the AADT. This chapter offers a synthesis of these available studies that examined both lane or shoulder width for both two-lane rural roadways (specifically for this report) and other roadway cross sections.

Safety Effects of Lane and Shoulder Width

A good deal of research has been conducted to examine the relationship between lane and shoulder widths and safety. Many of these studies focused on crash types that were only relevant to changes in lane and shoulder width. Although these crash types varied somewhat from study to study, they generally included: run-off-road (ROR), opposite direction (OD), single vehicle, and/or sideswipe crashes.

Because lane and shoulder width are similar in their effects of safety on the roadway, they are often studied together as “pavement width.” For this report, in order to analyze the effect of each element separately, it was important to keep these cross section elements separate. Previous studies that combined the elements are not covered in-depth.

Two-Lane Rural Highways

Early pavement width studies were identified from the late 1970s and early 1980s; however, many of these dated studies did not look at lane width and shoulder width separately and were not used as a basis in later studies to develop CMFs. CMF development regarding lane width and shoulder width began with the 1987 study by Zegeer and Deacon.(4) This study aimed to develop a regression model for predicting the number of related crashes using lane width, shoulder width, and shoulder type (width of paved and unpaved shoulder sections) as variables. Using previously collected data from 9 other studies, the researchers were able to plot the relationship between the variables for lane widths of 7 to 12 ft and shoulder widths from 0 to 10 ft for both paved and unpaved shoulder types. These results showed that as shoulder width and lane width increase (separately), the number of crashes decrease. The relationship between the shoulder width/lane width increase and the crash reduction was non-linear. This means that the expected crash reduction benefits from increasing the lane width from 10 ft to 11 ft is much higher than that expected from increasing the lane width from 11 ft to 12 ft.

Based on his previous model, Zegeer et al. completed another study in 1988 using traffic, crash, roadway, and roadside data from 7 different states and over 4,951 miles of two-lane rural roadways.(5) This study aimed to determine the effects of lane widening, shoulder widening, and shoulder surface change on crash rates by developing a crash prediction model similar to the previous study, but including more variables to more accurately predict field conditions. The variables used in this analysis included: AADT, lane width, average paved shoulder, average unpaved shoulder, median roadside (hazard) rating, and terrain rating. Again, this model was for computing related crashes only (in this case defined as: run-off-road, head-on, and sideswipe) and was applied to lane widths of 8 to 12 ft and shoulder widths of 0 to 12 ft. Ultimately, Zegeer et al. estimated the percent reductions in related crashes for both lane and shoulder widths, which can be seen in Table 3 and Table 4, respectively.(5) It should be noted that this study focused primarily on rural roadways; however, the average traffic volume in the roadway segments used in the study was relatively higher than the average traffic volume for most rural highways in Idaho.

Table 3. Percent Reduction in Related Crash Types for Various Lane Widths(5)

Amount of Lane Widening (ft)	Reduction in Crashes (percent)
1	12
2	23
3	32
4	40

Table 4. Percent Reduction in Related Crash Types for Various Shoulder Widths(5)

Shoulder Widening (ft)	Reduction in Crashes (percent)	
	Paved	Unpaved
2	16	13
4	29	25
6	40	35
8	49	43

In general, the study concluded that as either lane or shoulder width is increased, there was a decrease in the percentage of crashes. It also showed that paved shoulders may have a better safety effect than unpaved shoulders. The researchers also compared lane width and shoulder width crash rates with 2 studies in order to validate the model. These studies included:

1. Previous primitive study completed by Zeeger et al. for rural roads in Kentucky.[6]
2. Early study by Smith et al. that examined different two-lane roadway problems and solutions.[7]

Both supported the findings of this study.

A study completed in 1995 by Hadi et al. also looked at related crash reduction trends and supported Zegeer's findings.[8] Hadi aimed to estimate the effects of cross section design elements on total, fatal, and injury crash rates for both rural and urban highway types at different traffic levels using negative binomial regression models. The results showed that increasing median width, inside and/or outside shoulder width, and/or lane width reduces crash frequency. More specifically for two-lane rural highways, a significant reduction in crashes was associated with increasing lane width and total shoulder.

In 2000, a study by Harwood et al., developed 1 of the first sets of CMFs for lane and shoulder widths based off Zegeer's 1988 study.[9,5] The study aimed to develop an algorithm for predicting the safety performance, using CMFs, of two-lane rural highways using binomial regression with an expert panel oversight. The parameters used were: lane width, shoulder width, shoulder type, horizontal curve, grade, driveway density, and roadside design/cross section. Harwood's 2000 study looked at only non-intersection, single-vehicle ROR and OD crashes.[9] The CMFs developed as part of this study are presented in Table 5 and Table 6. Using 12 ft lanes for the base condition, the resulting CMFs for lane width are presented in Table 5. For validation, the researchers compared the results with data from other published sources. The results agreed with data from three similar studies:

1. A previous study completed by Zegeer in 1994 looking at crash relationships on low volume roads.[10]
2. A study by Zegeer et al. in 1981 that examined crash reduction on rural roadways.[11]
3. A study by Miauo in 1996 that analyzed the goodness-of-fit for crash prediction models.[12]

Using 6 ft shoulders as the base condition, the resulting CMFs for shoulder widths from Harwood's 2000 study are shown in Table 6.[9] As was done with lane width, the shoulder width results showed strong agreement with three similar studies:

1. Miauo's 1996 study that looked at goodness-of-fit of crash prediction models.[122]
2. 1995 study by Miauo that developed crash factors for crash rates on curves and grades.[13]
3. 1977 study by Rinde for the California Department of Transportation.[14]

Table 5. Lane Width CMFs for Low and High Volume Two-Lane Rural Highways[9]

Lane Width (ft)	Low Volume (< 400 veh/day)	High Volume (> 2,000 veh/day)
9	1.05	1.50
10	1.02	1.30
11	1.01	1.05
12	1.00	1.00

Table 6. Shoulder Width CMFs for Low and High Volume Two-Lane Rural Highways[9]

Shoulder Width (ft)	Low Volume (< 400 veh/day)	High Volume (> 2,000 veh/day)
0	1.10	1.50
2	1.07	1.30
4	1.02	1.15
6	1.00	1.00
8	0.98	0.87

Harwood et al. completed a study in 2003 that confirmed his CMFs.[15] This study, which examined his previous CMFs as part of resurfacing, restoration, and rehabilitation (3R) projects, was aimed to develop a resource allocation process that optimized system wide safety for a set of resurfacing projects without going over the specified budget. More explicitly, for two-lane highway safety, the study examined the effects of geometric improvements on safety and traffic operations and developed analytical tools to be used to determine the most appropriate mix of resurfacing and geometric improvements. The panel of experts for the study reviewed and confirmed Harwood's previous CMFs.

In 2008, a study by Harkey et al. reviewed and eventually verified Harwood's original CMFs.[16] The study was designed to review, verify, modify, and/or develop CMFs for 100 different roadway cross section scenarios in order to increase the level of predictive certainty of current or newly developed CMFs. As part of the study, researchers developed a list of 35 sets of CMFs that the panel of experts felt was of "*high or medium high quality*." Included in this were Harwood's CMFs.[15]

A separate study by Bonneson et al., performed in 2006, developed its own set of CMFs for two-lane and four-lane highways in Texas.[17] The goal of this research was to develop CMFs using regression for severe crashes only. The variables used in the prediction model included: AADT, segment length, and lane/shoulder width. The base conditions were 12 ft lane-width and 8 ft shoulder-width. The study considered only three crash types that might be impacted by lane width and shoulder width: single-vehicle run-off-road crashes, sideswipe same direction crashes, and multi-vehicle opposite direction crashes. The CMFs developed in the study were corrected using a predetermined value of 42 percent which represents the proportion of crashes used in the analysis to the total crashes. Table 7 and Table 8 show the resulting CMFs for lane width and shoulder width from Bonneson's study.[17] The study reported CMFs for high-volume and low-volume roads, however, the difference between the estimated CMFs for the two volume levels was negligible.

Table 7. Texas Lane Width CMFs for Severe Crashes - Two-Lane Highways[17]

Lane Width (ft)	CMF
9	1.18
10	1.11
11	1.06
12	1.00

Table 8. Texas Shoulder Width CMFs for Severe Crashes - Two-Lane Highways[17]

Shoulder Width (ft)	CMF
0	1.39
2	1.29
4	1.19
6	1.09
8	1.00
10	0.91

In 2007, Lord et al. conducted a study to develop safety performance functions and CMFs for rural frontage road segments from Texas data with both one-way and two-way segments based off of Bonneson's study.[18] Researchers analyzed crash data for a total of 123 segments over a 5-year period (1997-2001), focusing on crashes that were deemed "segment related." The researchers excluded ramp-frontage road terminals and frontage road-crossroad intersections from the analysis. The model used to develop CMFs was a form of the Poisson distribution using 12 ft lane width and 1.5 ft shoulder widths as the base conditions. Although this study did not directly deal with two-lane rural highways, the study results were consistent with the CMFs developed in Bonneson's previous study.[17] In addition, the report showed that for frontage roads, both wider lanes and shoulders show a reduction in segment related crashes. Frontage roads and two-way two-lane rural highways experienced the same severity of crashes with the same traffic volume.

A recent study in 2009 by Gross et al. looked into creating CMFs using the combination of lane and shoulder widths while keeping the pavement width constant for a road segment.[19] This study had models for both narrow (less than 26-ft) pavement widths and wide (from 26 to 36-ft) pavement widths while maintaining a minimum AADT of 1,000 vehicles per day, with speeds of at least 25 mph. Gross concluded that wider lanes, shoulders, and total pavement widths result in fewer related crashes. This is consistent with other prior studies. However, the results did not clearly show whether lane or shoulder width was more effective in reducing crashes. The results do give some insight into the general effect that wider is safer.

Multi-Lane Highways

In addition to studies of two-lane highways, many studies have examined the relationship between lane and shoulder width and safety on multi-lane roadways. Although the CMFs from these studies cannot be directly applied to two-lane highways, they give insight into how lane and shoulder widths impact safety in other highway facilities. A 1999 study by Council et al. examined the initial safety effects resulting from converting two-lane rural roads to four-lane (divided and undivided) to relieve congestion on the rural roadways.[20] As part of the study, a cross sectional model was developed using different road segments from four states: California, Michigan, North Carolina, and Washington. A form of the Poisson model was used in the Statistical Analysis System (SAS) program with the General Linear Models (GENMOD) procedure for regression. The model used AADT, segment length, surface width, and lane/shoulder widths (separately) for variables. Researchers found that a conversion from a two- to a four-lane cross section resulted in a 40 percent to 60 percent reduction in crashes per kilometer. Although this research had a few shortcomings, it was an initial effort to compare two-lane and four-lane roadway types in terms of lane and shoulder widths.

In 2008, Lord et al. conducted research focusing on four-lane highways.(21) The goal of this National Cooperative Highway Research Program (NCHRP) study was to develop tools for estimating the safety performance of multi-lane rural highways. The study included a survey, collection of data from five state DOTs (California, Minnesota, New York, Texas, and Washington), and development of CMFs using statistical models with covariates and an expert panel. Using baseline conditions of 12 ft lanes and 8 ft shoulders, the resulting CMFs for lane and shoulder widths are presented in Table 9 and Table 10, respectively.

Table 9. Lane Width CMFs for Four-Lane Highways(21)

Lane Width (ft)	Four-Lane Undivided	Four-Lane Divided
9	1.13	1.09
10	1.08	1.05
11	1.02	1.01
12	1.00	1.00

Table 10. Shoulder Width CMFs for Four-Lane Highways, From NCHRP Web Only Document 126(21)

Shoulder Width (ft) Both Sides	Four-Lane Undivided	Four-Lane Divided
0	1.18	1.18
2	1.11	1.13
4	1.05	1.09
6	1.00	1.04
8	0.95	1.00

Fitzpatrick's 2008 study was designed to develop CMFs were for median characteristics on urban and rural freeways and on rural multi-lane highways. The data was collected in Texas over a 5-year period (1997-2001).(22) A series of negative binomial regression models (using GENMOD in SAS) were developed with these variables: AADT, left-shoulder width (4 ft baseline condition), barrier offset, median width, and pole density. The results from the study (shoulder width only) support the CMFs relationship for Lord's previous study.(21)

Stamatiadis's 2009 NCHRP 633 Report compiled shoulder and median characteristic CMFs using regression (generalized liner models) and an expert panel.(23) The results are shown in Table 11. Overall, this study provided great support for the relationship of increasing shoulder width to decrease in crashes.

Table 11. Shoulder Width CMFs for Four-Lane Highways, From NCHRP Report 633[23]

Shoulder Width (ft)	Four-Lane Undivided	Four-Lane Divided
0	1.22	1.17
3	1.00	1.00
4	0.94	0.95
5	0.87	0.90
6	0.82	0.85
7	0.76	0.81
8	0.71	0.77

Literature Review Summary

A substantial body of research has been done to quantify the relationship between safety and lane and shoulder width. Many of these studies have shown that increasing lane width and/or shoulder width, can contribute to a reduction in crashes. Although there has been some research done nationally, and in other states, little research has been done using Idaho-specific crash data. This type of research is needed to develop CMFs that ITD staff can use to assess the potential safety benefits of proposed lane and/or shoulder widening projects. The main objective of the analysis conducted as part of this research project is to develop Idaho-specific CMFs for shoulder and lane width. The research methodology, data analysis, and results are presented in the following chapters.

Chapter 3
Research Methodology and Data Collection

Overview

This chapter documents the research methodology used in this study and data collection efforts. The first section presents the methodological approach, focusing on the development of CMFs for lane and shoulder widths. The second section documents the collection of data and summarizes the data used in the crash prediction models.

Methodology

The purpose of this section is to describe the methodology used for developing crash prediction models for various lane and shoulder widths on Idaho highways. Ultimately, these prediction models will be used to evaluate the safety effects of lane and/or shoulder widths on two-lane rural highways in Idaho.

Based on the review of past literature, significant efforts have been made to develop models to estimate the safety effects from changes in certain cross sectional elements. Moreover, these models, commonly referred to as crash prediction models, are aimed to predict the crash frequency (number of crashes) based on geometric and traffic variables. Most crash prediction models that have been used in safety research are a form of generalized linear models (GLM). One common form is the negative binomial model. This model uses a Poisson distribution to represent the crashes seen within data sites while using a gamma distribution to represent the unobserved crash frequency of roadway segments.[24] The typical form for this model is shown in Figure 1.

$$\mathrm{E[N]} = \mathrm{EXPO}e^{b_0+b_1X_1+b_2X_2+\cdots+b_nX_n}.$$

where:

$E[N]$ = Predicted Number of Crashes per Year for a Specific Road Section.
$EXPO$ = Exposure to Crashes.
e = The base of Napierian or natural logarithms (approximately equal to 2.71828).
$b_0,\ldots,b_n$ = Regression Coefficients.
$X_1,\ldots,X_n$ = Predictor Variables.

Figure 1. Poisson-Gamma (Negative Binomial) Model

The "EXPO" or exposure measure used in this model can take one of two forms:

1. Vehicle-miles, or the length of the roadway segment multiplied by the AADT and the number of years studied for the particular segment.
2. Length multiplied by the number of years that volume can be used as a predictor variable in the regression.

Currently, two common methods are used for determining CMFs from GLMs. The first, and generally simpler method, uses the coefficients directly from the model. Due to its simple nature, it assumes variables to be independent and, therefore, does not correlate between them. This method can be seen in Figure 2.

$$\mathrm{CMF}_i = e^{(\beta_i[X_i - Y_i])}.$$

where:

CMF_i = CMF for Coefficient i.
X_i = Range of Values or Specific Value (i.e. lane or shoulder width) for CMF_i.
Y_i = Baseline or Average Condition for the Variable X_i.
β_i = Regression Coefficient.

Figure 2. CMF Equation Using Method 1

The second method creates a baseline model from normal base conditions that are commonly used by engineers in the field. For example, base conditions for lane and shoulder widths for two-lane rural Idaho highways could be 12 ft lanes and 6 ft shoulder due to recommended use by ITD. The baseline model is then applied to data that does not meet the set of base conditions to determine the difference in crash rates. These models are usually thought of as more complex, but tend to represent a more accurate estimate of the safety effects of the design elements. The general linear equation, produced from regression, for the second model is shown in Figure 3.

$$\mathrm{Y}_i - \mu_i = \gamma_1 \mathrm{X}_1 + \cdots + \gamma_m \mathrm{X}_m.$$

where:

μ_i = Predicted Number of Crashes for Site i per Year Determined from Baseline Model.
Y_i = Observed Number of Crashes for Site i per Year.
$X_1, X_2, .X_m$ = A Vector of the Baseline Variables.
$\gamma_1, \gamma_2, \gamma_m$ = A Vector of Coefficients to be Estimated.

Figure 3. Linear Equation for Method 2

The CMFs are then estimated using the statistically significant variables with the equation shown in Figure 4 below.

$$CMF_m = \frac{\sum_{i=1}^{n} Y_i/n}{\sum_{i=1}^{n} \frac{Y_i}{n} - \gamma_m}$$

where:

CMF_m	= CMF for Coefficient m.
n	= Number of Observations in the Sample.

Figure 4. CMF Equation Using Method 2

Data Collection

An Idaho vehicle collision report (VCR) must be completed by the local law enforcement agency for every crash in Idaho that involves a motor vehicle, occurs on public property, and results in more than $1,500 in property damage for any 1 person involved (prior to January 1, 2006 - $750), or results in an injury to any person involved. All VCR forms must be sent to ITD's Office of Highway Safety (OHS), which maintains the state's crash database. Crash data, used in this analysis, were obtained from ITD's OHS crash database through a web-based crash analysis interface (WebCARS).[(25)] This online database, developed and maintained by ITD's OHS, provided the required crash data for each selected segment used in the analysis.

In addition to crash data, the geometric characteristics of two-lane rural state highways in Idaho were obtained from ITD's OHS. The data included lane width, shoulder width, and shoulder type. A total of 127 roadways segments from 48 different highways in Idaho with lengths ranging from 5 miles to 8 miles were selected for the analysis. The total length of the roadway segments included in this study is 923 miles of rural two-lane two-way state highways. A total of 7,977 crashes occurred on these segments covering the years from 1993 through 2010. As the focus of this study is rural two-lane state highways, roadway sections within city limits or in urbanized areas were not included in the study. The study sites included:

1. Roadway segments with lane widths of 10, 11, and 12 feet.
2. Roadway segments with right paved shoulder widths of 0, 1, 2, 3, 4, 5, 6, 7, and 8 or more feet.

Vehicle exposure data, in the form of AADT, were obtained from ITD's Automatic Traffic Recorders (ATRs).[(26)] Table 12 shows the crash frequency for analysis variables (severity, lane width, shoulder width, and AADT) as well as crash type (all crashes, single-vehicle, multi-vehicle, and crashes that included pedestrians and bicycles). Table 12 shows that the majority of crashes occurred on lower volume roads (AADT of 400 vehicles per days or less) with 12 ft lanes, and involved a single-vehicle. The characteristics of the sites included in this study are presented in Appendix A.

Table 12. Idaho Crash Frequency (Number of Crashes) per Category, 1993 - 2010

Variable	Categories	Two-Lane Undivided (Number of Crashes)			
		All Crashes	Single-Vehicle Crashes	Multi-Vehicle Crashes	Pedestrian and Bicycle Crashes
Severity	All	7,977	5,291	2,681	5
	Fatal	175	98	76	1
	Severe Injury	720	410	309	1
	Visible injury	1,128	728	399	1
	Possible injury	1,335	830	503	2
	Property Damage	4,619	3,225	1,394	0
Lane Width (ft)	10	187	128	59	0
	11	407	291	116	0
	12	7,383	4,872	2,506	5
Right Paved Shoulder Width (ft)	0	818	654	163	1
	1	1,492	1,186	304	2
	2	564	392	171	1
	3	1,320	802	518	0
	4	672	527	145	0
	5	1,192	752	440	0
	6	951	601	350	0
	7	64	31	33	0
	8	694	252	441	1
	9	0	0	0	0
	10	210	94	116	0
AADT (veh/day; 000s)[1]	< 2	2,007	1,573	433	1
	2 to 4	1,895	1,301	593	1
	4 to 6	845	556	289	0
	6 to 8	831	323	507	1
	8 to 10	157	78	79	0
	10 to 12	115	64	51	0
	12 to 14	72	47	25	0
	14 to 16	81	59	22	0
	> 16	13	6	7	0

1. AADT data were not available for some road segments. As a result, this analysis was limited to the 6,016 crashes for which data were available.

Chapter 4
Safety Effect of Lane Width and Shoulder Width

Overview

The analysis presented in this chapter provides a comprehensive evaluation of the safety effect of lane width and shoulder width using Idaho crash data from 1993 to 2010. The analysis focused on two-lane rural undivided state highways. Chapter 3 described the development of prediction equations from which a set of recommended CMFs could be determined. CMFs for three different crash types (all crashes, single-vehicle crashes, and multiple-vehicle crashes) were developed as part of this study. Multiple-vehicle crashes consisted mostly of opposite direction crashes, but some rear-end crashes are also included in this category. In addition, the characteristics of pedestrian and bicycle crashes on two-lane rural state highways were investigated. To isolate the effect of lane width and shoulder width, roadway sections that have shoulder rumble strips and/or centerline rumble strips were excluded from the analysis.

Prediction Models

The primary objective of the data analysis for this part of the study was to develop prediction models for assessing the safety impacts of different lane width and shoulder width values. The potential safety effects were expressed as the expected number of crashes per time unit. In addition to all crashes, models for predicting single-vehicle and multiple-vehicle crashes were also developed. Models for specific crash types, however, were not developed due to the small sample size available. As discussed in Chapter 3, GLMs were used in the development of the prediction models in this study. These models are considered more appropriate for variables that are not normally distributed, such as crashes which are considered random events that follow a Poisson distribution.

The Generalized Modeling procedure (GENMOD) in SAS statistical software was used to develop the prediction models. The model coefficients were estimated using the maximum-likelihood method. This approach is suitable for models that have predictor variables that are either continuous or categorical. Variables with coefficients that were not statistically significant at the 95 percent confidence level were removed from the model. This process was followed until a model was obtained in which all variables entered were statistically significant. The signs of the coefficients were also evaluated to ensure that they were consistent with observed crash trends. Figure 5 demonstrates the general form of the negative binomial models used in this study:

$$E[N] = Le^{b_0 + b_1 LANE + b_2 S + b_3 \ln AADT + b_4 C + b_5 W}.$$

where:

E[N] = Expected Number of Crashes per Year for a Specific Road Section.
L = Exposure to Crashes Expressed as the Length of the Segment (in miles) Multiplied by the Number of Years.
LANE = Lane Width (ft).
S = Shoulder Width (ft).
C = Degree of Curvature.
AADT = Average Annual Daily Traffic (veh/day).
W = Total Width of the Roadway (ft).
b_0 = Model Intercepts.
b_1, b_2, b_3, b_4 and b_5 = Regression Coefficients.

Figure 5. Negative Binomial Model Used in the Analysis

Crash Modification Factors

A CMF represents the anticipated change in safety when a particular geometric design element value changes. A CMF greater than 1.0 represents a situation where the design change is associated with more crashes; a CMF less than 1.0 indicates fewer crashes. Typically, CMFs are estimated directly from the coefficients of prediction models derived using crash data. Two regression model methods can be used to estimate CMFs, both were described in Chapter 3 (Figure 2, 3, and 4). In this study, CMFs were estimated directly from the coefficients of statistical models using the equation presented in Figure 2. This method provides a simple way to estimate the effects of changes in lane width and shoulder width.

Lane Width

CMFs for lane width developed using Idaho's crash data, are presented in **Table 13** and Figure 6. The results indicate that there is no significant difference between 12 ft lanes and 11 ft lanes in terms of safety for all types of crashes. When all crashes were considered, the CMF for highways with 11 ft lanes was 1.02 indicating a marginal 2 percent increase in crashes when compared to highways with standard 12 ft lanes. The CMF values for single-vehicle crashes and multiple-vehicle crashes were 2 percent and 3 percent, respectively. The CMF for highways with 10 ft lanes was 1.05 for all crashes, 1.07 for single-vehicle crashes, and 1.04 for multiple-vehicle crashes. The coefficient for the total roadway width was not statistically significant at the 95 percent confidence level.

Table 13. Idaho CMFs for Lane Width

Crash Type	**Lane Width (ft)**		
	10	**11**	**12**
All Crashes	1.05	1.02	1.00
Single-Vehicle Crashes	1.07	1.02	1.00
Multiple-Vehicle Crashes	1.04	1.03	1.00

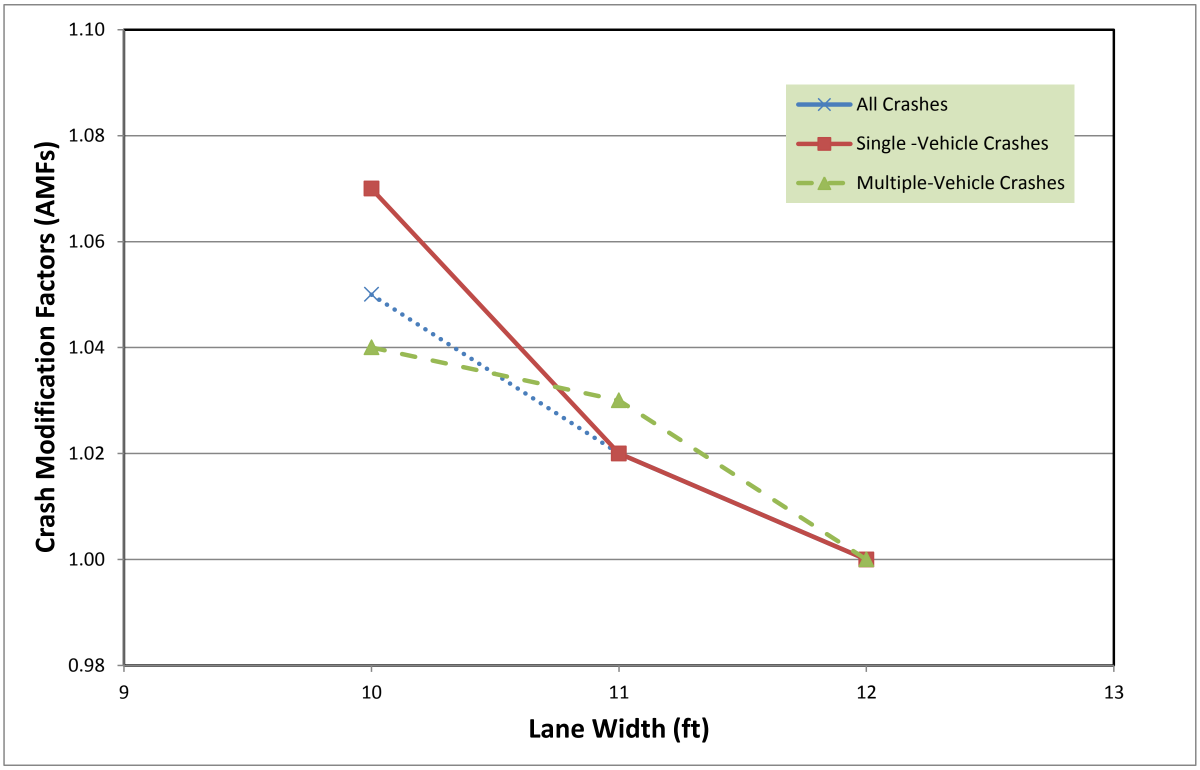

Figure 6. Idaho CMFs for Lane Width

Table 14 and Figure 7 present the CMFs for lane width for low-volume highways (highways with AADTs less than 400 vehicles per day). The CMFs values are slightly lower than the values presented Table 13 in and Figure 6 for all highways. The CMF for highways with 11-ft lanes was 1.01 for all crashes, 1.02 for single-vehicle crashes, and 1.02 for multiple-vehicle crashes. For highways with 10-ft lane width, these values were 1.04, 1.06, and 1.05, respectively. Again, for the low-volume highways model, the coefficients for the degree of curvature and total roadway width were not statistically significant at the 95 percent confidence level.

Table 14. Idaho CMFs for Lane Width – Low Volume Highways

Crash Type	Lane Width (ft)		
	10	**11**	**12**
All Crashes	1.04	1.01	1.00
Single-Vehicle Crashes	1.06	1.02	1.00
Multiple-Vehicle Crashes	1.04	1.02	1.00

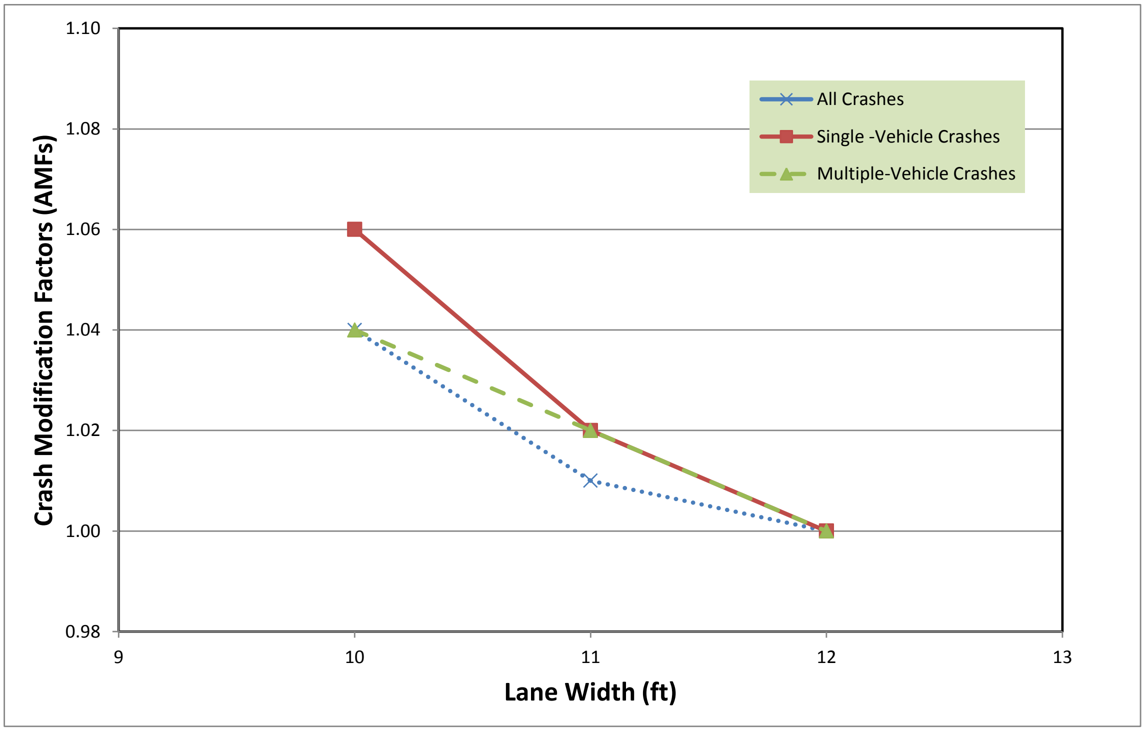

Figure 7. Idaho CMFs for Lane Width – Low Volume Highways

Shoulder Width

CMFs for shoulder width, developed using Idaho's crash data, are listed in Table 15 for the 3 crash types considered in this study. Figure 8 shows CMFs for shoulder width for all crashes. Figure 9 and Figure 10 show CMFs for single-vehicle crashes and multiple-vehicle crashes, respectively. CMFs for shoulder width for low-volume highways are presented in Table 16 and in Figure 11-13. In general, shoulder width was found to have a significant influence on crashes, with increasing shoulder width having a positive effect on crashes (i.e. reduction in crashes). There is also some evidence that wider shoulders provide drivers with a wider space for correcting errors, thus reducing both single-vehicle and multiple-vehicle crashes. The models and the CMFs developed in this study demonstrated and quantified the relationship between shoulder width and crashes based on Idaho specific crash data. The general trends observed from previous studies were supported by the values of the CMFs developed.

The CMFs for highways with a very small shoulder (less than 1 ft) were 1.16, 1.17, and 1.15 for all crashes, single-vehicle crashes, and multiple-vehicle crashes, respectively. This corresponds to an average increase in crashes of 16 percent when compared to highways with a 3 ft shoulder width. For low-volume highways, the average increase in crashes for highways with no shoulders was slightly lower at 13 percent. For highway sections with a shoulder width of 8 ft or more, the CMFs were 0.87, 0.90, and 0.83 for all crashes, single-vehicle crashes, and multiple-vehicle crashes, respectively, indicating an average reduction in crashes of approximately 13 percent. Low-volume highways experienced a similar reduction of crashes with an average value of 12 percent. The coefficients for the degree of curvature and total roadway width were not statistically significant at the 95 percent confidence level.

The CMFs for shoulder width listed in Table 15 and Table 16 should be used by ITD staff to assess the potential safety benefits of proposed shoulder widening projects and to develop a guideline for determining appropriate shoulder widths for different roadway segments factoring in safety and cost.

Table 15. Idaho CMFs for Shoulder Width

Crash Type	Shoulder Width (ft)								
	0	1	2	3	4	5	6	7	8
All Crashes	1.16	1.13	1.03	1.00	0.97	0.95	0.93	0.91	0.87
Single-Vehicle Crashes	1.17	1.07	1.02	1.00	0.95	0.93	0.91	0.92	0.90
Multiple-Vehicle Crashes	1.15	1.18	1.03	1.00	0.97	0.95	0.94	0.89	0.83

Table 16. Idaho CMFs for Shoulder Width - Low-Volume Highways

Crash Type	Shoulder Width (ft)								
	0	1	2	3	4	5	6	7	8
All Crashes	1.13	1.11	1.03	1.00	0.98	0.94	0.93	0.90	0.88
Single-Vehicle Crashes	1.14	1.09	1.03	1.00	0.94	0.94	0.90	0.92	0.91
Multiple-Vehicle Crashes	1.11	1.13	1.02	1.00	0.97	0.93	0.94	0.88	0.84

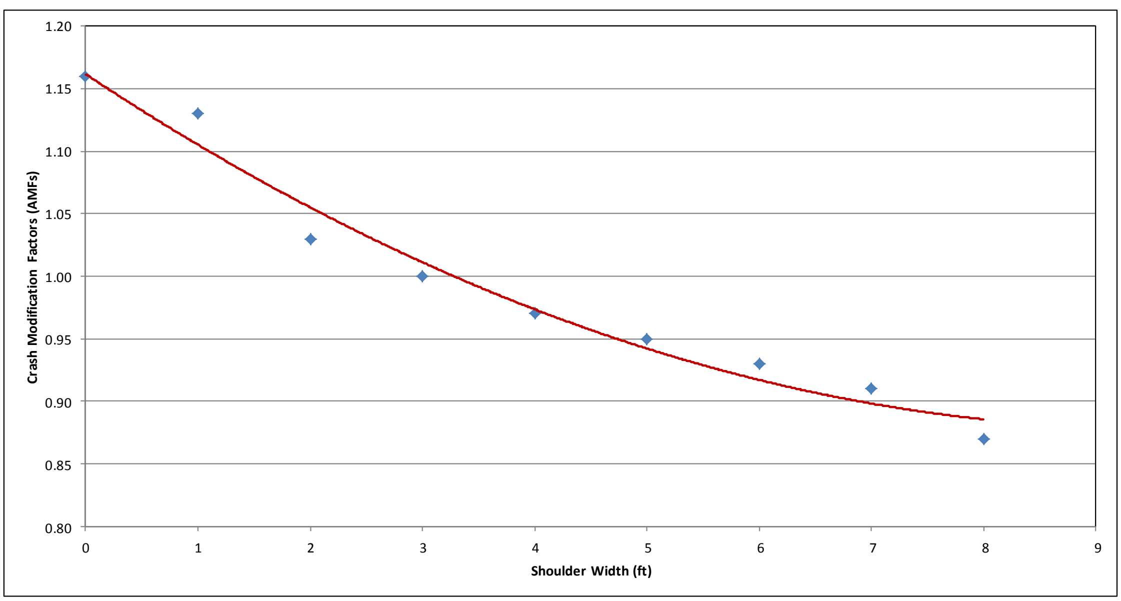

Figure 8. Idaho CMFs for Shoulder Width – All Crashes

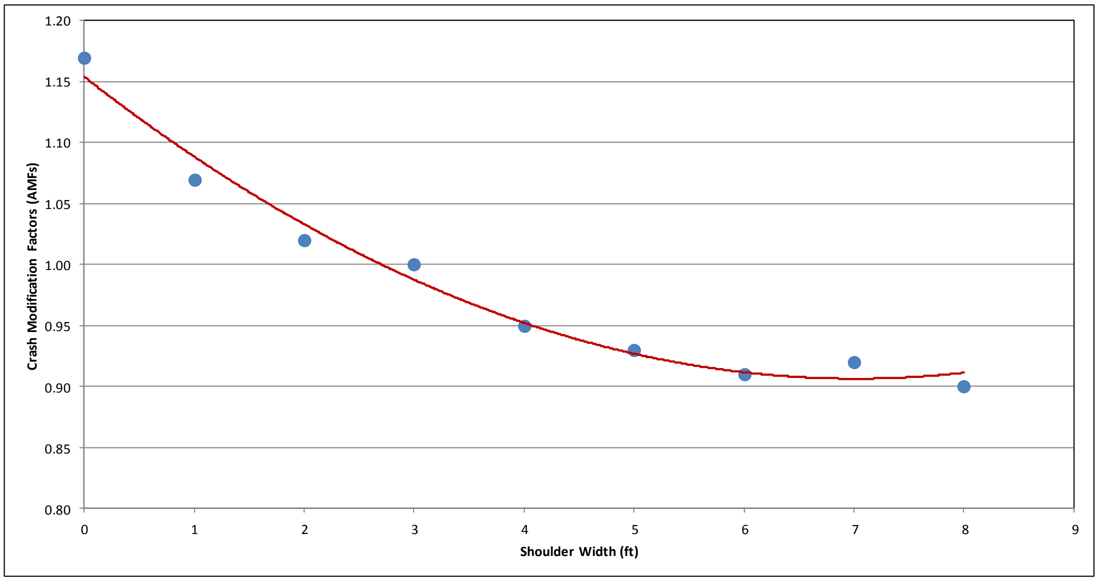

Figure 9. Idaho CMFs for Shoulder Width Based – Single-Vehicle Crashes

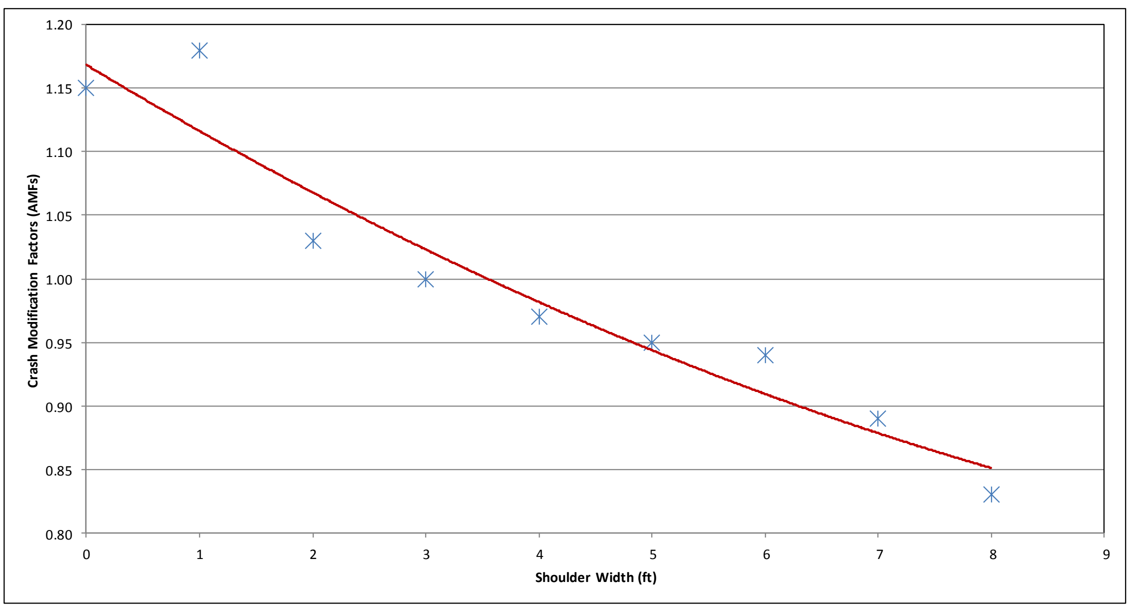

Figure 10. Idaho CMFs for Shoulder Width – Multiple-Vehicle Crashes

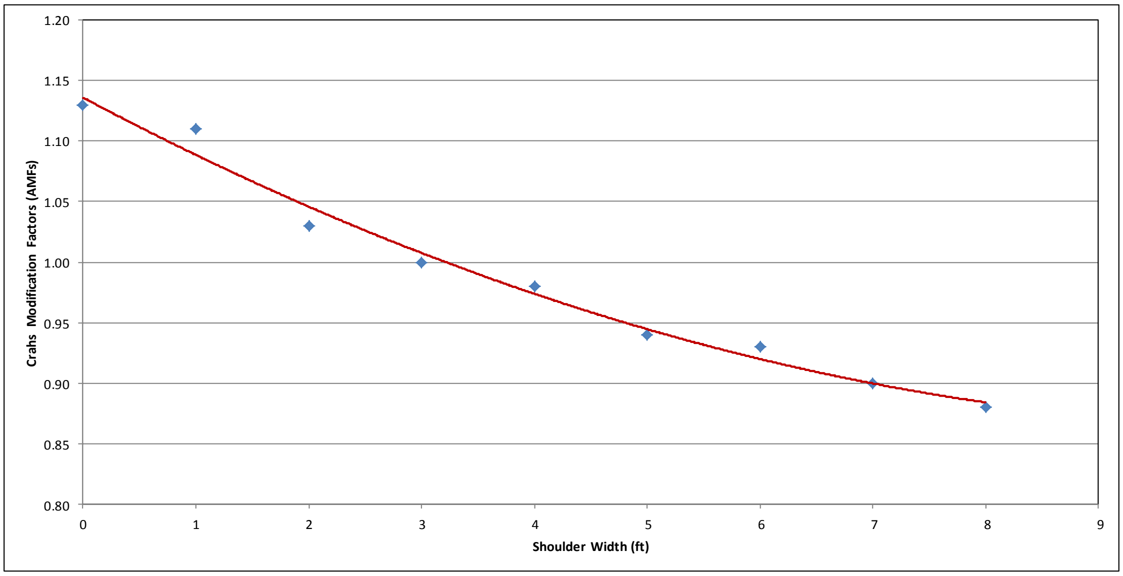

Figure 11. Idaho CMFs for Shoulder Width on Low-Volume Highways – All Crashes

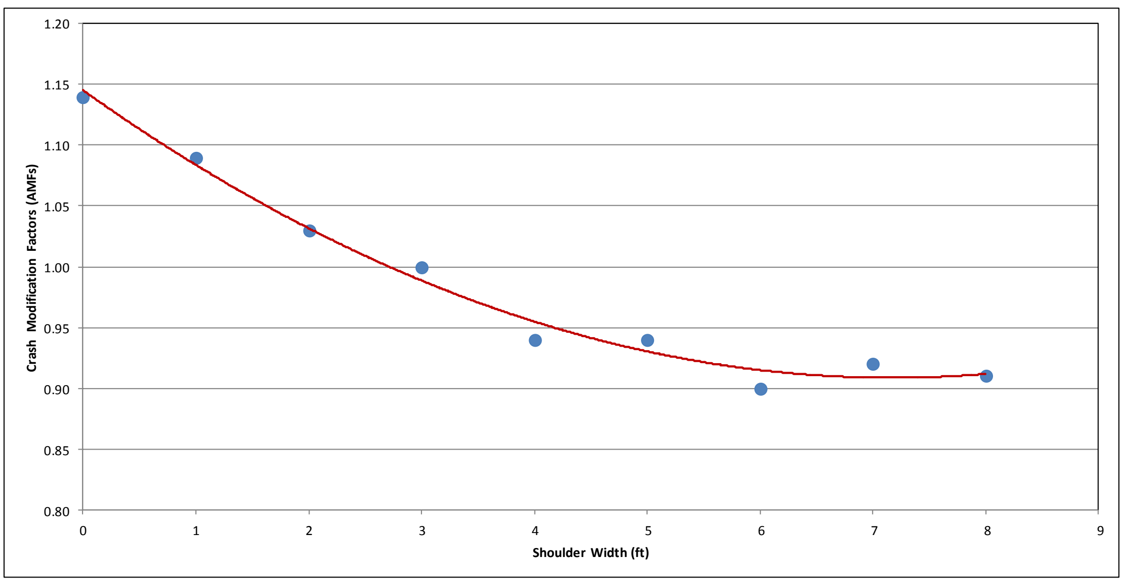

Figure 12. Idaho CMFs for Shoulder Width on Low-Volume Highways – Single-Vehicle Crashes

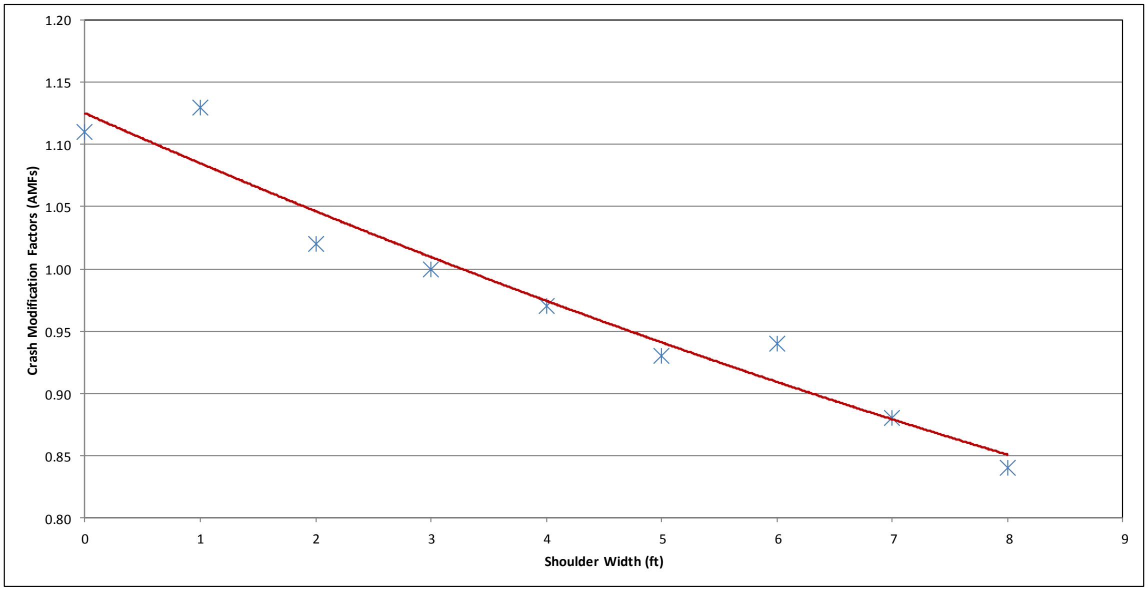

Figure 13. Idaho CMFs for Shoulder Width on Low-Volume Highways – Multiple-Vehicle Crashes

Relationship Between Shoulder Width and Pedestrian and Bicycle Crashes

Idaho crash data indicates that approximately 22 percent of Idaho's pedestrian and bicycle fatal and injury crashes occur on rural highways. The geometric and operational characteristics of two-lane rural highways, such as higher average vehicle speeds and a lack of sidewalk provisions, make these crashes more hazardous to pedestrians and bicyclists. While pedestrian and bicycle crashes on Idaho mostly occur in urban areas within or near city limits, pedestrian and bicycle crashes in rural highways more often results in pedestrian or bicyclist death or serious injury, possibly due to higher vehicle speeds.

Most pedestrian crashes on two-lane rural highways in Idaho occurred when the pedestrian was walking or running along the roadway and was struck from the front or from behind by a vehicle. Most bicycle crashes occurred as a result of drivers overtaking a bicyclist on rural two-lane roads. Groups that were overrepresented in two-lane rural highway pedestrian and bicycle crashes in Idaho were young pedestrians and bicyclists (18 years of age or younger), pedestrians and bicyclists who had consumed alcohol, and older pedestrians and bicyclists (65 years or older).

Potential pedestrian crash countermeasures for rural areas include improving roadway lighting, educating pedestrians and drivers, and adding sidewalks and paved shoulders. Potential bicycle crash countermeasures for rural areas include adding paved shoulders and improving roadway lighting.
Figure 14 presents the relationship between the width of the right paved shoulder and pedestrian and bicycle crashes in two-lane rural highways in Idaho. The crash data used for this part of the analysis covered a 9-year period spanning from 2002 to 2010. The results show that roadway sections with a right

paved shoulder width of 4 ft to 6 ft had the lowest number of pedestrian and bicycle crashes. The probability for a pedestrian/bicycle crash increases significantly for roadway sections with shoulder width less than 3 ft. The likelihood of a crash also increases for roadway sections with shoulder width of 8 ft or more.

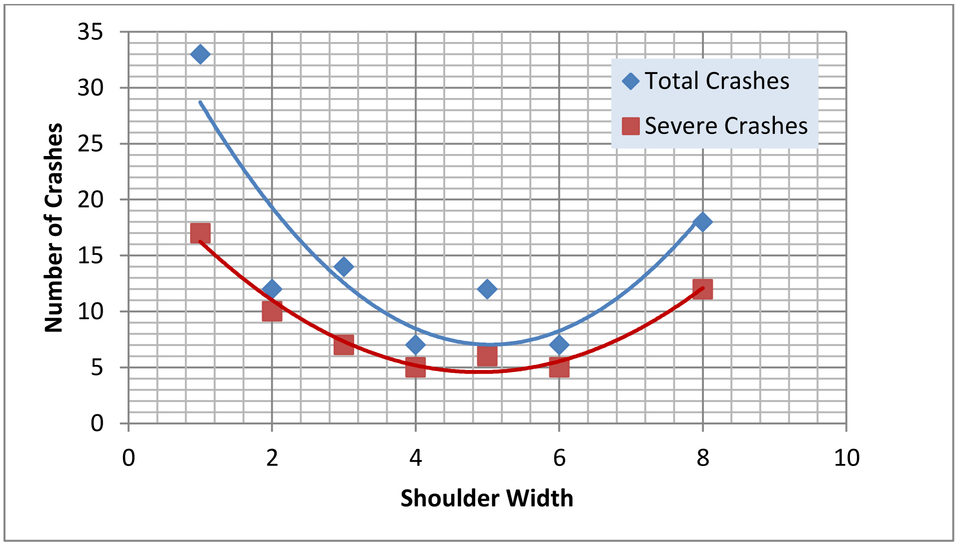

Figure 14. Relationship Between Shoulder Width and Pedestrian and Bicycle Crashes on Two-Lane Rural Highways in Idaho, 2002-2010

Chapter 5
Conclusions and Recommendations

This study examined the relationship between crash rates and shoulder width and lane width for two-lane rural highways in Idaho. CMFs for shoulder width and lane width were developed using Idaho crash data covering the period from 1993 to 2010. The CMFs developed as part of this project will allow ITD to assess the potential safety benefits of shoulder widening projects and develop guidelines for determining appropriate lane width and shoulder width factoring in safety and cost. The research was conducted in two stages. The first stage was comprised of a literature review and the development of methodology for data collection and analysis. In the second stage, data were collected and analyzed to develop an understanding of the safety and operational impacts of shoulder width and lane width.

Generalized linear negative binomial models, a well-accepted method of modeling discrete rare events such as roadway accidents, were used to develop prediction models for assessing the safety impacts of using different lane width and shoulder width values. Models were developed for all crashes, single-vehicle crashes and multiple-vehicle crashes. Models for specific crash types, however, were not developed due to the limited number of crashes and the small sample size available. The model coefficients were estimated using the maximum-likelihood method. This approach is suitable for models that have predictor variables that are either continuous or categorical. Variables with coefficients that were not statistically significant at the 95 percent confidence level were removed from the model. This process was followed until a model was obtained in which all variables entered were statistically significant. The signs of the coefficients were also evaluated to ensure that they are consistent with observed crash trends. Table 17 and Table 18 document the findings from the analyses.

Table 17. Recommended CMFs for Lane Width in Idaho

Highway	Crash Type	Lane Width (ft)		
		10	11	12
All Highways	All Crashes	1.05	1.02	1.00
	Single-Vehicle Crashes	1.07	1.02	1.00
	Multiple-Vehicle Crashes	1.04	1.03	1.00
Low-Volume Highways	All Crashes	1.04	1.01	1.00
	Single-Vehicle Crashes	1.06	1.02	1.00
	Multiple-Vehicle Crashes	1.04	1.02	1.00

Table 18. Recommended CMFs for Shoulder Width in Idaho

Highway	Crash Type	Shoulder Width (ft)								
		0	1	2	3	4	5	6	7	8
All Highways	All Crashes	1.16	1.13	1.03	1.00	0.97	0.95	0.93	0.91	0.87
	Single-Vehicle Crashes	1.17	1.07	1.02	1.00	0.95	0.93	0.91	0.92	0.90
	Multiple-Vehicle Crashes	1.15	1.18	1.03	1.00	0.97	0.95	0.94	0.89	0.83
Low-Volume Highways	All Crashes	1.13	1.11	1.03	1.00	0.98	0.94	0.93	0.90	0.88
	Single-Vehicle Crashes	1.14	1.09	1.03	1.00	0.94	0.94	0.90	0.92	0.91
	Multiple-Vehicle Crashes	1.11	1.13	1.02	1.00	0.97	0.93	0.94	0.88	0.84

- No significant differences were shown between 12 ft lanes and 11 ft lanes in terms of safety for all types of crashes. The CMF for highways with 11 ft lanes was 1.02 indicating a marginal 2 percent increase in all crashes in comparison to highways with standard 12 ft lanes. The CMF values for single-vehicle crashes and multiple-vehicle crashes were 2 percent and 3 percent, respectively. This conclusion is also valid for low-volume highways. The CMF for low-volume highways with 11 ft lanes was 1.01 for all crashes, 1.02 for single-vehicle crashes, and 1.02 for multiple-vehicle crashes.

- The CMFs for highways with very small shoulders (less than 1 ft) were 1.16, 1.17, and 1.15 for all crashes, single-vehicle crashes, and multiple-vehicle crashes, respectively. This corresponds to an average increase in crashes of 16 percent when compared to highways with a 3 ft shoulders. For low-volume highways, the average increase in crashes for highways with no shoulders was slightly lower at 13 percent.

- For highway sections with a shoulder width of 8 ft or more, the CMFs were 0.87, 0.90, and 0.83 for all crashes, single-vehicle crashes, and multiple-vehicle crashes, respectively, indicating an average reduction in crashes of approximately 13 percent when compared to highways with a 3 ft shoulders. Low-volume highways experienced a similar reduction of crashes with an average value of 12 percent.

- Idaho's crash data was also used to investigate the characteristics of pedestrian and bicycle crashes on two-lane rural highways. Data used for this part of the study covered a 9-year period spanning from 2002 to 2010. Most pedestrian crashes on two-lane rural highways in Idaho occurred when the pedestrian was walking or running along the roadway and was struck from the front or from behind by a vehicle. Most bicycle crashes occurred as a result of drivers overtaking a bicyclist on rural two-lane roads. Groups that were overrepresented in two-lane rural highway pedestrian and bicycle crashes in Idaho were young pedestrians and bicyclists (18 years or younger), pedestrians and bicyclists who had consumed alcohol, and older pedestrians and bicyclists (65 years or older).

- The results show that roadway sections with a right paved shoulder width of 4 to 6 ft had the lowest number of pedestrian crashes. The probability for a pedestrian/bicycle crash increases significantly for roadway sections with shoulder widths less than 3 ft. The likelihood of a crash also increases for roadway sections with shoulder widths of 8 ft or more.

- Potential pedestrian crash countermeasures for rural areas include improving roadway lighting, educating pedestrians and drivers, and adding sidewalks and paved shoulders. Potential bicycle crash countermeasures for rural areas include adding paved shoulders and improving roadway lighting.

- A shoulder width of 4 ft to 6 ft seems optimal from the pedestrian and bicycle safety point of view, however, economic analysis is needed to examine if the safety benefits of increasing width of the paved shoulder are justifiable.

- The CMFs developed in this study based on Idaho data, allow ITD to quantify the crash reduction benefits associated with lane width and shoulder width improvement projects. Comparing the monetary value of the prevented crashes to the cost of implementing the safety improvement project provides a quantitative measure to assist ITD in prioritizing projects and optimizing the return on safety investment.

References

1. **American Association of State Highway and Transportation Officials (AASHTO).** *A Policy on Geometric Design of Highways and Streets*. Washington, D.C.: AASHTO, 2001.

2. **American Association of State Highway and Transportation Officials (AASHTO).** *Highway Safety Manual*. Washington, D.C.: AASHTO, 2010.

3. **Shannon, P., and A. Stanley.** *Pavement Width Standards for Rural, Two-Lane Highways.* Boise, ID: Pacific Northwest Regional Commission and the Idaho Transportation Department, 1976.

4. **Zegeer, C. V., and J. A. Deacon.** "Effect of Lane Width, Shoulder Width, and Shoulder Type on Highway Safety" *State-of-the-Art Report: Relationship Between Safety and Key Highway Features: a Synthesis of Prior Research,* Vol. 6, (1987): 1-21.

5. **Zegeer, C. V., D. W. Reinfurt, J. Hummer, L. Herf, and W. Hunter.** "Safety Effects of Cross-Section Design for Two-Lane Roads." *Transportation Research Record: Journal of the Transportation Research Board,* No. 1195 (1988): 20-32.

6. **Zegeer, C. V., R. C. Deen and J. G. Mayes.** *Cost-Effectiveness of Lane and Shoulder Widening of Rural, Two-Lane Roads in Kentucky*. Frankfort, KY: Kentucky Transportation Cabinet, KYP-72-40, 1979.

7. **Smith, S. A., J. Purdy, H. W. McGee, D. W. Harwood, and J. C. Glennon**. (1983). *Identification, Quantification, and Structuring of Two-Lane Rural Highway Safety Problems and Solutions.* Washington, DC: Federal Highway Administration, Report No. FHWA-RD-83-021, 1983.

8. **Hadi, M. A., J. Aruldhas, L. F. Chow, and J. A. Wattleworth.** "Estimating Safety Effects of Cross-Section Design for Various Highway Types Using Negitive Binomial Regession." *Transportation Research Record: Journal of the Transportation Research Board*, No. 1500 (1995): 169-177.

9. **Harwood, D. W., F. M. Council, E. Hauer, W. E. Hughes, and A. Vogt.** *Prediction of the Expected Safety Performance of Rural Two-Lane Highways.* Washington DC: Federal Highway Administration, Report No. FHWA-RD-99-207, 2000.

10. **Zegeer, C. V., R. Stewart, F. Council, and T. R. Neuman**. "Crash Relationships of Roadway Width on Low-Volume Roads." *Transportation Research Record: Journal of the Transportation Research Board,* No*. 1445*, (1994): 160-168.

11. **Zegeer, C. V., R. C. Deen, and J. G. Mayes**. "Effect of Lane and Shoulder Width on Crash Reduction on Rural, Two-Lane Roads." *Transportation Research Record: Journal of the Transportation Research Board,* No. 806, (1981): 33-43.

12. **Miaou, S. P.** *Measuring the Goodness-of-Fit of Crash Prediction Models.* Washington, DC: Federal Highway Administration, FHWA-RD-96-040, 1996.

13. **Miaou, S. P.** *Development of Adjustment Factors for Single-Vehicle Run-off-Road Accidents Rates by Horizontal Curve and Grade*. Oak Ridge, TN: Oak Ridge National Laboratory, 1995.

14. **Rinde, E. A.** *Crash Rates vs. Shoulder Width: Two Lane Roads, Two Lane Roads with Passing Lanes.* Sacramento, CA: California Department of Transportation, Report No. CA-DOT-TR-3147-17701, 1977.

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

16. **Harkey, D. L., R. Srinivasan, J. Baek, F. M. Council, K. A. Eccles, N. X. Lefler, F. Gross, B. N. Persaud, C. Lyon, E. Hauer, and J. A. Bonneson**. *Crash Modification Factors for Traffic Engineering and ITS Improvements.* Washington DC: Transportation Research Board, NCHRP Report 617, 2008.

17. **Bonneson, J., K. Zimmerman, and K. Fitzpatrick.** *Interm Roadway Safety Design Workbook.* College Station, TX: Texas Transportation Institute, 2005.

18. **Lord, D., and J. A. Bonneson**. "Development of Crash Modification Factors for Rural Frontage Road Segments in Texas." *Transportation Research Record: Journal of the Transportation Research Board*, No. 2023 2007): 20-27.

19. **Gross, F., and K. Eccles.** *Safety Evaluation of Lane and Shoulder Width Combinations on Rural, Two-Lane, Undivided Roads.* Washington, D.C.: Federal Highway Administration, Report No. FHWA-HRT-09-032, 2009.

20. **Council, F. M., and J. R. Stewart**. "Safety Effects of the Conversion of Rural Two-Lane to Four-Lane Roadways Based on Cross-Sectional Models." *Transportation Research Record: Journal of the Transportation Research Board,* No. 1665, (1999): 35-43.

21. **Lord, D., S. R. Geedipally, B. N. Persaud, S. P. Washington, I. Van Schalkwyk, J. N. Ivan, C. Lyon,and T. Jonsson**. *Methodology to Predict the Safety Performance of Rural Multi-lane Highways.* Washington, DC: Transportation Research Board, NCHRP Web-Only Document 126, 2008.

22. **Fitzpatrick, K., D. Lord, and B. J. Park**. "Accident Modification Factors for Medians on Freeways and Multilane Rural Highways in Texas." *Transportation Research Record: Journal of the Transportation Research Board,* No. 2083, (2008): 62-71.

23. **Stamatiadis, N., J. G. Pigman, J. Sacksteder, W. Ruff,and D. Lord**. *Impact of Shoulder Width and Median Width on Safety.* Washington, DC: Transportation Research Board, NCHRP Report 633, 2009.

24. **Washington, S. P., B. N. Persaud, C. Lyon, and J. Oh**. *Validation of Crash Models for Intersections.* Washington, DC: Federal Highway Administration, Report No. FHWA-RD-03-037, 2005.

25. **Idaho Transportation Department,** Office of Highway Safety (OHS) WebCARs (2010) http://apps.itd.idaho.gov/apps/webcars/ Accessed November 2010

26. **Idaho Transportation Department**. Automatic Traffic Recorders (ATR) Website (2010) http://itd.idaho.gov/highways/roadwaydata/Maps/ATR_WIMmap_map.html Accesed June 2010.

Appendix A
Characteristics of Sites Included in the Analysis

Segment ID	Lane Width (ft)	Shoulder Width (ft)	Average AADT	Length (mile)	Beginning MP	Ending MP	Analysis Period	
							Begin Year	End Year
SH003-1	11	1	1,503	7.0	95.88	102.88	2000	2000
SH003-2	12	1	1,499	8.5	39.47	47.97	1994	2008
SH003-3	12	1	1,546	8.0	109.36	117.36	1998	2008
SH006-1	12	2	527	7.0	9.89	16.89	1996	2008
SH006-2	10	0	2,623	4.0	100.00	104.00	1997	2002
SH007-1	10	0	750	11.5	36.78	48.28	2009	2009
SH007-2	10	0	750	8.5	40.15	48.65	1994	2008
SH008-1	12	2	4,816	6.5	36.27	42.77	1994	2006
SH008-2	12	3	4,833	8.0	17.52	25.52	1997	2008
SH011-1	11	0	750	7.0	35.16	42.16	1999	2009
SH011-2	11	1	750	4.0	18.68	22.68	1996	1998
SH011-3	11	1	750	4.0	25.26	29.26	2001	2008
SH011-4	11	2	2,000	4.0	18.68	22.68	1999	2000
SH013-1	11	1	750	5.0	1.12	6.12	2001	2008
SH013-2	12	1	750	6.5	15.10	21.60	1995	2008
SH013-3	12	3	750	4.5	6.61	11.11	1997	2008
SH014-1	11	0	750	7.5	8.70	16.20	1994	2008
SH016-1	12	6	8,862	8.5	0.00	8.50	2001	2008
SH021-1	11	0	3,132	11.0	58.00	69.00	1998	2008
SH021-2	12	3	412	7.0	105.52	112.52	2006	2008
SH021-3	12	3	440	5.5	116.50	122.00	2001	2009
SH022-1	12	4	186	4.0	38.26	42.26	2001	2008
SH024-1	10	1	750	0.5	5.12	5.62	1998	2004
SH025-1	12	3	750	4.0	10.42	14.42	2001	2007
SH025-2	12	6	750	4.0	46.41	50.41	1999	2008
SH028-1	12	2	501	8.5	73.00	81.50	2005	2008
SH028-2	12	2	546	9.0	88.20	97.20	2001	2004
SH028-3	12	5	519	5.5	15.15	20.65	1997	2008
SH028-4	12	3	519	6.5	58.90	65.40	1997	2008
SH029-1	11	0	750	8.5	0.00	8.50	1994	2008
SH031-1	10	4	1,318	4.5	0.00	4.50	1997	1997
SH032-1	12	0	498	9.0	18.89	27.89	2005	2008
SH032-2	12	1	457	6.0	7.93	13.93	1998	2008
SH033-1	12	2	510	8.0	8.63	16.63	2001	2008

Segment ID	Lane Width (ft)	Shoulder Width (ft)	Average AADT	Length (mile)	Beginning MP	Ending MP	Analysis Period	
							Begin Year	End Year
SH033-2	12	3	513	7.0	51.71	58.71	1997	2008
SH033-3	12	4	513	7.0	58.91	65.91	1997	2008
SH033-4	12	5	510	4.0	73.44	77.44	1997	2009
SH033-5	12	6	513	5.5	125.44	130.94	1997	2008
SH034-1	12	0	750	6.0	103.90	109.90	1999	2006
SH034-2	12	4	750	4.5	35.28	39.78	2000	2008
SH036-1	12	0	750	11.5	100.00	111.50	1994	2006
SH036-2	12	0	750	6.5	114.86	121.36	1994	2006
SH036-3	12	4	750	5.0	126.54	131.54	1999	2008
SH037-1	11	0	750	12.5	37.48	49.98	1994	2006
SH038-1	12	0	750	6.5	6.31	12.81	1994	2008
SH039-1	12	5	897	7.5	3.28	10.78	2000	2008
SH039-2	12	4	897	5.0	29.92	34.92	2000	2008
SH041-1	12	3	8,167	9.5	22.70	32.20	1997	2004
SH045-1	12	3	750	7.5	14.17	21.67	2000	2008
SH046-1	12	5	750	5.5	1.21	6.71	1997	2008
SH051-1	12	4	750	7.5	76.60	84.10	2001	2008
SH052-1	11	1	1,843	3.5	35.09	38.59	1994	2000
SH052-2	12	2	2,049	7.5	18.04	25.54	2001	2008
SH053-1	12	5	6,484	8.0	0.00	8.00	1997	2009
SH055-1	11	1	3,728	3.0	150.00	153.00	2001	2008
SH055-2	11	2	3,656	2.5	153.43	155.93	2000	2008
SH055-3	12	1	5,110	13.5	66.70	80.20	1998	2008
SH055-4	12	4	5,110	6.5	84.39	90.89	2001	2008
SH055-5	12	5	5,110	4.5	101.89	106.39	2001	2008
SH055-6	12	6	3,749	6.5	116.00	122.50	2001	2007
SH055-7	12	3	3,539	11.0	131.40	142.40	1998	2008
SH057-1	12	1	1,756	10.0	8.68	18.68	2001	2008
SH064-1	10	0	750	3.0	26.93	29.93	1994	2008
SH069-1	11	2	7,700	4.5	2.52	7.02	1999	2000
SH071-1	12	0	271	6.5	21.37	27.87	1998	2008
SH071-2	12	1	271	8.0	13.32	21.32	1998	2008
SH075-1	11	0	711	7.0	195.08	202.08	1994	2008
SH075-2	12	1	1,236	9.0	148.26	157.26	1994	2008
SH075-3	12	5	2,144	5.5	80.95	86.45	2001	2004
SH075-4	12	3	13,135	5.0	102.13	107.13	2001	2008
SH075-5	12	6	1,555	6.5	129.87	136.37	1999	2008

Segment ID	Lane Width (ft)	Shoulder Width (ft)	Average AADT	Length (mile)	Beginning MP	Ending MP	Analysis Period	
							Begin Year	End Year
SH077-1	11	3	1,300	4.0	23.07	27.07	1994	1994
SH078-1	12	1	522	8.0	67.00	75.00	2000	2008
SH078-2	12	2	506	14.5	36.75	51.25	1996	2008
SH078-3	12	3	750	7.5	0.00	7.50	1998	2008
SH078-4	12	4	515	7.0	29.16	36.16	1998	2008
SH078-5	11	4	1,320	3.0	26.00	29.00	1998	1998
SH087-1	12	5	750	4.5	0.00	4.50	1997	2008
SH087-2	12	5	750	4.0	4.59	8.59	1997	2008
SH097-1	10	0	1,413	5.0	60.63	65.63	1994	1999
SH097-2	10	0	1,402	12.5	69.13	81.63	1994	2000
SH097-3	10	0	1,390	6.5	82.33	88.83	1994	1999
SH099-1	12	2	531	8.5	2.72	11.22	1999	2008
SH162-1	11	1	750	4.5	8.78	13.28	2001	2009
SH200-1	10	0	3,404	7.5	55.17	62.67	1994	1999
SH200-2	12	3	3,583	4.5	31.61	36.11	1999	2008
SH200-3	12	4	3,571	7.5	44.14	51.64	1997	2008
US002-1	12	5	7,449	4.5	0.53	5.03	2001	2009
US012-1	12	0	3,341	14.0	51.57	65.57	1994	2007
US012-2	12	0	612	14.0	96.87	110.87	1999	2008
US012-3	12	0	705	18.0	155.78	173.78	1994	2000
US012-4	12	1	3,293	13.5	73.47	86.97	1994	2008
US012-5	12	1	628	7.5	128.23	135.73	1995	2008
US012-6	12	3	3,389	5.5	43.96	49.46	1997	2008
US020-1	12	1	1,858	20.0	171.08	191.08	1998	2008
US020-2	12	5	2,003	8.5	256.07	264.57	1997	2008
US020-3	12	6	2,185	4.5	284.00	288.50	1998	2008
US020-4	12	6	2,244	6.5	294.00	300.50	2001	2009
US026-1	12	4	1,448	6.5	138.97	145.47	2001	2008
US026-2	12	6	1,448	9.0	156.14	165.14	2001	2008
US026-3	12	3	3,413	4.0	376.95	380.95	1997	2008
US026-4	12	5	3,762	8.0	378.39	386.39	1997	2008
US091-1	12	2	1,280	7.5	21.80	29.30	2000	2009
US093-1	11	1	1,045	4.5	263.85	268.35	2004	2008
US093-2	12	0	5,102	7.5	140.76	148.26	1994	2008
US093-3	12	2	1,078	7.0	208.77	215.77	1998	2008
US093-4	12	4	3,633	5.5	20.30	25.80	1994	1996
US093-9	12	5	5,102	7.0	121.96	128.96	1997	2008

Segment ID	Lane Width (ft)	Shoulder Width (ft)	Average AADT	Length (mile)	Beginning MP	Ending MP	Analysis Period	
							Begin Year	End Year
US095-1	12	6	5,651	7.0	74.23	81.23	1998	2008
US095-2	12	5	3,332	7.0	97.29	104.29	1998	2008
US095-3	11	4	2,272	2.5	178.50	181.00	2001	2003
US095-4	12	4	2,244	12.0	182.42	194.42	2000	2008
US095-5	12	6	10,354	4.0	300.31	304.31	1997	2008
US095-6	12	6	15,106	4.5	454.00	458.50	2001	2009