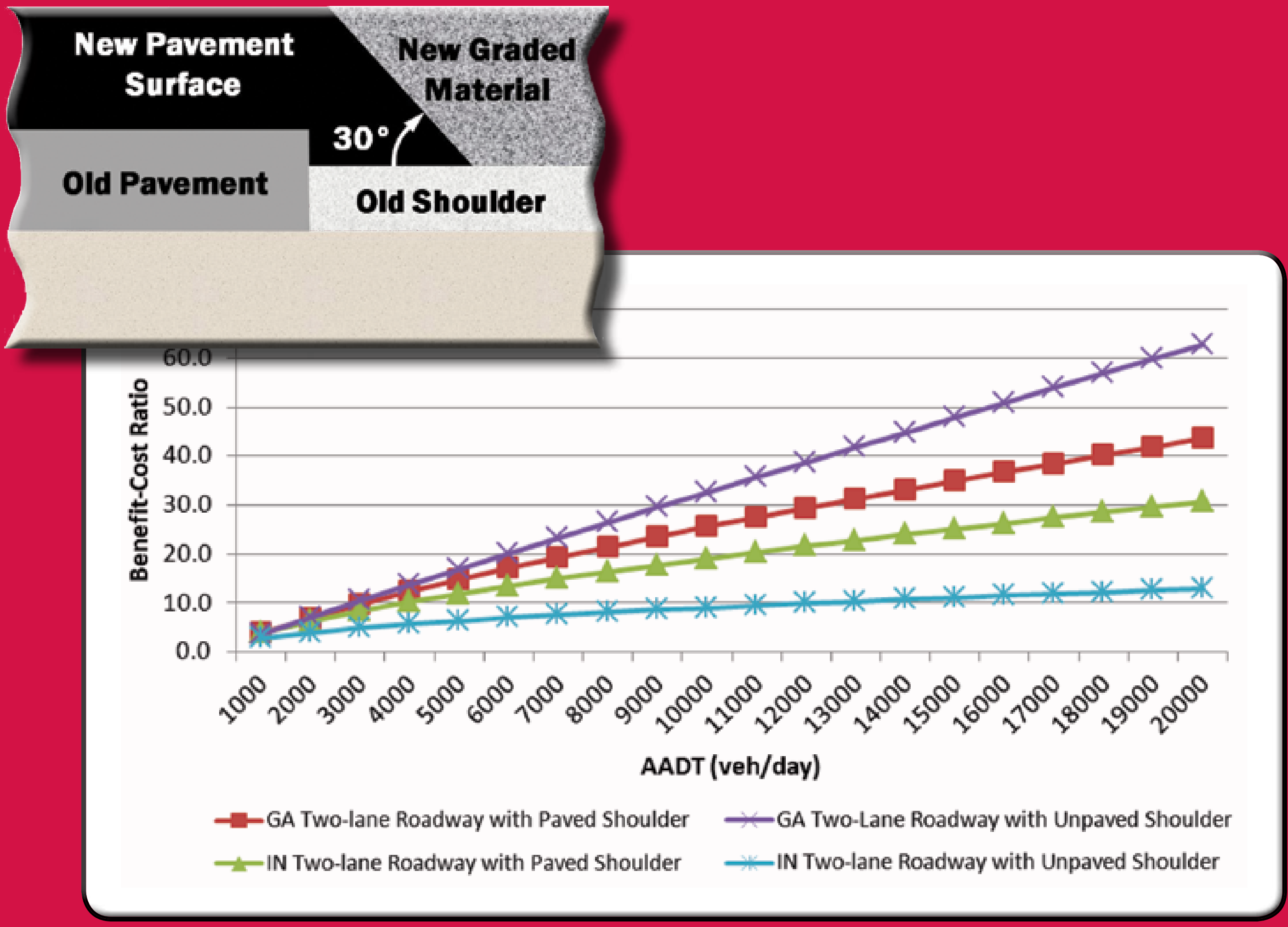
Safety Evaluation of the Safety Edge Treatment

PUBLICATION NO. FHWA-HRT-11-024 APRIL 2011



U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

Advancing the safety of America's highways is a top priority for the Federal Highway Administration (FHWA). Through roadway design, cost-effective countermeasures, and advanced analytical practices, the FHWA Office of Safety Research and Development supports this objective by encouraging the development and implementation of improvements, such as the safety edge, that exhibit real safety benefits for the driving public.

This study evaluated the safety effectiveness of the safety edge treatment in conjunction with resurfacing, a cost-effective safety improvement that can reduce crashes and fatalities. Development of the safety edge treatment was based on a need to reduce drop-off-related crashes and on engineering judgment. The evaluation utilized a before-after empirical Bayes analysis for determining a crash reduction factor for this roadway treatment. Furthermore, the study conducted a benefit-cost analysis to determine the advantages of applying this treatment to rural highways. This analysis of the safety edge highlights the benefits of a low-cost improvement through improved roadway design and evaluation.

This report will interest safety and highway agency engineers who have a shared responsibility for public safety and an interest in implementing low-cost roadway safety treatments.

Monique R. Evans
Director, Office of Safety
Research and Development

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA-HRT-11-024	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Safety Evaluation of the Safety Edge Treatment		5. Report Date March 2011 6. Performing Organization Code: 440545878
7. Author(s) J.L. Graham, K.R. Richard, M.K. O'Laughlin, and D.W. Harwood		8. Performing Organization Report No. 110495.1.001
9. Performing Organization Name and Address MRIGlobal 425 Volker Blvd. Kansas City, MO 64110		10. Work Unit No. 11. Contract or Grant No. DTFH61-06-C-00013
12. Sponsoring Agency Name and Address Federal Highway Administration Turner-Fairbank Highway Research Center Office of Safety Research and Development 6300 Georgetown Pike McLean, VA 22101-2296		13. Type of Report and Period Covered Final Report, 9/1/2006–7/31/2010 14. Sponsoring Agency Code HRDS-20

15. Supplementary Notes
The FHWA Contracting Officer's Technical Representative (COTR) was Carol Tan, HRDS-20.

16. Abstract
Between periods of maintenance, pavement-edge drop-offs can form along the edge of highways. When a driver runs off the roadway, such drop-offs can hinder reentry and may lead to driver overcorrection, loss of control, or overturning on the roadway or roadside. The safety edge is a treatment that is implemented in conjunction with pavement resurfacing and is intended to help minimize drop-off-related crashes.

This report examines the safety effects, costs, and benefits of this low-cost treatment for two-lane and multilane rural highways. The safety research was conducted as an observational before-after evaluation of treated sites using the empirical Bayes method. The economic appraisal consisted of a benefit-cost analysis.

The safety evaluation found that the safety edge treatment appears to have a small positive crash reduction effect. The best effectiveness measure for the safety edge treatment was a 5.7 percent reduction in total crashes on rural two-lane highways. However, this result was not statistically significant. The economic analysis showed that the treatment is very inexpensive and that its application is highly cost-effective for a broad range of conditions on two-lane highways. Inconsistent results were found for rural multilane highways due to a small data sample.

17. Key Words Safety edge, Pavement-shoulder drop-off, Pavement resurfacing, Run-off-road crash		18. Distribution Statement No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 95	22. Price N/A

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

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1. BACKGROUND AND RESEARCH OBJECTIVES

This chapter describes the background and objectives of this research and the organization of the remainder of the report.

1.1 PURPOSE OF THE SAFETY EDGE TREATMENT

Many two-lane rural highways have unpaved shoulders immediately adjacent to the traveled way. Other two-lane highways and many multilane rural highways have narrow paved shoulders with widths of 1–4 ft. If roadway maintenance crews do not keep material against the pavement edge, a pavement-edge drop-off may form. The drop-off height can vary from less than 1 inch to 6 inches or more, even though maintenance performance standards usually require maintenance when the drop-off exceeds 1.5–2 inches.(1)

When a vehicle leaves the traveled way and encounters a pavement-edge drop-off, it can be difficult for the driver to return safely to the roadway. As the driver attempts to steer back onto the pavement, the side of the tire may scrub along the drop-off, resisting the driver's attempts. This resistance often leads the driver to overcorrect with a greater steering angle than desired to remount the drop-off. When the tire does remount the pavement, the increased tire angle may "slingshot" the vehicle across the road, resulting in a collision with other traffic or a loss of control and overturning on the roadway or roadside.

The *safety edge* is a treatment that is intended to minimize drop-off-related crashes. With this treatment, the pavement edge is sloped at an angle of 30 degrees to reduce the resistance of the tire remounting the drop-off (see figure 1). The reduced resistance is intended to allow a more controlled reentry onto the traveled way.

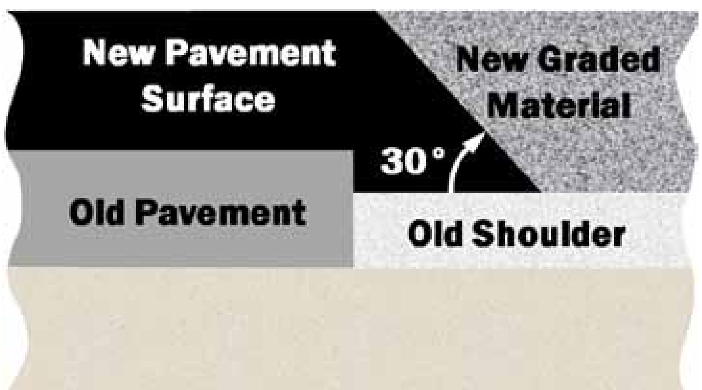


Figure 1. Diagram. Safety edge detail.

Research conducted by the Texas Transportation Institute (TTI) in the 1980s found that drivers rated a 45-degree wedge as a much safer pavement edge to remount than either the vertical or rounded edges normally found with portland cement concrete and asphalt pavements.(2) Because drivers in the study were instructed to go off the pavement edge, the TTI research has been criticized as not being representative of naïve drivers. Prior to this research, actual field evaluation of the safety edge had not been completed.

Selected highway agencies have begun to use the safety edge treatment as part of their pavement resurfacing projects. However, there has been no formal evaluation of the effectiveness of this treatment in reducing drop-off-related crashes on rural highways. Such an evaluation is needed to determine whether this treatment should receive more widespread use.

1.2 RESEARCH OBJECTIVES AND SCOPE

Eight State highway agencies joined the Federal Highway Administration (FHWA) in a pooled-fund study to implement and evaluate the safety edge treatment in conjunction with pavement resurfacing projects. Four State agencies provided study sites for this evaluation: the Colorado Department of Transportation, the Georgia Department of Transportation, the Indiana Department of Transportation, and the New York State Department of Transportation. The evaluation of the safety edge treatment extended over a 3-year period. Unpublished interim reports were prepared for the first and second years after implementation of the safety edge treatment. This final report presents the evaluation results for the entire 3-year study following implementation of the treatment.

The primary objective of the evaluation was to quantify the safety effectiveness of the safety edge treatment. An evaluation was performed to determine whether including the safety edge treatment as part of a pavement resurfacing project reduces crashes in comparison to pavement resurfacing without the safety edge treatment. The evaluation results are presented in terms of the percentage reduction in specific crash types that can be expected from the provision of the safety edge treatment. Other objectives of the study were to document the effectiveness of the safety edge treatment in reducing the presence of pavement-edge drop-offs and to perform an economic analysis of the safety edge treatment. The economic analysis used the safety effectiveness evaluation results and project cost data to define the types of roadways and traffic volume levels for which the safety edge treatment would be cost-effective.

The project scope included two-lane rural roads with no paved shoulder and with a paved shoulder no wider than 4 ft. Multilane roads with paved shoulders no wider than 4 ft were also studied.

1.3 SUMMARY OF EVALUATION PLAN

The evaluation plan for the safety edge treatment was based on the following types of sites:

- Sites that were resurfaced and treated with the safety edge (referred to as *treatment* sites).
- Sites that were resurfaced but not treated with the safety edge (referred to as *comparison* sites).
- Sites that were similar to the treatment and comparison sites but were not resurfaced (referred to as *reference* sites).

This final report is based on data for the characteristics and performance of treatment, comparison, and reference sites during the period before the treatment and comparison sites were resurfaced and for 3 years after resurfacing. Data collected and analyzed in this report include field measurements of drop-offs present on the treated sites before and during the 3 years after resurfacing; crash records for 2–5 years before the site was resurfaced and 3 years after resurfacing; traffic volumes and road characteristics for each site; and the date and cost of resurfacing the treatment and comparison sites.

This report presents the results of a comparison of the presence of pavement-edge drop-offs between the treatment and comparison sites for the period before resurfacing and during the 3 years after resurfacing.

The report also presents the safety evaluation results using traffic volume and crash data for the period before resurfacing of the treatment and comparison sites and the 3 years after resurfacing. Two statistical approaches were used to analyze these data: (1) a before-after comparison using the empirical Bayes (EB) technique and (2) a cross-sectional comparison of the safety performance of sites that were resurfaced with and without the safety edge treatment based on the after period only.

To estimate the safety performance of the safety edge treatment in the before-after EB analysis, safety performance functions (SPFs) were developed from the reference site data using negative binomial regression analysis.

The frequencies of specific target crash types were used as the dependent variables for the safety evaluation. The target crashes for the safety evaluation exclude at-intersection and intersection-related crashes because the safety edge treatment is targeted primarily at non-intersection crashes.

Safety measures used as dependent variables for this report included the frequencies of total non-intersection crashes, run-off-road crashes, and drop-off-related crashes. Run-off-road crashes included those crashes in which one or more involved vehicles left the road. Drop-off-related crashes were a subset of run-off-road crashes for which the crash data included specific evidence that a pavement-edge drop-off may have been involved, such as the inclusion of "low shoulder" or "shoulder defect" as a contributing factor. Separate analyses were conducted for each target crash type for fatal and injury crashes, property-damage-only crashes, and all crash severity levels combined.

Cost data for the resurfacing projects at the treatment and comparison sites are included in the report, and findings are presented concerning the cost-effectiveness of the safety edge treatment.

1.4 ORGANIZATION OF REPORT

The remainder of this report is organized as follows:

- Chapter 2 documents the project database, including a summary of the length of the sites studied, the crash data analyzed, traffic volumes and characteristics of the sites, and field measurements of the pavement-edge drop-offs.
- Chapter 3 presents the analysis results for the field measurements of pavement-edge drop-offs.
- Chapter 4 presents the safety effectiveness evaluation.
- Chapter 5 presents project cost comparisons for sites resurfaced with and without the safety edge.
- Chapter 6 presents the benefit-cost economic analysis.
- Chapter 7 presents conclusions drawn from the analysis results.
- Chapter 8 presents recommendations based on results of the 3-year evaluation.

CHAPTER 2. PROJECT DATABASE

Evaluation of the safety edge treatment required data on roadway geometrics, traffic volumes, crashes, construction costs, and implementation projects for sites where the safety edge treatment was implemented and for other similar sites. This chapter describes the selection of sites and assembly of the project database.

2.1 PARTICIPATING STATES AND SITE SELECTION

Three States agreed to implement the safety edge treatment and to participate in the study: Georgia, Indiana, and New York. Colorado also agreed to participate in the study, but no sites were resurfaced with the safety edge treatment in time for inclusion in the analysis. Sites for the study were selected with the assistance of the participating State highway agencies. However, the site selection approach varied for three types of study sites: sites that were resurfaced and treated with the safety edge (treatment sites); sites that were resurfaced but not treated with the safety edge (comparison sites); and sites that were similar to the treatment and comparison sites but were not resurfaced (reference sites).

Treatment sites were selected by the three participating States from among the sites considered for their normal resurfacing program for 2005. In Indiana and New York, the sites that received the safety edge treatment were selected by the State as representative resurfacing projects for which the safety edge treatment would be appropriate. In Georgia, the transportation department made a policy decision to include the safety edge treatment in all resurfacing projects let to contract in April 2005 or thereafter. The treatment sites for this evaluation were drawn from among the projects let to contract after that date.

Most of the sites selected by the State highway agencies were used in this evaluation. A few sites that were distinctly different from the remainder of the study sites were dropped from the evaluation. Based on a preliminary review of the available treated projects in Georgia, Indiana, and New York, the decision was made to focus the analysis on the following three types of roadway segments:

- Rural multilane roadways with paved shoulders with widths of 4 ft or less.
- Rural two-lane roadways with paved shoulders with widths of 4 ft or less.
- Rural two-lane roadways with no paved shoulders (i.e., unpaved shoulders only).

Comparison sites were selected from among projects that were resurfaced in 2005 but did not receive the safety edge treatment. In Georgia, the comparison sites were resurfacing projects that were let to contract prior to April 2005, the date on which the Georgia Department of Transportation began implementing the safety edge treatment in all resurfacing projects. The comparison sites were selected to include the same roadway types as the treatment sites. The comparison sites were located in the same highway districts as the treatment sites so they were in the same geographical area.

Reference sites in each participating State included sites that had not been resurfaced during the period before resurfacing of the treatment and comparison sites and were not expected to be resurfaced during the entire 3-year study period. The reference sites included the same roadway types as the treatment and comparison sites. The total length of reference sites selected in each State was at least the same length as the treated sites in the State and often larger. Reference sites were chosen from the same highway districts as the treatment sites so they were in the same geographical area. Input from district engineers was sought to ensure that the reference sites were similar to the treatment sites. No reference sites were selected in New York because the reference sites were needed only for the before-after EB evaluation and it appeared unlikely that an EB evaluation could be conducted for the limited set of treatment sites available in New York. The New York data were included in other evaluations without the need for reference sites.

Each resurfacing project was divided into smaller roadway segments as needed based on a review of site characteristics and traffic volumes to assure that each site was relatively homogenous with respect to lane width, shoulder type and width, and traffic volume. The project database included 415 sites: 261 in Georgia, 148 in Indiana, and 6 in New York. The individual sites ranged in length from 0.1 to 25.8 mi. The total length of all segments considered in the study was 685 mi in Georgia, 514 mi in Indiana, and 25 mi in New York. Table 1 summarizes the number of sites by State, roadway type, shoulder type, and site type.

Table 1. Summary of number and total length of sites.

State	Roadway type	Shoulder type	Site type	Number of sites	Length (mi)
GA	Multilane	Paved	T	10	18.9
			C	7	12.9
			R	15	23.5
	Two-lane	Paved	T	25	53.0
			C	19	26.9
			R	53	201.9
		Unpaved	T	22	45.2
			C	31	92.8
			R	79	210.1
		Combined		261	685.3
IN	Two-lane	Paved	T	14	25.5
			C	7	21.3
			R	29	101.3
		Unpaved	T	16	58.0
			C	18	71.2
			R	64	237.0
		Combined		148	514.1
NY	Two-lane	Paved	T	3	10.0
			C	3	15.2
		Combined		6	25.2

T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.
R = Reference sites not resurfaced.

Table 1 shows that the project database included 90 treatment sites with a total length of 211 mi, with 57 treatment sites in Georgia, 30 treatment sites in Indiana, and 3 treatment sites in New York. The project database also includes 85 comparison sites with a total length of 240 mi and 240 reference sites with a total length of 774 mi.

2.2 DATA COLLECTION

A substantial amount of data was collected and assembled into a database for consideration in the analysis phase of the study. Data were collected for the period before resurfacing of the treatment and comparison sites and for 3 years after resurfacing. Information concerning data availability, data collection procedures, and contents is presented below for the following data types:

- Project locations and roadway characteristics.
- Crashes.
- Traffic volumes.
- Field measurements of pavement-edge drop-offs.

2.2.1 Project Locations and Roadway Characteristics

For each treatment, comparison, and reference site, the project database included the following data elements: location on the agency's highway system, project construction dates, and basic roadway characteristics. The basic roadway characteristics obtained included road type, lane width, and shoulder type and width. These data were obtained from State highway databases or published reports. All State data were verified and supplemented by field visits to the sites.

Analysis units for the study (i.e., study sites) were created by subdividing resurfacing projects into sections that were generally homogeneous with respect to roadway geometrics. The roadway characteristics used to define the site boundaries were monitored for changes other than resurfacing.

2.2.2 Crashes

The crash database for the study included all non-intersection crashes that occurred within the limits of each site during the study period. Crash data, provided by the participating agencies from their electronic crash record databases, contained sufficient summary information to identify the target crash types most likely to be affected by provision of the safety edge.

Where possible, it was desirable to limit the evaluation to specific target crash types that were most likely affected by the implementation of the safety edge. If the crash data for both the before and after periods included crash types that could not conceivably be affected by the safety edge treatment, then this "noise" could introduce unnecessary variability into the crash counts and mask the safety effect of the treatment. For example, the installation of the safety edge treatment is likely to have a greater effect on run-off-road crashes than on rear-end crashes. By limiting the analysis to include only run-off-road crashes, the likelihood of finding statistically significant effects may be improved. However, the more restrictive the crash type definition used, the smaller the crash counts available for analysis, making it more difficult to find statistically significant effects. Because of this tradeoff between the relevance of the target crash type to the treatment being evaluated and the number of crashes available for analysis, a range of target crash type definitions from more inclusive and less relevant to less inclusive and more relevant was considered.

The selection of the target crash types to be evaluated was guided by two recent studies of crashes related to pavement-edge drop-offs by Council and Hallmark et al.[(1)] These studies identified five scenarios (crash sequences) in which over-steering may result in a crash related to a pavement-edge drop-off. This report assumes that only these types of crashes and no others would be affected by provision of the safety edge.

The five types of crashes used to identify potential drop-off-related crashes are as follows:

- Head-on collision with an oncoming vehicle.
- Sideswipe collision with an oncoming vehicle.
- Run-off-road crash on the opposite side of the road.
- Overturning within the traveled way or on the opposite side of the road.
- Same-direction sideswipe collision on multilane roads.

Head-on crashes may involve a vehicle that crossed the centerline without first running off the road. Such head-on crashes were not classified as drop-off-related nor treated as target crashes.

The target crash types described represent potential drop-off-related crashes, defined as precisely as possible without obtaining and reviewing individual police crash forms. Past research by Council, which included a detailed analysis of hard-copy reports, indicated that a larger percentage of potential crashes were judged as probable or possible drop-off crashes when the officer had noted a shoulder defect. Therefore, if the agency's crash form had an item for "low shoulder" or "shoulder defect," then this item was used to identify potential drop-off-related crashes.

This methodology represents a narrow interpretation of drop-off-related crashes. Therefore, it was also recommended that crashes that showed evidence of a vehicle leaving the road and run-off-road crashes be included, such as the following:

- Run-off-road right, cross centerline/median, hit vehicle traveling in the opposite direction (head-on or sideswipe).
- Run-off-road right, sideswipe with vehicle in same direction (multilane roads).
- Run-off-road right, rollover (in road or on roadside).
- Run-off-road right, then run-off-road left.
- Single vehicle run-off-road right.

Selection of the crash types was based on descriptors in the crash database furnished by the participating States. The data fields used included sequence of events, location of first harmful event, type of collision, driver, and roadway contributing circumstances. The specific fields used to identify drop-off-related crashes in this study for each participating State are described in appendix A.

Crash severity levels considered in the evaluation are as follows:

- Fatal, injury, and property-damage-only (PDO) crashes (i.e., all crash severity levels combined).

- Fatal and injury crashes.
- PDO crashes.

The highest priority in assessment of the safety edge treatment is the evaluation of its effect on fatal and injury crashes because these categories include the most severe crashes among the target crash types of interest. Crashes of all severity levels (i.e., including PDO crashes) were considered because the larger crash sample size made it easier to detect statistically significant effects. It would have been more desirable to consider only PDO crashes that were severe enough for at least one vehicle to be towed from the crash scene since PDO tow-away crashes are more consistently reported than other PDO crashes. However, this exclusion was not applied because only one of the participating States (Indiana) identified tow-away crashes in its data.

Table 2 and table 3 summarize the crash data for total and fatal and injury crashes, respectively, including the breakdown of total, run-off-the-road, and drop-off-related crashes for each State, roadway type, shoulder type, and site type .

Indiana was able to provide only reference-point (i.e., milepost) information and latitude and longitude information for some of the crashes. Additionally, some of the reference-point information provided with the crashes indicated that the crashes occurred on side roads at intersections. Approximately 40 percent of the crashes had wrong or missing reference point or coordinate information but contained a verbal description of the crash. Extensive efforts to better locate these crashes were undertaken during the execution of the work plan.

Table 2. Summary of total non-intersection crash data for study sites.

State	Roadway type	Shoulder type	Site type	Number of sites	Dates for study periods: Before resurfacing	Dates for study periods: After resurfacing	Site length (mi)	Number of crashes during before and after study periods combined[1]: Total crashes	Run-off-road crashes	Drop-off-related crashes
GA	Multilane	Paved	T	10	1999 to 2004	2006 to 2008	18.9	563	162	99
			C	7	1999 to 2004	2006 to 2008	12.9	368	120	81
			R	15	1999 to 2004	2006 to 2008	23.5	927	199	118
	Two-lane	Paved	T	25	1999 to 2004	2006 to 2008	53.0	844	306	186
			C	19	1999 to 2004	2006 to 2008	26.9	475	223	157
			R	53	1999 to 2004	2006 to 2008	201.9	2,489	924	573
		Unpaved	T	22	1999 to 2004	2006 to 2008	45.2	820	335	216
			C	31	1999 to 2004	2006 to 2008	92.8	874	427	289
			R	79	1999 to 2004	2006 to 2008	210.1	2,105	995	631
			Combined	261	1999 to 2004	2006 to 2008	685.3	9,465	3,691	2,350
IN	Two-lane	Paved	T	14	2003 to 2004	2006 to 2008	25.5	250	58	12
			C	7	2003 to 2004	2006 to 2008	21.3	234	55	25
			R	29	2003 to 2004	2006 to 2008	101.3	646	176	59
		Unpaved	T	16	2003 to 2004	2006 to 2008	58.0	169	59	16
			C	18	2003 to 2004	2006 to 2008	71.2	287	145	73
			R	64	2003 to 2004	2006 to 2008	237.0	810	260	96
			Combined	148	2003 to 2004	2006 to 2008	514.1	2,396	753	281
NY	Two-lane	Paved	T	3	1999 to 2004	2006 to 2008	10.0	130	66	3
			C	3	1999 to 2004	2006 to 2008	15.2	218	79	4
			Combined	6	1999 to 2004	2006 to 2008	25.2	348	145	7
Combined				415			1,224.6	12,209	4,589	2,638

[1] Does not include at-intersection or intersection-related crashes.
T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.
R = Reference sites not resurfaced.

Table 3. Summary of fatal and injury non-intersection crash data for study sites.

State	Roadway type	Shoulder type	Site type	Number of sites	Dates for study periods: Before resurfacing	Dates for study periods: After resurfacing	Site length (mi)	Number of fatal and injury crashes during before and after study periods combined[1]: Total crashes	Run-off-road crashes	Drop-off-related crashes
GA	Multilane	Paved	T	10	1999 to 2004	2006 to 2008	18.9	154	64	47
			C	7	1999 to 2004	2006 to 2008	12.9	121	49	37
			R	15	1999 to 2004	2006 to 2008	23.5	366	108	71
	Two-lane	Paved	T	25	1999 to 2004	2006 to 2008	53.0	313	137	99
			C	19	1999 to 2004	2006 to 2008	26.9	229	125	96
			R	53	1999 to 2004	2006 to 2008	201.9	856	437	315
		Unpaved	T	22	1999 to 2004	2006 to 2008	45.2	279	162	120
			C	31	1999 to 2004	2006 to 2008	92.8	374	225	166
			R	79	1999 to 2004	2006 to 2008	210.1	892	512	366
			Combined	261	1999 to 2004	2006 to 2008	685.3	3,584	1,819	1,317
IN	Two-lane	Paved	T	14	2003 to 2004	2006 to 2008	25.5	37	14	3
			C	7	2003 to 2004	2006 to 2008	21.3	57	20	7
			R	29	2003 to 2004	2006 to 2008	101.3	129	73	29
		Unpaved	T	16	2003 to 2004	2006 to 2008	58.0	31	18	5
			C	18	2003 to 2004	2006 to 2008	71.2	83	58	32
			R	64	2003 to 2004	2006 to 2008	237.0	141	91	35
			Combined	148	2003 to 2004	2006 to 2008	514.1	478	274	111
NY	Two-lane	Paved	T	3	1999 to 2004	2006 to 2008	10.0	59	42	3
			C	3	1999 to 2004	2006 to 2008	15.2	75	42	3
			Combined	6	1999 to 2004	2006 to 2008	25.2	134	84	6
Combined				415			1,224.6	4,196	2,177	1,434

[1] Does not include at-intersection or intersection-related crashes.
T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.
R = Reference sites not resurfaced.

2.2.3 Traffic Volumes

Annual average daily traffic (AADT) volume data for all study locations were obtained through agency databases or published sources from each of the participating agencies, so no field traffic counts were required as part of the database development. When possible, separate AADT values for each year of the study period were obtained. When AADT values were not available for all years of the study period, values were interpolated or extrapolated for the missing years.

Table 4 summarizes the traffic volume data assembled for the project database. Ideally, the AADT ranges should be as similar as possible for the various site types within each State/road type/shoulder type combination. In particular, it was desirable for reference sites to cover the entire range of values of the treatment and comparison sites, as SPF performance outside the range of the reference sites is not optimum. It was also desirable that the comparison and reference sites have nearly identical ranges. The AADT ranges were found to be similar for most cases except for multilane highway sites with paved shoulders in Georgia. For these sites, the AADT ranges were higher for treatment sites than for comparison or reference sites. To a lesser extent, the same is true for two-lane highway sites with paved shoulders in Indiana.

Table 4. Summary of traffic volume data for study sites.

State	Roadway type	Shoulder type	Site type	Number of sites	Site length (mi)	AADT (vehicles/day)			
						Minimum	Mean before resurfacing	Mean after resurfacing	Maximum
GA	Multilane	Paved	T	10	18.9	7,639	15,417	14,966	23,825
			C	7	12.9	4,467	9,988	11,148	22,160
			R	15	23.5	6,087	10,060	10,373	22,302
			Combined	32	55.3	4,467	11,874	12,124	23,825
	Two-lane	Paved	T	25	53.0	410	4,046	3,983	13,237
			C	19	26.9	1,453	4,929	6,104	11,247
			R	53	201.9	397	4,118	4,122	18,697
			Combined	97	281.9	397	4,182	4,285	18,697
		Unpaved	T	22	45.2	1,285	3,418	3,601	9,650
			C	31	92.8	413	3,134	2,976	15,000
			R	79	210.1	310	2,996	3,001	9,660
			Combined	132	348.1	310	3,087	3,073	15,000
IN	Two-lane	Paved	T	14	25.5	2,198	6,584	6,561	14,662
			C	7	21.3	3,406	5,067	5,047	7,457
			R	29	101.3	1,170	4,046	4,056	8,958
			Combined	50	148.0	1,170	4,629	4,629	14,662
		Unpaved	T	16	58.0	376	1,444	1,436	3,158
			C	18	71.2	996	1,858	1,845	6,423
			R	64	237.0	478	2,554	2,548	13,615
			Combined	98	366.1	376	2,243	2,235	13,615
NY	Two-lane	Paved	T	3	10.0	1,058	3,601	3,776	5,797
			C	3	15.2	1,110	3,687	3,693	7,047
			Combined	6	25.2	1,058	3,653	3,726	7,047
Combined				415	1,224.6	310	3,682	3,712	23,825

T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.
R = Reference sites not resurfaced.

2.2.4 Lane Width

Lane widths ranged from 9 to 13 ft across all sites and States, with the majority of lanes being 12-ft wide. The distribution of lane width is summarized in table 5 by State and site type. The variability in lane width was most evident for the unpaved shoulder type, so it was decided to include this variable in modeling efforts for these sites.

Table 5. Summary of lane widths for study sites.

State	Road type	Shoulder type	Site type	Number of sites	Site length (mi)	Lane width (ft) Minimum	Mean	Maximum
GA	Multilane	Paved	T	10	18.9	12	12.3	13
			C	7	12.9	12	12.7	13
			R	15	23.5	12	12.3	13
			Combined	32	55.3	12	12.4	13
	Two-lane	Paved	T	25	53.0	11	12.0	13
			C	19	26.9	12	12.6	13
			R	53	201.9	11	12.3	13
			Combined	97	281.9	11	12.3	13
		Unpaved	T	22	45.2	11	11.9	13
			C	31	92.8	10	12.0	13
			R	79	210.1	10	12.2	13
			Combined	132	348.1	10	12.1	13
IN	Two-lane	Paved	T	14	25.5	12	12.0	13
			C	7	21.3	12	12.2	13
			R	29	101.3	9	11.5	13
			Combined	50	148.0	9	11.8	13
		Unpaved	T	16	58.0	10	11.4	13
			C	18	71.2	9	10.2	11
			R	64	237.0	9	11.3	13
			Combined	98	366.1	9	11.1	13
NY	Two-lane	Paved	T	3	10.0	10	10.6	11
			C	3	15.2	9	11.0	12
			Combined	6	25.2	9	10.8	12

T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.
R = Reference sites not resurfaced.

2.2.5 Field Drop-Off Measurements

Field visits were made to each treatment and comparison site to collect pavement-edge drop-off measurements and additional geometric design variables. Field measurements of pavement-edge drop-offs were made before resurfacing and during each of the 3 years after resurfacing. However, some of the project sites were resurfaced before field visits could be made, which prevented supplemental data collection before resurfacing at some sites. Drop-off height was measured 4 inches from the pavement edge for all sites. The types of data collected and the methodology for collecting these data are documented in appendix B.

CHAPTER 3. PRELIMINARY ANALYSIS RESULTS FOR FIELD MEASUREMENTS OF PAVEMENT-EDGE DROP-OFFS

This chapter presents preliminary analysis results for field measurements of pavement-edge drop-offs. Field measurements of drop-off heights were made to evaluate the comparability of existing pavement-edge drop-offs for the treatment and comparison sites in the period before resurfacing and to verify that the safety edge treatment does not encourage the development of pavement-edge drop-offs in the period after resurfacing.

Field data for pavement-edge drop-off heights were collected for each participating agency for both treatment and comparison sites in the period before resurfacing and during each year after resurfacing. The field data collection methodology is presented in appendix B. A few sites were resurfaced before field visits could be made. Consequently, these sites were excluded from the analysis of before-period drop-off height data presented in this chapter.

3.1 COMPARISON OF DROP-OFF MEASUREMENTS FOR TREATMENT AND COMPARISON SITES BEFORE RESURFACING

A formal assessment of the comparability of the treatment and comparison sites with respect to the presence of pavement-edge drop-offs in the period before resurfacing was undertaken. The measure used for this comparison was the proportion of drop-off heights exceeding 2 inches. This criterion was used based on research indicating that pavement-edge drop-off heights exceeding 2 inches may affect safety.[(1)] It should be noted that this previous research was conducted on sites without the safety edge treatment.

It would be desirable if the proportion of sites with pavement-edge drop-off heights exceeding 2 inches were similar for the treatment and comparison sites in the period before resurfacing. An analysis to make this comparison was conducted by performing a logistic regression analysis using the LOGISTIC procedure in SAS®.[(3)] This procedure uses the Fisher scoring method to estimate the statistical significance of differences in proportions between the treatment and comparison sites.

Ideal results for this analysis would have been obtained if the difference between the proportions of drop-off heights exceeding 2 inches for the treatment and comparison sites were not statistically significant at some predetermined significance level. A statistically significant result would be indicated by an odds ratio point estimate that was significantly greater than or less than 1.0 (i.e., the confidence interval for the odds ratio does not contain 1.0). Conversely, for a difference that is not statistically significant, the odds ratio for the difference would contain 1.0. If the odds ratio could not be determined by maximum likelihood due to small sample size or poor variation of responses (i.e., identical responses for each site type or non-overlapping responses between site types), then an exact test was performed and a median unbiased estimate of the odds ratio was provided.

The results of this analysis for each State, roadway type, shoulder type, and treatment type combination, including the frequency and proportion of measurements exceeding 2 inches, the odds ratio point estimate, the odds ratio confidence interval, and the statistical significance of the odds ratio point estimate, are given in table 6. Odds ratio values above 1.0 in this table indicate that comparison sites had a greater probability of experiencing drop-offs exceeding 2 inches than treatment sites.

Table 6. Comparison of the proportions of drop-off heights exceeding 2 inches for the period before resurfacing.

State	Roadway type	Shoulder type	Site type	Drop-off heights that exceed 2 inches		Odds ratio point estimate	Lower confidence limit	Upper confidence limit	Statistically significant at 0.05 level?
				Number	Proportion				
GA	Multilane	Paved	T	2	0.07	0.909	0.184	6.596	No
			C	5	0.06				
	Two-lane	Paved	T	10	0.03	4.591	2.211	10.259	Yes
			C	25	0.14				
		Unpaved	T	23	0.09	1.557	0.876	2.799	No
			C	29	0.13				
IN	Two-lane	Paved	T	6	0.04	2.519	0.902	7.642	No
			C	10	0.10				
		Unpaved	T	150	0.39	0.423	0.291	0.608	Yes
			C	53	0.22				
NY	Two-lane	Paved	T	36	0.38	0.028	0.000	1.620	No[1]
			C	0	0.00				

[1] Indicates that median unbiased estimate was used.
T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.

The results in table 6 indicate that in the period before resurfacing, there were relatively equal proportions of extreme drop-off heights between treatment and comparison sites for Georgia sites on multilane highways with paved shoulders and two-lane highways with unpaved shoulders. This finding indicates that these two types of sites were relatively well matched in terms of shoulder conditions in the period before resurfacing. By contrast, the findings for Georgia sites on two-lane highways with paved shoulders suggest that there was a statistically significant chance that comparison sites had greater proportions of drop-offs exceeding 2 inches.

For Indiana sites on two-lane highways with paved shoulders, there was a greater proportion of extreme drop-off heights for the comparison sites than for the treatment sites in the period before resurfacing, but the difference was not statistically significant. The opposite was the case for Indiana sites on two-lane highways with unpaved shoulders and for New York sites on two-lane highways with paved shoulders. In these cases, the treatment and comparison sites were not perfectly matched in terms of shoulder conditions in the period before resurfacing. For Indiana, this difference was statistically significant. Some differences of this sort may have been inevitable because resurfacing projects that received the safety edge treatment were not selected based on consideration of the existing shoulder condition. This is a potential confounding factor that should be considered in interpreting the research results.

3.2 COMPARISON OF DROP-OFF MEASUREMENTS BETWEEN THE BEFORE AND AFTER RESURFACING PERIODS

The field measurement data for pavement-edge drop-offs were initially reviewed by State, roadway type, shoulder type, and treatment type. Table 7 presents summary descriptive statistics for these measures for each study period. Figure 2 presents histograms for a sample of the distributions and shows the impact of resurfacing for both treatment and comparison sites.

Table 7. Summary of pavement-edge drop-off height measurements.

State	Road type	Shoulder type	Site type	Before resurfacing: Number of measurements	Before resurfacing: Drop-off height (inches) Minimum	Mean	Median	Maximum	Standard deviation	Coefficient of variation %	After resurfacing (Year 1): Number of measurements	After resurfacing (Year 1): Drop-off height (inches) Minimum	Mean	Median	Maximum	Standard deviation	Coefficient of variation %
GA	Multilane	Paved	T	30	0	0.783	0.750	2.000	0.618	79	59	0.375	1.047	0.875	2.875	0.504	48
			C	82	0	0.811	0.750	3.000	0.710	88	86	0.250	1.038	1.000	2.375	0.467	45
	Two-lane	Paved	T	291	0	0.546	0.500	3.750	0.611	112	289	0.000	0.960	1.000	2.375	0.495	52
			C	178	0	0.912	0.750	4.000	0.912	100	150	0.000	0.887	0.875	1.875	0.471	53
		Unpaved	T	270	0	0.881	0.750	3.750	0.695	79	273	0.000	0.941	0.875	2.500	0.495	53
			C	229	0	1.076	1.000	4.750	0.804	75	466	0.000	0.945	0.875	2.875	0.556	59
IN	Two-lane	Paved	T	136	0	0.630	0.500	3.500	0.598	95	158	0.000	0.703	0.625	1.875	0.356	51
			C	96	0	0.960	0.750	3.250	0.708	74	137	0.250	1.340	1.125	4.250	0.707	53
		Unpaved	T	380	0	1.758	1.625	5.125	0.778	44	367	0.250	1.653	1.500	4.500	0.737	45
			C	245	0	1.353	1.250	6.875	0.930	69	279	0.125	1.168	1.000	5.250	0.673	58
NY	Two-lane	Paved	T	94	0	1.681	1.500	5.125	1.270	76	77	0.000	1.110	0.875	4.000	0.886	80
			C	42	0	0.777	0.750	1.750	0.487	63	83	0.000	1.065	1.000	2.750	0.480	45

State	Road type	Shoulder type	Site type	After resurfacing (Year 2): Number of measurements	After resurfacing (Year 2): Drop-off height (inches) Minimum	Mean	Median	Maximum	Standard deviation	Coefficient of variation %	After resurfacing (Year 3): Number of measurements	After resurfacing (Year 3): Drop-off height (inches) Minimum	Mean	Median	Maximum	Standard deviation	Coefficient of variation %
GA	Multilane	Paved	T	65	0.500	1.175	1.000	3.000	0.448	38	65	0.500	1.175	1.000	3.000	0.448	38
			C	86	0.250	0.906	0.813	2.500	0.455	50	86	0.250	0.907	0.875	2.500	0.442	49
	Two-lane	Paved	T	212	0.000	0.956	0.875	2.250	0.455	48	254	0.000	1.087	1.000	3.375	0.432	40
			C	152	0.375	1.166	1.125	2.250	0.356	31	164	0.250	1.104	1.125	2.250	0.372	34
		Unpaved	T	238	0.125	1.179	1.000	3.563	0.571	48	259	0.250	1.107	1.000	3.563	0.566	51
			C	426	0.000	1.163	1.125	3.250	0.548	47	448	0.000	1.119	1.063	3.250	0.526	47
IN	Two-lane	Paved	T	187	0.000	0.788	0.750	2.250	0.379	48	189	0.125	0.780	0.750	2.250	0.398	51
			C	102	0.250	1.456	1.250	4.375	0.857	59	147	0.000	1.344	1.250	3.875	0.609	45
		Unpaved	T	370	0.250	1.916	1.750	6.875	0.993	52	373	0.250	1.584	1.375	4.500	0.774	49
			C	280	0.000	1.353	1.250	5.500	0.764	56	290	0.125	1.236	1.125	4.500	0.676	55
NY	Two-lane	Paved	T	78	0.375	1.786	1.344	5.125	1.191	67	78	0.375	1.786	1.344	5.125	1.191	67
			C	81	0.625	1.446	1.375	3.250	0.497	34	81	0.625	1.446	1.375	3.250	0.497	34

T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.

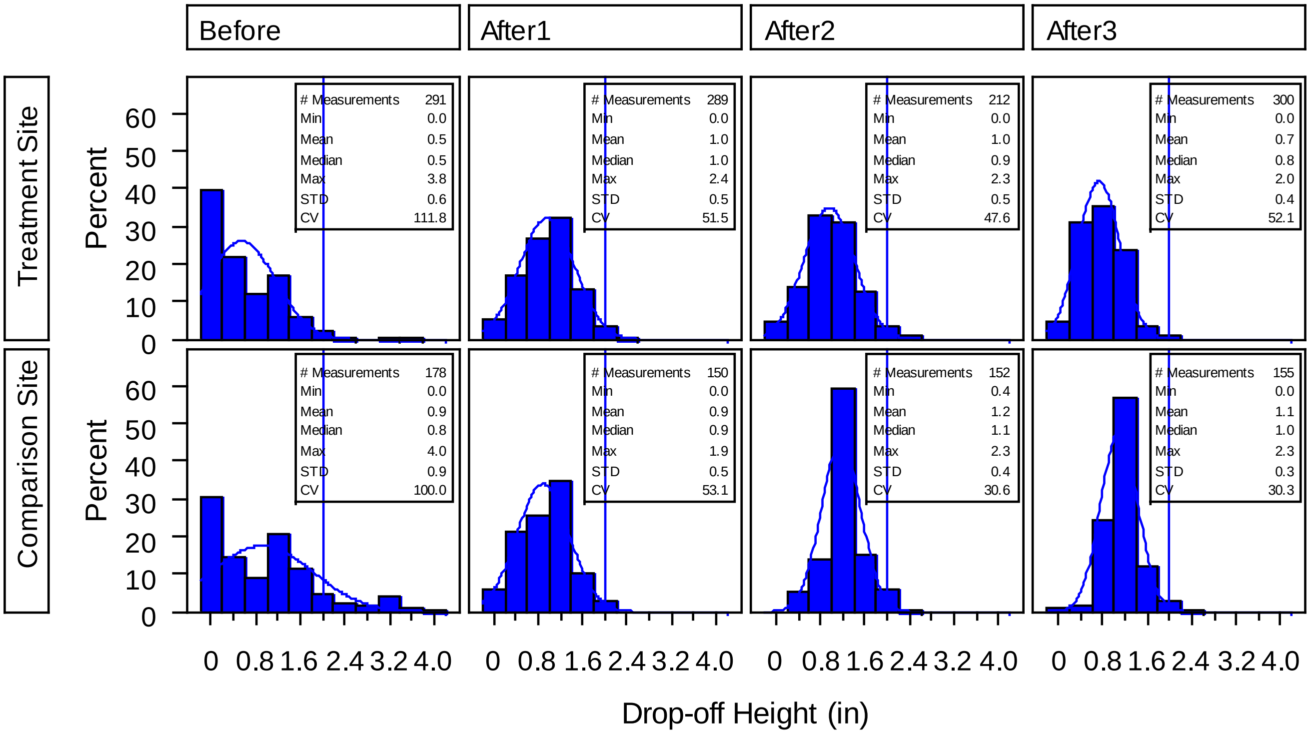


Figure 2. Graph. Drop-off height measurement distributions for two-lane highways with paved shoulders in Georgia.

In each graph shown in figure 2, the vertical blue line marks a 2-inch drop-off height. The mean drop-off height did not vary between the before and after periods. For almost all roadway type/ shoulder type/treatment type combinations, the coefficient of variation (i.e., relative standard deviation) of drop-off height decreased substantially between before resurfacing and each of the first 2 years after resurfacing but increased again following the second year after resurfacing.

To formally assess whether the safety edge treatment has any effect on pavement-edge drop-offs, a trend analysis evaluating the change in drop-offs from before to after resurfacing was conducted. Specifically, the proportion of drop-off height measurements exceeding 2 inches was evaluated to determine if there were differences between the before and after study periods. This analysis was carried out using the same logistic regression approach presented in section 3.1. However, in this case, the proportions of drop-off heights exceeding 2 inches were compared between the periods before and after resurfacing for each type of site rather than between treatment and comparison sites.

The ideal trend for this analysis would be indicated by a substantial decrease in drop-off height for the first year after resurfacing, possibly followed by a slow increasing trend in the later years back to the drop-off height that existed before resurfacing. To evaluate this trend, all pairwise comparisons between years were evaluated for statistical significance. Four of the comparisons: before versus after year 1, after year 1 versus after year 2, after year 2 versus after year 3, and before versus after year 3 have been summarized.

For before versus after year 1, an odds ratio point estimate less than 1.0 indicates that after year 1 had more drop-off heights exceeding 2 inches than the period before resurfacing. A confidence interval for the odds ratio that does not contain the value 1.0 indicates statistical significance.

Since the odds ratios were less than 1.0 in 3 of the 12 cases shown in table 8, the sites in after year 1 generally had fewer drop-off heights exceeding 2 inches than the sites in the period before resurfacing. Also, the three cases when after year 1 had more drop-off heights exceeding 2 inches than the period before resurfacing were not significant. Thus, it appears that resurfacing tends to reduce the proportion of extreme drop-off heights.

Table 8. Comparison of the proportions of drop-off heights exceeding 2 inches between the before and after resurfacing periods.

State	Roadway type	Shoulder type	Site Type	Test	Proportion Period 1	Proportion Period 2	Odds ratio point estimate	Lower 95% confidence limit	Upper 95% confidence limit	Statistically significant at the 0.05 level?
GA	Multilane	Paved	C	Period Before vs AfterY1	0.06	0.06	1.05	0.28	3.92	No
			C	Period Before vs AfterY2	0.06	0.03	1.80	0.43	8.99	No
			C	Period Before vs AfterY3	0.06	0.08	0.73	0.21	2.39	No
			C	Period AfterY1 vs AfterY2	0.06	0.03	0.59	0.12	2.46	No
			C	Period AfterY1 vs AfterY3	0.06	0.08	1.44	0.44	5.03	No
			C	Period AfterY2 vs AfterY3	0.03	0.08	2.45	0.66	11.68	No
			T	Period Before vs AfterY1	0.07	0.07	0.98	0.13	5.35	No
			T	Period Before vs AfterY2	0.07	0.08	0.86	0.12	4.25	No
			T	Period Before vs AfterY3	0.07	0.09	0.70	0.10	3.27	No
			T	Period AfterY1 vs AfterY2	0.07	0.08	1.15	0.29	4.83	No
			T	Period AfterY1 vs AfterY3	0.07	0.09	1.40	0.38	5.72	No
			T	Period AfterY2 vs AfterY3	0.08	0.09	1.22	0.35	4.44	No
	Two-lane	Paved	C	Period Before vs AfterY1	0.14	0	infinity	12.13	infinity	Yes
			C	Period Before vs AfterY2	0.14	0.05	3.38	1.49	8.70	Yes
			C	Period Before vs AfterY3	0.14	0.03	6.17	2.33	21.32	Yes
			C	Period AfterY1 vs AfterY2	0	0.05	infinity	3.24	infinity	Yes
			C	Period AfterY1 vs AfterY3	0	0.03	infinity	1.60	infinity	Yes
			C	Period AfterY2 vs AfterY3	0.05	0.03	0.55	0.14	1.86	No
			T	Period Before vs AfterY1	0.03	0.03	1.11	0.44	2.83	No
			T	Period Before vs AfterY2	0.03	0.02	1.85	0.61	6.82	No
			T	Period Before vs AfterY3	0.03	0	10.64	2.02	195.83	Yes
			T	Period AfterY1 vs AfterY2	0.03	0.02	0.60	0.16	1.86	No
			T	Period AfterY1 vs AfterY3	0.03	0	0.10	0.01	0.56	Yes
			T	Period AfterY2 vs AfterY3	0.02	0	0.17	0.01	1.19	No
		Unpaved	C	Period Before vs AfterY1	0.13	0.06	2.36	1.36	4.10	Yes
			C	Period Before vs AfterY2	0.13	0.1	1.29	0.78	2.12	No
			C	Period Before vs AfterY3	0.13	0.08	1.68	0.99	2.84	No
			C	Period AfterY1 vs AfterY2	0.06	0.1	1.83	1.11	3.04	Yes
			C	Period AfterY1 vs AfterY3	0.06	0.08	1.40	0.83	2.38	No
			C	Period AfterY2 vs AfterY3	0.1	0.08	0.77	0.48	1.23	No
			T	Period Before vs AfterY1	0.09	0.03	2.73	1.28	6.34	Yes
			T	Period Before vs AfterY2	0.09	0.13	0.62	0.35	1.10	No
			T	Period Before vs AfterY3	0.09	0.09	0.99	0.53	1.85	No
			T	Period AfterY1 vs AfterY2	0.03	0.13	4.39	2.13	9.99	Yes
			T	Period AfterY1 vs AfterY3	0.03	0.09	2.76	1.28	6.46	Yes
			T	Period AfterY2 vs AfterY3	0.13	0.09	0.63	0.35	1.12	No

See notes at end of table.

Table 8. Comparison of the proportions of drop-off heights exceeding 2 inches between the before and after resurfacing periods—Continued.

State	Roadway type	Shoulder type	Site Type	Test	Proportion Period 1	Proportion Period 2	Odds ratio point estimate	Lower 95% confidence limit	Upper 95% confidence limit	Statistically significant at the 0.05 level?
IN	Two-lane	Paved	C	Period Before vs AfterY1	0.10	0.17	0.58	0.25	1.24	No
			C	Period Before vs AfterY2	0.10	0.27	0.31	0.13	0.66	Yes
			C	Period Before vs AfterY3	0.10	0.1	0.70	0.30	1.52	No
			C	Period AfterY1 vs AfterY2	0.17	0.27	1.88	1.01	3.53	Yes
			C	Period AfterY1 vs AfterY3	0.17	0.14	0.83	0.43	1.57	No
			C	Period AfterY2 vs AfterY3	0.27	0.14	0.44	0.23	0.83	Yes
			T	Period Before vs AfterY1	0.04	0	infinity	3.18	infinity	Yes
			T	Period Before vs AfterY2	0.04	0.01	8.58	1.44	163.10	Yes
			T	Period Before vs AfterY3	0.04	0.02	2.86	0.74	13.75	No
			T	Period AfterY1 vs AfterY2	0.00	0.01	infinity	0.15	infinity	No
			T	Period AfterY1 vs AfterY3	0.00	0.02	infinity	0.94	infinity	No
			T	Period AfterY2 vs AfterY3	0.01	0.02	3.00	0.38	60.92	No
		Unpaved	C	Period Before vs AfterY1	0.22	0.11	2.21	1.37	3.61	Yes
			C	Period Before vs AfterY2	0.22	0.16	1.48	0.95	2.31	No
			C	Period Before vs AfterY3	0.22	0.14	1.68	1.07	2.64	Yes
			C	Period AfterY1 vs AfterY2	0.11	0.16	1.49	0.91	2.46	No
			C	Period AfterY1 vs AfterY3	0.11	0.14	1.32	0.80	2.18	No
			C	Period AfterY2 vs AfterY3	0.16	0.14	0.88	0.56	1.40	No
			T	Period Before vs AfterY1	0.39	0.28	1.65	1.22	2.24	Yes
			T	Period Before vs AfterY2	0.39	0.42	0.88	0.66	1.18	No
			T	Period Before vs AfterY3	0.39	0.30	1.52	1.12	2.06	Yes
			T	Period AfterY1 vs AfterY2	0.28	0.42	1.86	1.37	2.54	Yes
			T	Period AfterY1 vs AfterY3	0.28	0.30	1.09	0.79	1.49	No
			T	Period AfterY2 vs AfterY3	0.42	0.30	0.58	0.43	0.79	Yes
NY	Two-lane	Paved	C	Period Before vs AfterY1	0	0.02	-infinity	-infinity	3.18	No
			C	Period Before vs AfterY2	0	0.12	-infinity	-infinity	0.37	Yes
			C	Period Before vs AfterY3	0	0.18	-infinity	-infinity	0.23	Yes
			C	Period AfterY1 vs AfterY2	0.02	0.12	5.70	1.44	37.92	Yes
			C	Period AfterY1 vs AfterY3	0.02	0.18	9.07	2.44	58.83	Yes
			C	Period AfterY2 vs AfterY3	0.12	0.18	1.59	0.67	3.89	No
			T	Period Before vs AfterY1	0.38	0.31	2.79	1.39	5.84	Yes
			T	Period Before vs AfterY2	0.38	0.27	1.68	0.88	3.26	No
			T	Period Before vs AfterY3	0.38	0.27	1.72	0.91	3.30	No
			T	Period AfterY1 vs AfterY2	0.18	0.27	1.66	0.78	3.63	No
			T	Period AfterY1 vs AfterY3	0.18	0.27	1.62	0.77	3.52	No
			T	Period AfterY2 vs AfterY3	0.27	0.27	0.98	0.49	1.98	No

T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.

The odds ratio for the treatment sites was less than 1.0 for one out of six cases, indicating that resurfacing with the safety edge treatment is effective in reducing the proportion of extreme drop-off heights. Resurfacing without the safety edge treatment was effective in reducing the proportion of extreme drop-off heights in four of six cases. Additionally, none of the observed odds ratios less than 1.0 and almost all of the observed odds ratios greater than 1.0 were statistically significant.

For after year 1 versus after year 2, an odds ratio point estimate greater than 1.0 indicates that the second year after resurfacing had more drop-off heights exceeding 2 inches than the first year after resurfacing. Since there were more drop-off heights exceeding 2 inches in after year 2 as compared to after year 1 (10 of the 12 cases shown in table 8), there appears to be deterioration of the shoulder condition in the second year after resurfacing. However, only about half of these observed differences in the proportion of drop-off heights exceeding 2 inches were statistically significant at the 5 percent significance level.

For after year 2 versus after year 3, an odds ratio point estimate greater than 1.0 indicates that the third year after resurfacing had more drop-off heights exceeding 2 inches than the second year after resurfacing. Since 7 of the 12 cases shown in table 8 have an odds ratio point estimate of 1.0 (or nearly 1.0), which indicates no change in the proportion of drop-off heights exceeding 2 inches, there appears to be minimal deterioration of the shoulder condition in the third year after resurfacing.

The before period drop-off height data were compared to the after year 3 drop-off height data to determine whether drop-off heights had increased to the levels that existed before resurfacing. For this comparison, an odds ratio point estimate less than 1.0 indicates that after year 3 had more drop-off heights exceeding 2 inches than the period before resurfacing. Since the odds ratios were greater than 1.0 in 7 of the 12 cases shown in table 8, there does not seem to be much evidence to suggest the proportion of high drop-offs after year 3 differs from the before period.

A final comparison of drop-off height data was made between sites resurfaced with and without the safety edge treatment in the third year after resurfacing to determine if the safety edge treatment has any role in development of drop-offs. The results of this analysis are given in table 9. Odds ratio values above 1.0 indicate that comparison sites had more drop-off heights exceeding 2 inches than treatment sites.

Table 9. Comparison of the proportions of drop-off heights exceeding 2 inches between treatment and comparison sites for the final period after resurfacing.

State	Road type	Shoulder type	Site type	Drop-off heights that exceed 2 inches		Odds ratio point estimate	Lower 95% confidence limit	Upper 95% confidence limit	Statistically significant
				Number	Proportion				
GA	Multilane	Paved	C	2	0.02	0.286	0.040	1.374	No
			T	5	0.08				
	Two-lane	Paved	C	6	0.04	1.034	0.341	2.922	No
			T	9	0.04				
		Unpaved	C	38	0.08	0.796	0.476	1.349	No
			T	27	0.1				
IN	Two-lane	Paved	C	21	0.14	10.332	3.470	44.394	Yes
			T	3	0.02				
		Unpaved	C	41	0.14	0.384	0.256	0.567	Yes
			T	112	0.3				
NY	Two-lane	Paved	C	10	0.12	0.382	0.161	0.858	Yes

T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.

The results in table 9 indicate that there were no differences in extreme drop-offs between sites resurfaced with and without the safety edge in Georgia. In Indiana, sites with paved shoulders resurfaced with the safety edge had fewer drop-offs. However, sites with unpaved shoulders showed the reverse trend. In New York, sites resurfaced without the safety edge had fewer proportions of extreme drop-off heights. Taken together, these results are inconclusive.

The analysis of the field measurements of drop-off-heights suggests that resurfacing is effective in reducing the proportion of extreme drop-off heights. It also suggests that resurfacing with the safety edge treatment does not increase the number of extreme drop-off heights and is similar to resurfacing without the safety edge treatment in reducing the proportion of extreme drop-off heights over time.

CHAPTER 4. ANALYSIS RESULTS FOR SAFETY EVALUATION

This chapter presents the safety evaluation approach, the development of SPFs, and the safety evaluation results. The safety evaluation results include the findings of a before-period compatibility study, a before-after evaluation using the EB technique, a cross-sectional analysis, and an analysis of shifts in crash severity.

4.1 EVALUATION APPROACH

Two statistical approaches were used to evaluate the safety effectiveness of the safety edge treatment: (1) a before-after comparison of the effect of pavement resurfacing with and without the safety edge treatment using the EB technique and (2) a cross-sectional comparison of the effect of pavement resurfacing with and without the safety edge treatment based on after-period data only. These two evaluation approaches were applied concurrently to provide alternative statistical approaches to the key issues being addressed. The following discussion describes these evaluations, including issues related to the specific nature of the safety edge treatment.

A key objective of the evaluation was to determine the safety effectiveness of the safety edge treatment while avoiding the potential confounding effects of regression to the mean and the safety effect of pavement resurfacing. *Regression to the mean* is a characteristic of repeated measures data in which observations move toward the mean value over time. That is, if an observation in a year is unusually high, then the observation in the following year will nearly always be lower (and vice versa), returning to the mean. This phenomenon often leads to an overestimation or underestimation of safety for some sites. Thus, the effect of the treatment is likely to be partially confounded with the expected decrease or increase in crash experience from regression to the mean. Regression to the mean can only be accounted for with knowledge of the "normal" or expected value of before-period crash experience at the treated sites. The EB technique has the advantage of compensating for regression to the mean. The cross-sectional approach does not explicitly compensate for regression to the mean. This concern is lessened by the availability of 3 years of crash data for the period after resurfacing.

The second potential confounding effect is the safety effect of pavement resurfacing since it is always used in conjunction with the safety edge treatment. Previous research has indicated that pavement resurfacing by itself may have an effect on safety, increasing crashes because of increased speeds. This effect was found in one study to be statistically significant but was found to persist for only 12–30 months after resurfacing.[4] However, a more recent, larger study in National Cooperative Highway Research Program Project 17-9(2) found inconsistent results; increases in crash frequency with resurfacing were found in some States, but decreases in crash frequency with resurfacing were found in others.[5] Therefore, the safety effects of the pavement resurfacing and installation of the safety edge treatment will be confounded, at least for some time, following resurfacing.

The study design was developed to address the safety effect of resurfacing and the safety edge treatment as well as the confounding effect of resurfacing. First, the study period after resurfacing was selected to be 3 years. This is sufficiently long as to extend beyond the duration of any short-term resurfacing effect. Annual interim evaluations to monitor time trends were conducted to address this issue. Thus, the results for safety effectiveness of the safety edge treatment in the first- and second-year interim reports may be confounded by the safety effect of pavement resurfacing, but it is expected that this confounding effect is lessened in the final results. Second, resurfaced sites both with and without the safety edge treatment were considered. The ratio of safety between resurfaced sites with and without the safety edge treatment (i.e., the treatment and comparison sites) may represent an effect of the safety edge treatment as long as the sites can be assumed comparable in other respects.

The first evaluation approach is an observational before-after comparison using the EB technique, as formulated by Hauer.[6,7] The specific version of the EB technique used in this evaluation was developed for the FHWA SafetyAnalyst software tools.[8] The primary objective of the before-after evaluation is to compare the observed number of crashes after the treatment is implemented to the expected number of crashes in the after period had the countermeasure not been implemented. This provides an estimate of the overall safety effectiveness of the countermeasure expressed as a percent change in the crash frequency.

When performing before-after evaluations using the EB technique, it is typical to collect data at sites where countermeasures were implemented (i.e., treatment sites) and at sites similar to the treatment sites with respect to area type (rural/urban), geometric design, and traffic volumes, but where no countermeasures were installed. Data from this comparison group of sites are used to create SPFs, which are then used with the observed crash counts at the treated sites in the before period to estimate the number of crashes that would have occurred at the treated sites in the after period if no improvement had been made. These SPFs are discussed in section 4.2.

The comparability before resurfacing of the two types of sites (treatment and comparison sites) is critical to interpreting the difference of the two estimated before-after effects as an effect of the safety edge treatment. For example, if one of the site types had a higher mean in the before period and both site types had the same mean in the after period, then the effectiveness of one treatment may be presumed greater than the other treatment. The comparability of sites was established through analysis of the before-period crash data. These analyses are discussed in section 4.3.1.

The EB before-after evaluation produced separate estimates of the effectiveness of resurfacing with the safety edge (treatment sites) and resurfacing only (comparison sites) for each target crash type in each State. From each pair of estimated percent changes in safety (treatment and comparison), the effect of the safety edge alone was estimated as the ratio between the two measures of effectiveness. For every combination of site characteristics under consideration, the mean and standard error of the percent change in target crash frequency and its statistical significance are presented in section 4.3.2.

It was anticipated that the effectiveness measure for the safety edge treatment would be relatively small since it was expected that the safety edge treatment would affect only certain crash types and would have the greatest impact on two-lane highways with no paved shoulders. Most such sites have relatively low traffic volume and therefore are not expected to have a high frequency of run-off-the-road and drop-off-related crashes.

The EB-based before-after comparison technique is theoretically the strongest approach to evaluations of this type. However, because of the confounding of the pavement resurfacing effect and the safety edge treatment effect, it cannot be assured that this approach correctly identifies the treatment effectiveness. Therefore, an alternative cross-sectional comparison was also conducted.

A cross-sectional evaluation of the after data at the treated sites was conducted to directly compare the crash data between the two types of treatment—resurfacing with the safety edge treatment and resurfacing without the safety edge treatment. Assuming that all roadway factors except resurfacing are held constant, one could hypothesize that the differences in either after-period crash frequencies or crash severity distributions between treatment and comparison sites are due to the provision of the safety edge treatment. This comparison was made with a cross-sectional approach using data for the period after resurfacing while accounting for the effects of AADT.

The cross-sectional comparison of crash data for the period after resurfacing was conducted using negative binomial regression models to compare the crash frequencies for the period after resurfacing for the sites with the safety edge treatment to those of the sites resurfaced without the safety edge treatment. Site type (i.e., treatment versus comparison) was the main factor of interest in the analysis. The effect of AADT was accounted for in this approach by quantifying the relationship between AADT and specific target crash types. When significant, the effect of lane width was also accounted for in the model. The safety edge treatment effect and its standard error were then calculated for each target crash type. The treatment effect was converted to a percent change in crash frequency for ease in interpreting the results. The results of the cross-sectional analysis are presented in section 4.4.3.

In addition to evaluating mean crash frequencies, a comparison of the before-after data by crash severity level was performed to determine shifts in the crash severity distribution. These comparisons were accomplished by calculating a confidence interval for the average difference in proportions across all sites at a preselected significance level of 10 percent. However, a non-parametric statistical test, the Wilcoxon signed-rank test, was also applied as the differences in proportions may not follow a normal distribution. Results from this analysis are presented in section 4.4.4.[9]

4.2 SAFETY PERFORMANCE FUNCTIONS

This section documents the SPFs and calibration factors developed for use in the before-after EB evaluation of the safety effectiveness of the safety edge treatment. SPFs are regression relationships between target crash frequencies and traffic volumes that can be used to predict the long-term crash frequency for a site. SPFs are used in the before-after EB evaluation to estimate what the safety performance of a treated site would be in the after period if the treatment had not been implemented.

Negative binomial regression models were developed using data from the reference group of untreated sites for use in three categories of target crashes (all crash types combined, run-off-road crashes, and drop-off-related crashes) and two severity levels (total crashes and fatal and injury crashes). Thus, a total of six dependent variables were considered. Traffic volume and lane width were the only independent variables considered in the SPFs. Separate models were developed for Georgia and Indiana for each of the three classifications, as follows:

- Rural multilane highways with paved shoulders with widths of 4 ft or less.
- Rural two-lane highways with paved shoulders with widths of 4 ft or less.
- Rural two-lane highways with no paved shoulders (i.e., unpaved shoulders only).

Regression models were not developed for New York due to the limited number of treated sites.

All regression models were developed to predict target crash frequencies per mile per year as a function of traffic volume and, in some cases, lane width in the functional forms shown in equation 1 and equation 2.

$$N = \exp(a + b \ln AADT) \quad (1)$$

$$N = \exp(a + b \ln AADT + c\,LW) \quad (2)$$

Where:

N = predicted number of target crashes per mile per year

AADT = average daily traffic volume (vehicles per day) for the roadway segment

LW = lane width for the roadway segment (ft)

a, b, c = regression coefficients

The AADT in the regression models was statistically significant in all cases. The lane width term was included in the regression model only when it was statistically significant.

Two generalized linear modeling techniques were used to fit the data. The first method used a repeated measures correlation structure to model yearly crash counts for a site. In this method, the covariance structure, assuming compound symmetry, is estimated before final regression parameter estimates are determined by general estimating equations. Consequently, model convergence for this method is dependent on the covariance estimates as well as parameter estimates. When the model failed to converge for the covariance estimates, an alternative method was considered. In this method, yearly crash counts for a site were totaled and annual daily traffic (ADT) values were averaged to create one summary record for a site. Regression parameter estimates were then directly estimated by maximum likelihood without an additional covariance structure being estimated.

Both methods produced an estimate of the overdispersion parameter, the estimate for which the variance exceeds the mean. Overdispersion occurs in traffic data when a number of sites being modeled have zero accident counts, which creates variation in the data. When the estimate for dispersion was very small or even slightly negative, the model was refit assuming a constant value. Both methods were accomplished with the GENMOD procedure of SAS®.(3)

Statistically significant models were not found for all dependent variables for some road type/ shoulder type combinations. In these three cases, the intercept coefficient of the total crashes or fatal and injury crashes model was adjusted by the proportion of the applicable dependent variable to produce the final model. The model coefficients with their standard errors are presented in table 10 for Georgia and in table 11 for Indiana. All AADT coefficients shown are significant at the 10 percent significance level or better. Lane width coefficients shown are significant at the 20 percent significance level or better. Total crash and fatal and injury crash SPFs are illustrated in figure 3 for Georgia and in figure 4 for Indiana.

Table 10. SPFs for Georgia sites.

Roadway type	Shoulder type	Number of site-years	Intercept (standard error)	AADT coefficient (standard error)	Lane width coefficient (standard error)	Overdispersion parameter	R^2_{LR} (%)
Total crashes							
Multilane	Paved	192	-4.801 (1.608)	0.642 (0.172)		0.487	9.2
Two-lane	Paved	582	-8.921 (1.189)	1.108 (0.141)		0.724	36.4
Two-lane	Unpaved	792	-7.730 (0.783)	0.978 (0.095)		0.425	25.1
Fatal and injury crashes							
Multilane	Paved	192	-2.204 (1.752)	0.252 (0.184)		0.588	0.2
Two-lane	Paved	582	-7.818 (1.116)	0.853 (0.132)		0.401	21.3
Two-lane	Unpaved	792	-8.556 (0.796)	0.958 (0.098)		0.346	16.0
PDO crashes							
Multilane	Paved	192	-6.611 (1.747)	0.787 (0.189)		0.540	14.0
Two-lane	Paved	582	-11.414 (1.397)	1.349 (0.164)		0.982	34.6
Two-lane	Unpaved	792	-8.470 (0.981)	1.011 (0.119)		0.623	19.3
Total run-off-road crashes							
Multilane	Paved	192	-3.475 (2.145)	0.360 (0.228)		0.213	1.9
Two-lane	Paved	582	-2.625 (1.710)	0.783 (0.134)	-0.376 (0.109)	0.464	19.9
Two-lane	Unpaved	132	-4.405 (1.443)	0.757 (0.141)	-0.199 (0.106)	0.472	14.8
Fatal and injury run-off-road crashes							
Multilane	Paved	192	-3.425(1.752)	0.252 (0.184)		0.588	0.2
Two-lane	Paved	582	-1.848(1.618)	0.544 (0.128)	-0.339 (0.110)	0.374	8.1
Two-lane	Unpaved	132	-5.556(1.543)	0.743 (0.139)	-0.151 (0.115)	0.341	15.8
PDO run-off-road crashes							
Multilane	Paved	192	-7.742(3.004)	0.750 (0.320)		0.117	5.6
Two-lane	Paved	582	-5.029(2.236)	1.033 (0.154)	-0.406 (0.144)	0.598	19.2
Two-lane	Unpaved	132	-4.544(1.709)	0.752 (0.173)	-0.238 (0.126)	0.636	9.7
Total drop-off-related crashes							
Multilane	Paved	192	-3.583(2.126)	0.318 (0.226)		0.131	1.6
Two-lane	Paved	582	-4.586(2.069)	0.884 (0.169)	-0.327 (0.125)	0.585	16.3
Two-lane	Unpaved	132	-4.140(1.495)	0.770 (0.141)	-0.270 (0.114)	0.427	14.0
Fatal and injury drop-off-related crashes							
Multilane	Paved	192	-2.344(1.974)	0.113 (0.141)		0.294	0.1
Two-lane	Paved	582	-3.297(1.894)	0.604 (0.154)	-0.290 (0.121)	0.558	6.2
Two-lane	Unpaved	132	-4.869(1.654)	0.699 (0.148)	-0.209 (0.127)	0.357	11.9
PDO drop-off-related crashes							
Multilane	Paved	192	-6.690(3.194)	0.574 (0.340)		0.101	2.7
Two-lane	Paved	582	-8.291(3.272)	1.269 (0.217)	-0.359 (0.195)	0.754	16.3
Two-lane	Unpaved	792	-4.345(3.899)	0.872 (0.157)	-0.388 (0.290)	0.565	6.6

Note: Blank cells indicate lane width coefficient was not significant.

Table 11. SPFs for Indiana sites.

Road type	Shoulder Type	Number of site-years	Intercept (standard error)	AADT coefficient (standard error)	Lane width coefficient (standard error)	Overdispersion parameter	R^2_{LR} (%)
Total crashes							
Two-lane	Paved	100	-5.500(1.317)	0.737(0.154)		0.444	15.3
Two-lane	Unpaved	98	-3.865(1.118)	0.701(0.146)	-0.156(0.086)	0.654	15.5
Fatal and injury crashes							
Two-lane	Paved	100	-6.279(1.977)	0.642(0.233)		0.563	5.1
Two-lane	Unpaved	196	-2.707(1.305)	0.427(0.139)	-0.198(0.098)	0.211	7.2
PDO crashes							
Two-lane	Paved	100	-5.572(1.373)	0.718(0.161)		0.398	14.8
Two-lane	Unpaved	98	-4.348(1.153)	0.694(0.148)	-0.128(0.089)	0.661	15.9
Total run-off-road crashes							
Two-lane	Paved	100	-3.250(1.962)	0.303(0.231)		0.413	1.5
Two-lane	Unpaved	196	-1.700(1.221)	0.490(0.119)	-0.278(0.103)	0.438	10.9
Fatal and injury run-off-road crashes							
Two-lane	Paved	296	-3.127(1.034)	0.346(0.105)	-0.132(0.078)	0.154	2.5
Two-lane	Unpaved	196	-1.467(1.432)	0.331(0.129)	-0.284(0.102)	0.027	6.4
PDO run-off-road crashes							
Two-lane	Paved	100	-4.764(2.398)	0.426(0.286)		0.212	2.5
Two-lane	Unpaved	196	-2.752(1.260)	0.573(0.133)	-0.279(0.112)	0.540	8.6
Total drop-off-related crashes							
Two-lane	Paved	100	-4.477(3.598)	0.313(0.421)		0.738	0.6
Two-lane	Unpaved	98	-2.352(1.489)	0.356(0.192)	-0.232(0.111)	0.310	1.5
Fatal and injury drop-off-related crashes							
Two-lane	Paved	100	-7.772(1.977)	0.642(0.233)		0.563	5.1
Two-lane	Unpaved	98	-2.943(1.989)	0.227(0.258)	-0.167(0.147)	0.276	0.3
PDO drop-off-related crashes							
Two-lane	Paved	100	-7.464(5.554)	0.597(0.653)		0.623	1.4
Two-lane	Unpaved	98	-3.006(1.593)	0.419(0.209)	-0.266(0.122)	0.069	1.7

Note: Blank cells indicate lane width coefficient was not significant.

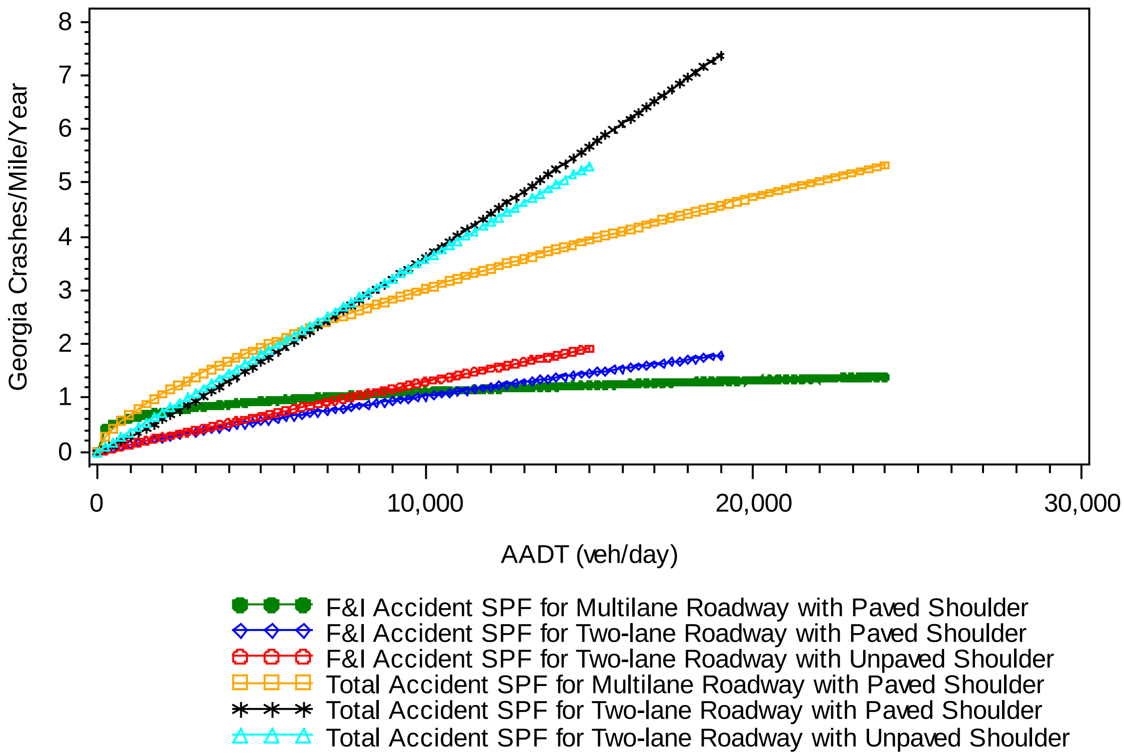


Figure 3. Graph. Comparison of Georgia SPFs by crash severity and roadway and shoulder type.

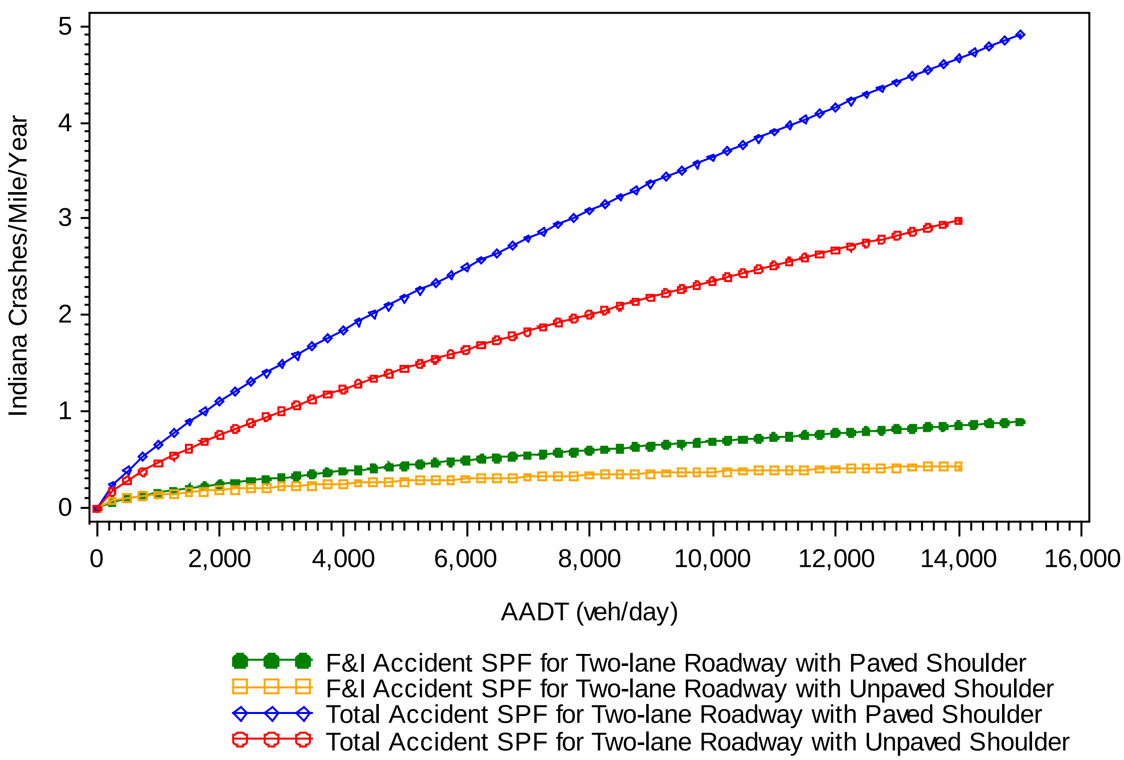


Figure 4. Graph. Comparison of Indiana SPFs by crash severity and roadway and shoulder type.

As noted earlier, the proportion of run-off-road and drop-off-related crashes (developed from reference sites) was sometimes needed to adjust total or fatal and injury SPFs for prediction of those crash types. Table 12 presents these proportions estimated from the reference site data.

Table 12. Run-off-road and drop-off-related crash frequencies as a proportion of total crashes.

State	Roadway type	Shoulder type	Crash severity Level	Proportion of run-off-road crashes	Proportion of drop-off-related crashes
GA	Multilane	Paved	Total	0.215	0.127
			FI	0.295	0.194
			PDO	0.162	0.084
	Two-lane	Paved	Total	0.371	0.230
			FI	0.511	0.368
			PDO	0.298	0.158
		Unpaved	Total	0.473	0.300
			FI	0.574	0.410
			PDO	0.398	0.219
IN	Two-lane	Paved	Total	0.272	0.091
			FI	0.566	0.225
			PDO	0.199	0.058
		Unpaved	Total	0.321	0.119
			FI	0.645	0.248
			PDO	0.253	0.091

FI = Fatal and injury crashes.
PDO = Property-damage-only crashes.

Additionally, yearly calibration factors were developed from the SPFs to provide a better yearly prediction in the methodology. These factors are needed because the SPFs are developed as an average of all years. The yearly calibration factor is determined as the ratio of the sum of observed crashes for all sites for a specific roadway type/shoulder type combination to the sum of the predicted crashes for the same sites using the AADT and crash count values for that year. These factors are presented in table 13 for Georgia and in table 14 for Indiana.

Table 13. Georgia SPF calibration factors.

Roadway type	Shoulder type	Crash severity level	Yearly calibration factors 2001	2002	2003	2004	2005	2006	2007	2008
Total crashes										
Multilane	Paved	Total	0.956	1.023	1.071	0.943	1.078	1.178	0.993	0.983
		FI	0.908	1.091	0.950	1.153	1.168	1.170	0.959	0.942
		PDO	0.998	1.005	1.155	0.849	1.049	1.203	1.031	1.021
Two-lane	Paved	Total	0.856	0.949	0.919	1.044	0.990	1.045	1.025	1.023
		FI	0.926	0.979	0.996	1.114	1.139	1.167	1.115	1.075
		PDO	0.823	0.933	0.873	0.998	0.905	0.977	0.969	0.990
	Unpaved	Total	0.996	0.876	0.884	1.061	1.068	1.112	0.895	1.024
		FI	1.056	0.999	0.840	1.106	1.318	1.202	1.031	1.167
		PDO	0.964	0.804	0.910	1.036	0.922	1.062	0.817	0.943
Run-off-road crashes										
Multilane	Paved	Total	0.958	1.135	1.174	0.891	1.094	0.974	0.962	0.819
		FI	1.167	1.268	1.267	1.267	1.425	1.216	1.048	1.064
		PDO	0.928	1.168	1.241	0.731	0.987	0.917	0.999	0.747
Two-lane	Paved	Total	1.192	1.389	1.131	1.397	1.307	1.542	1.458	1.378
		FI	1.302	1.188	1.226	1.502	1.481	1.688	1.474	1.416
		PDO	1.110	1.581	1.058	1.318	1.168	1.430	1.451	1.355
	Unpaved	Total	1.107	1.064	1.089	1.201	1.335	1.280	1.046	1.183
		FI	1.150	1.167	0.828	1.241	1.405	1.232	1.114	1.265
		PDO	1.003	0.905	1.282	1.095	1.194	1.256	0.923	1.036
Drop-off-related crashes										
Multilane	Paved	Total	1.040	1.102	1.134	1.101	1.034	1.003	1.156	0.774
		FI	0.925	1.320	0.989	1.121	0.989	1.254	1.117	0.860
		PDO	1.156	0.874	1.275	1.075	1.075	0.741	1.188	0.683
Two-lane	Paved	Total	1.203	1.410	1.144	1.385	1.364	1.609	1.491	1.511
		FI	1.290	1.135	1.270	1.449	1.549	1.652	1.543	1.636
		PDO	1.111	1.746	1.001	1.312	1.154	1.564	1.429	1.368
	Unpaved	Total	1.129	1.035	1.133	1.240	1.397	1.409	1.194	1.303
		FI	1.217	1.212	0.818	1.186	1.426	1.409	1.345	1.393
		PDO	0.997	0.794	1.506	1.285	1.335	1.384	0.982	1.165

FI = Fatal and injury crashes.
PDO = Property-damage-only crashes.

Table 14. Indiana SPF calibration factors.

Roadway type	Shoulder type	Crash severity level	Yearly calibration factors					
			2003	2004	2005	2006	2007	2008
Total crashes								
Two-lane	Paved	Total	0.932	0.944	0.579	0.605	0.320	0.384
		FI	0.918	1.006	0.456	0.586	0.343	0.326
		PDO	0.943	0.936	0.616	0.615	0.317	0.402
	Unpaved	Total	1.268	1.011	0.629	0.556	0.365	0.265
		FI	0.914	1.002	0.471	0.472	0.287	0.182
		PDO	1.322	0.968	0.650	0.557	0.373	0.279
Run-off-road crashes								
Two-lane	Paved	Total	1.092	0.936	0.607	0.551	0.304	0.497
		FI	1.266	1.097	0.489	0.651	0.407	0.448
		PDO	1.074	0.911	0.713	0.535	0.268	0.558
	Unpaved	Total	1.002	0.863	0.479	0.363	0.279	0.177
		FI	0.850	1.041	0.503	0.446	0.232	0.154
		PDO	1.068	0.754	0.457	0.313	0.300	0.186
Drop-off-related crashes								
Two-lane	Paved	Total	0.994	0.946	0.646	0.431	0.431	0.690
		FI	0.729	0.722	0.362	0.434	0.290	0.290
		PDO	1.016	0.929	0.777	0.310	0.467	0.934
	Unpaved	Total	1.289	1.038	0.544	0.545	0.520	0.249
		FI	1.265	0.989	0.661	0.441	0.385	0.220
		PDO	1.298	1.066	0.459	0.613	0.610	0.267

FI = Fatal and injury crashes.
PDO = Property-damage-only crashes.

4.3 SAFETY EVALUATIONS

As previously discussed, four types of safety evaluations were performed as part of this study: (1) a safety comparison of treatment and comparison sites in the period before resurfacing; (2) an EB before-after evaluation; (3) a cross-sectional analysis; and (4) an analysis of shifts in the severity distribution from before to after resurfacing. The findings of these evaluations are presented in this section.

4.3.1 Safety Comparison of Treatment and Comparison Sites in the Period Before Resurfacing

An evaluation was conducted to compare the safety performance of treatment and comparison sites before resurfacing for specific States and roadway type/shoulder type combinations. This evaluation is critical to the interpretation of the safety differences between the treatment and comparison sites as an effect of the safety edge treatment. If the safety performance of the two types of sites differed in the period before resurfacing, the comparison of treatment and comparison sites in the period after resurfacing may be influenced.

Initial comparisons were made by examination of scatter plots of crashes and traffic volumes (crashes per mile per year versus lnAADT). Ideal plots would contain no discernable differences between treatment and comparison sites nor any extreme points. Separation of the data points between the two groups may indicate a potential concern in the subsequent analyses. Furthermore, if one group had systematically higher crash frequencies in the period before resurfacing, then the analysis for the period after resurfacing might need to account for this difference. Finally, large variation in crash frequencies for the same AADT values could inhibit crash analysis of the treatment and comparison groups. Inspection of these plots with data from year 3 (see appendix C) showed an improvement in the plots from year 1 and year 2.

Yearly total crash and target crash distributions were also presented in box plots to review data consistency from year to year. Ideal plots would have approximately the same distribution for crashes each year within a given site type and between site types. Additionally, potential concerns for the crash analysis—specifically, a regression to the mean or resurfacing effect— may be identified if the period after resurfacing is included.

Since crash frequencies are known to experience random variation around the mean or regression to the mean, the average over several years for the period before resurfacing should be compared to the average of several years for the period after resurfacing. Therefore, if the after period data are within the range of yearly crash means but numerically higher than the before period average, then safety analyses might show an increase in crash frequency due to the treatment (provided AADT growth was minimal). Conversely, if the after implementation year data are lower than the before period average, then the treatment effect would be a decrease in crash frequency. Examination of these graphs indicated that the after period data were almost always higher than the average of the before years but within the range of variation in yearly crash totals for both types of treated sites.

The apparent increase in crashes was examined to determine if it could be attributed to resurfacing. A resurfacing effect occurs when the reference sites remain the same or decrease in crashes while the treatment and comparison sites both increase. This effect was observed in nearly all of the plots.

One additional potential problem was found in this analysis. One treatment site on a two-lane highway with paved shoulders in Georgia site doubled in crash frequency from the before to the after period. Subsequent investigation found that this site was reconstructed during the second year after resurfacing, and therefore, it was excluded from the safety analysis presented in this report.

Formal crash frequency comparisons of means between the treatment and comparison sites for the period before resurfacing were conducted for each State/roadway type/shoulder type combination and target crash type. Two types of comparisons were made, a comparison of EB-adjusted expected crash frequencies and a comparison of observed crash frequencies. Both comparisons were performed using PROC GENMOD, a generalized linear model procedure available in SAS®, assuming a negative binomial crash distribution.[3] This procedure uses predictive modeling to test the means between the two treatment groups for statistical significance.

The results of these analyses are presented in table 15 and table 16. For the EB-adjusted crash analysis, results are provided only for those roadway type/shoulder type combinations for which SPFs could be developed. However, all target crash types were considered as they can be estimated by the EB technique. Regression coefficients with their standard errors are shown in the tables for each independent variable, including AADT and the treatment versus comparison site effect. The significance and *p*-value for each effect are also presented. Blank rows in the tables represent models that did not converge.

Table 15. Evaluation of treatment versus comparison site effect for the period before resurfacing using EB-adjusted crash frequencies.

State	Roadway type	Shoulder type	Crash type and severity level	Number of site-years	Intercept	AADT effect: Coefficient	AADT effect: Standard error	AADT effect: *p*-value	AADT effect: Statistically significant?[1]	Lane width effect: Coefficient	Lane width effect: Standard error	Lane width effect: *p*-value	Lane width effect: Statistically significant?[1]	Treatment versus comparison site effect: Coefficient	Treatment versus comparison site effect: Standard error	Treatment versus comparison site effect: *p*-value	Treatment versus comparison site effect: Statistically significant?[1]	Dispersion parameter	R^2_{LR}%
GA	Multilane	Paved	TOT	102	-3.965	0.572	0.143	0.001	Yes					-0.497	0.452	0.272	No	0.237	31.4
			FI	102	-2.115	0.239	0.165	0.148	No					-0.391	0.394	0.322	No	0.031	9.4
			PDO	102	-5.926	0.740	0.172	0.001	Yes					-0.531	0.525	0.312	No	0.282	35.3
			rorTOT	102	-5.253	0.559	0.179	0.002	Yes					-0.149	0.191	0.434	No	0.010	5.9
			rorFI	102	-3.843	0.328	0.158	0.038	Yes					-0.293	0.169	0.083	Yes	0.010	22.2
			rorPDO	102	-7.761	0.757	0.189	0.001	Yes					-0.043	0.239	0.856	No	0.010	8.1
			doTOT	102	-4.265	0.430	0.127	0.001	Yes					-0.095	0.132	0.469	No	0.010	21.2
			doFI	102	-3.620	0.285	0.104	0.006	Yes					-0.134	0.106	0.204	No	0.010	24.1
			doPDO	102	-6.240	0.569	0.172	0.001	Yes					-0.060	0.177	0.734	No	0.010	19.1
	Two-lane	Paved	TOT	264	-12.086	1.475	0.089	0.000	Yes					0.154	0.177	0.384	No	0.010	56.9
			FI	264	-11.367	1.306	0.099	0.000	Yes					-0.104	0.129	0.420	No	0.010	33.5
			PDO	264	-13.244	1.534	0.095	0.000	Yes					0.302	0.222	0.175	No	0.010	48.0
			rorTOT	264	-5.358	1.133	0.107	0.000	Yes	-0.361	0.093	0.001	Yes	-0.259	0.141	0.067	Yes	0.010	25.3
			rorFI	264	-4.377	0.973	0.132	0.001	Yes	-0.381	0.070	0.001	Yes	-0.338	0.126	0.007	Yes	0.010	5.2
			rorPDO	264	-7.053	1.173	0.100	0.000	Yes	-0.314	0.128	0.014	Yes	-0.190	0.167	0.255	No	0.010	15.9
			doTOT	264	-7.238	1.221	0.116	0.000	Yes	-0.303	0.067	0.001	Yes	-0.312	0.120	0.009	Yes	0.010	19.0
			doFI	264	-6.870	1.207	0.124	0.000	Yes	-0.366	0.102	0.000	Yes	-0.369	0.158	0.020	Yes	0.010	1.7
			doPDO	264	-10.155	1.290	0.105	0.000	Yes	-0.189	0.107	0.078	Yes	-0.169	0.123	0.171	No	0.010	12.1
		Unpaved	TOT	318	-8.117	1.001	0.098	0.000	Yes					0.611	0.149	0.001	Yes	0.010	61.2
			FI	318	-8.026	0.899	0.102	0.000	Yes					0.237	0.137	0.084	Yes	0.010	39.1
			PDO	318	-9.051	1.031	0.079	0.000	Yes					0.902	0.180	0.001	Yes	0.010	57.8
			rorTOT	318	-7.230	0.819	0.088	0.000	Yes					0.358	0.159	0.024	Yes	0.010	37.3
			rorFI	318	-6.816	0.703	0.077	0.000	Yes					0.179	0.133	0.179	No	0.010	20.6
			rorPDO	318	-8.895	0.909	0.071	0.000	Yes					0.574	0.208	0.006	Yes	0.010	30.0
			doTOT	318	-7.444	0.801	0.084	0.000	Yes					0.271	0.142	0.056	Yes	0.010	29.7
			doFI	318	-6.545	0.636	0.085	0.001	Yes					0.180	0.127	0.157	No	0.010	12.8
			doPDO	318	-10.351	1.026	0.107	0.000	Yes					0.414	0.196	0.035	Yes	0.010	21.4

See notes at end of table.

Table 15. Evaluation of treatment versus comparison site effect for the period before resurfacing using EB-adjusted crash frequencies—Continued.

						AADT effect				Lane width effect				Treatment versus comparison site effect					
State	Roadway type	Shoulder type	Crash type and severity level	Number of site-years	Intercept	Coefficient	Standard error	*p*-value	Statistically significant?[1]	Coefficient	Standard error	*p*-value	Statistically significant?[1]	Coefficient	Standard error	*p*-value	Statistically significant?[1]	Dispersion parameter	R^2_{LR}%
IN	Two-lane	Paved	TOT	42	-10.904	1.409	0.056	0.000	Yes					-0.517	0.307	0.092	Yes	0.150	7.3
			FI	42	-21.302	2.546	0.222	0.000	Yes					-1.076	0.338	0.001	Yes	0.010	9.3
			PDO	42	-2.772	0.422	0.114	0.000	Yes					-0.184	0.405	0.650	No	0.152	4.7
			rorTOT	42	-2.431	0.208	0.283	0.463	No					-0.054	0.208	0.793	No	0.010	23.8
			rorFI	42	-4.735	0.361	0.061	0.001	Yes					-0.073	0.078	0.352	No	0.010	34.0
			rorPDO	42															
			doTOT	42															
			doFI	42	-5.918	0.391	0.059	0.001	Yes					-0.269	0.159	0.090	Yes	0.010	35.2
			doPDO	42															
		Unpaved	TOT	68	-0.578	0.787	0.231	0.001	Yes	-0.506	0.117	0.001	Yes	0.097	0.273	0.723	No	0.137	43.8
			FI	68	-1.688	0.470	0.141	0.001	Yes	-0.312	0.061	0.001	Yes	-0.063	0.165	0.701	No	0.010	15.9
			PDO	68	-1.128	0.932	0.264	0.000	Yes	-0.584	0.141	0.001	Yes	0.172	0.302	0.570	No	0.212	40.4
			rorTOT	68	0.889	0.588	0.208	0.005	Yes	-0.585	0.103	0.001	Yes	-0.045	0.219	0.837	No	0.010	34.6
			rorFI	68	-1.126	0.283	0.035	0.001	Yes	-0.278	0.010	0.000	Yes	-0.039	0.040	0.328	No	0.010	17.1
			rorPDO	68	0.902	0.879	0.321	0.006	Yes	-0.838	0.174	0.001	Yes	-0.015	0.323	0.964	No	0.010	35.7
			doTOT	68	-0.837	0.211	0.106	0.047	Yes	-0.242	0.069	0.000	Yes	-0.433	0.169	0.011	Yes	0.010	5.1
			doFI	68	-1.842	0.139	0.056	0.013	Yes	-0.190	0.036	0.001	Yes	-0.246	0.092	0.008	Yes	0.010	21.4
			doPDO	68	-1.212	0.259	0.161	0.108	Yes	-0.285	0.107	0.008	Yes	-0.565	0.258	0.028	Yes	0.010	3.5

[1] At the 0.20 level.
TOT = total crashes (all severity levels combined).
FI = fatal and injury crashes.
PDO = property–damage-only crashes.
ror = run-off-road crashes.
do = drop-off-related crashes.
Note: Blank cells represent models that did not converge.

Table 16. Evaluation of treatment versus comparison site effect for the period before resurfacing using observed crash frequencies.

State	Roadway type	Shoulder type	Crash type and severity level	Number of site-years	Intercept	AADT effect				Lane width effect				Treatment versus comparison site effect				Dispersion parameter	R^2_{LR}%
						Coefficient	Standard error	*p*-value	Statistically significant?[1]	Coefficient	Standard error	*p*-value	Statistically significant?[1]	Coefficient	Standard error	*p*-value	Statistically significant?[1]		
GA	Multilane	Paved	TOT	102	-9.014	1.128	0.282	0.000	Yes					-0.878	0.505	0.082	Yes	0.378	27.7
			FI	102	-7.293	0.812	0.288	0.005	Yes					-0.826	0.516	0.109	No	0.338	10.1
			PDO	102	-10.881	1.286	0.321	0.000	Yes					-0.885	0.527	0.093	Yes	0.505	27.3
			rorTOT	102	-7.749	0.822	0.268	0.002	Yes					-0.295	0.225	0.188	No	0.015	15.0
			rorFI	102	-7.005	2.654	0.660	0.288	Yes					-0.547	0.259	0.035	Yes	0.010	5.6
			rorPDO	102	-9.207	3.372	0.911	0.353	Yes					-0.119	0.282	0.672	No	0.010	16.2
			doTOT	102	-8.374	2.175	0.844	0.229	Yes					-0.355	0.180	0.048	Yes	0.010	11.9
			doFI	102	-8.785	2.656	0.809	0.287	Yes					-0.442	0.221	0.046	Yes	0.010	5.0
			doPDO	102	-9.387	3.466	0.884	0.364	Yes					-0.304	0.272	0.264	No	0.010	7.6
	Two-lane	Paved	TOT	264	-8.045	0.982	0.130	0.000	Yes					0.222	0.176	0.207	No	0.247	35.7
			FI	264	-7.646	0.852	0.143	0.000	Yes					-0.121	0.152	0.426	No	0.018	21.3
			PDO	264	-10.106	1.147	0.139	0.000	Yes					0.447	0.200	0.025	Yes	0.436	30.8
			rorTOT	264	-3.346	0.666	0.121	0.000	Yes	-0.220	0.161	0.172	Yes	-0.231	0.206	0.261	No	0.166	13.9
			rorFI	264	-1.188	0.465	0.156	0.003	Yes	-0.303	0.161	0.059	Yes	-0.593	0.229	0.010	Yes	0.073	7.2
			rorPDO	264	-8.299	0.834	0.118	0.000	Yes					0.110	0.203	0.587	No	0.360	10.8
			doTOT	264	-6.541	0.673	0.173	0.000	Yes					-0.297	0.173	0.086	Yes	0.177	10.3
			doFI	264	-1.063	0.414	0.202	0.040	Yes	-0.300	0.170	0.077	Yes	-0.752	0.249	0.003	Yes	0.173	5.7
			doPDO	264	-10.600	1.038	0.204	0.000	Yes					-0.016	0.223	0.942	No	0.156	9.9
		Unpaved	TOT	318	-8.615	1.059	0.104	0.000	Yes					0.610	0.174	0.000	Yes	0.389	35.9
			FI	318	-8.473	0.940	0.097	0.000	Yes					0.258	0.177	0.143	No	0.318	21.3
			PDO	318	-9.950	1.148	0.119	0.000	Yes					0.864	0.197	0.000	Yes	0.419	34.3
			rorTOT	318	-7.022	0.774	0.106	0.000	Yes					0.441	0.194	0.023	Yes	0.309	19.4
			rorFI	318	-7.358	0.740	0.109	0.000	Yes					0.226	0.220	0.304	No	0.487	9.7
			rorPDO	318	-8.611	0.874	0.150	0.000	Yes					0.653	0.228	0.004	Yes	0.385	16.8
			doTOT	318	-7.106	0.736	0.132	0.000	Yes					0.397	0.212	0.061	Yes	0.247	15.6
			doFI	318	-6.937	0.645	0.139	0.000	Yes					0.270	0.245	0.272	No	0.548	6.9
			doPDO	318	-9.469	0.922	0.188	0.000	Yes					0.554	0.252	0.028	Yes	0.361	12.5

See notes at end of table.

Table 16. Evaluation of treatment versus comparison site effect for the period before resurfacing using observed crash frequencies—Continued.

State	Roadway type	Shoulder type	Crash type and severity level	Number of site-years	Intercept	AADT effect				Lane width effect				Treatment versus comparison site effect				Dispersion parameter	R^2_{LR}%
						Coefficient	Standard error	*p*-value	Statistically significant?[1]	Coefficient	Standard error	*p*-value	Statistically significant?[1]	Coefficient	Standard error	*p*-value	Statistically significant?[1]		
IN	Two-lane	Paved	TOT	42	-3.824	0.588	0.250	0.019	Yes					-0.380	0.364	0.296	No	0.416	6.6
			FI	42	-7.523	0.850	0.606	0.161	No					-0.842	0.533	0.114	No	0.629	7.9
			PDO	42	-3.076	0.465	0.235	0.048	Yes					-0.205	0.356	0.565	No	0.369	4.1
			rorTOT	42	-6.756	0.736	0.546	0.178	No					-0.468	0.396	0.237	No	0.446	5.1
			rorFI	42	-2.953	4.414	0.188	0.515	No					-0.830	0.457	0.069	Yes	0.010	6.0
			rorPDO	42	-8.070	0.815	0.589	0.167	No					-0.092	0.432	0.831	No	0.461	5.0
			doTOT	42	-13.860	1.420	1.212	0.241	No					-0.996	0.503	0.048	Yes	0.478	6.0
			doFI	42															0.0
			doPDO	42	-23.901	2.478	0.959	0.010	Yes					-0.477	0.529	0.368	No	0.010	11.9
		Unpaved	TOT	68	-0.761	0.918	0.248	0.000	Yes	-0.587	0.140	0.000	Yes	0.188	0.297	0.525	No	0.435	35.8
			FI	68	-0.041	0.732	0.347	0.035	Yes	-0.640	0.225	0.005	Yes	-0.050	0.347	0.884	No	0.093	23.4
			PDO	68	-1.612	0.998	0.270	0.000	Yes	-0.594	0.155	0.000	Yes	0.269	0.304	0.377	No	0.527	31.5
			rorTOT	68	1.418	0.806	0.316	0.011	Yes	-0.783	0.200	0.000	Yes	-0.068	0.331	0.838	No	0.221	34.7
			rorFI	68	1.478	3.119	0.435	0.358	No	-0.608	0.212	0.004	Yes	-0.268	0.340	0.431	No	0.010	18.7
			rorPDO	68	0.475	1.120	0.398	0.005	Yes	-0.974	0.313	0.002	Yes	0.091	0.365	0.804	No	0.377	29.2
			doTOT	68	1.029	0.101	0.386	0.794	No	-0.312	0.246	0.204	No	-1.107	0.596	0.063	Yes	0.010	21.7
			doFI	68															0.0
			doPDO	68	-4.194	0.270	0.560	0.630	No					-1.090	0.699	0.119	No	0.584	6.4
NY	Two-lane	Paved	TOT	36	-5.328	0.674	0.085	0.000	Yes					0.127	0.182	0.484	No	0.486	24.9
			FI	36	-6.943	0.766	0.113	0.000	Yes					0.308	0.172	0.074	Yes	0.674	19.3
			PDO	36	-5.467	0.625	0.083	0.000	Yes					-0.030	0.204	0.884	No	0.813	15.7
			rorTOT	36	-4.846	0.480	0.085	0.000	Yes					0.577	0.140	0.000	Yes	0.243	19.6
			rorFI	36	-5.333	0.486	0.122	0.000	Yes					0.643	0.175	0.000	Yes	0.410	14.4
			rorPDO	36	-5.784	0.372	0.467	0.048	Yes					0.475	0.105	0.000	Yes	0.010	13.0
			doTOT	36															
			doFI	36															
			doPDO	36															

[1] At the 0.20 significance level.
TOT = total crashes (all severity levels combined).
FI = fatal and injury crashes.
PDO = property–damage-only crashes.
ror = run-off-road crashes.
do = drop-off-related crashes.
Note: Blank cells indicate models that did not converge.

Results from the analysis of EB-adjusted crash frequencies in table 15 show that there tended to be significant differences between treatment and comparison site crash frequencies for Georgia sites with unpaved shoulders in the period before resurfacing. Comparison sites that had unpaved shoulders had lower crash rates than treatment sites. There is also evidence of differences in drop-off-related and run-off-road crashes for Georgia paved shoulder locations. Similarly, Indiana unpaved shoulder locations differed for drop-off-related crashes. These locations had treatment sites with lower crash rates.

Results from the analysis of observed crash frequencies somewhat confirmed the results of the EB-adjusted crashes. However, there tended to be fewer significant results and poorer fit of the models in general. This was to be expected because EB-adjusted crashes are smoothed by the SPF model predictions, causing smaller differences and less variation and leading to more significant results. Differences between treatment and comparison sites were confirmed for Georgia unpaved shoulder locations and drop-off-related crashes for paved shoulder locations. Additionally, New York locations, which were not tested by EB-adjusted crashes, showed differences for run-off-road crashes. All other significant differences were associated with poor models.

It was also desirable to confirm the existence of a cause-and-effect chain leading from the frequency and height of pavement-edge drop-offs to the likelihood of crashes. The drop-off height analysis reported in chapter 3 indicated that two-lane highway sites with unpaved shoulders and the multilane highway sites in Georgia did not have significant differences in the proportion of high drop-offs and therefore should have non-significant differences in crash frequency in the period before resurfacing. This expectation was not entirely supported by crash analysis results. However, for cases in which there were significant differences, these differences were in the same direction indicated in the drop-off analysis. That is, if drop-offs were more prevalent, then the sites had more crashes. Similarly, two-lane highway sites with paved shoulders in Georgia had comparison sites with a significantly higher probability of high drop-offs, and the crash analysis showed the comparison sites had more crashes, although the result was not significant.

Results for Indiana sites on two-lane highways with paved shoulders were consistent with the analysis of drop-off measurements, but the results for Indiana sites on two-lane highways with unpaved shoulders were not consistent with the analysis of drop-off measurements.

Overall, the treatment and comparison sites showed similar crash frequencies for paved shoulder sites in the period before resurfacing. By contrast, there were some statistically significant differences in crash frequencies between treatment and comparison sites for unpaved shoulders during the period before resurfacing. It should be noted that only 2 years of crash data were available for the period before resurfacing in Indiana, in comparison to 6 years for the period before resurfacing in Georgia. Thus, the variability of the Indiana crash frequencies was expected to be higher. In most cases (with the single exception previously noted), the differences in crash frequencies between treatment and comparison sites were similar to the differences in proportions of extreme drop-off heights for the period before resurfacing.

4.3.2 Before-After Evaluation Using the EB Technique

An observational before-after evaluation was conducted using the EB technique to estimate the safety effectiveness of the safety edge treatment. Separate before-after evaluations were conducted for resurfacing projects with the safety edge (treatment sites) and resurfacing projects without the safety edge (comparison sites). The ratio of these results was used to estimate the effect of the safety edge treatment.

All crash severity levels for total crashes, run-off-road crashes, and drop-off-related crashes were evaluated. The study period before resurfacing for these evaluations was the 4-year period from 2001 to 2004. The study period after resurfacing was the 3-year period from 2006 to 2008. The entire year in which resurfacing was performed, 2005, was excluded from the evaluation. The rationale for excluding crashes during the construction year is that it takes time for drivers to adjust to new driving conditions, and so the transition period is not necessarily representative of the long-term safety performance of the site. All of the crash data used in the evaluation were for complete calendar years so that there would be no opportunity for seasonal biases to affect the results.

The EB procedure was programmed and executed in SAS®.[3] Effectiveness estimates and their precision estimates, along with their statistical significance, are presented for specific crash types in table 17 through table 25.

Table 17. Before-after EB evaluation results for total crashes.

						Change in crash frequency from before to after resurfacing			Statistically significant?		Safety edge effect				
State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Percent change	Direction	Standard error (%)	5% level	10% level	Effect (%)	Direction	Standard error (%)	5% level	10% level
GA	Two-lane	Paved	T	25	1.804	13.123	Increase	7.276	No	Yes	7.732	Decrease	9.596	No	No
			C	19	2.262	22.602	Increase	9.993	Yes	Yes					
		Unpaved	T	22	2.246	-13.562	Decrease	6.038	Yes	Yes	11.361	Decrease	8.467	No	No
			C	31	0.389	-2.483	Decrease	6.376	No	No					
		Combined	T	47	0.143	-0.670	Decrease	4.697	No	No	6.817	Decrease	6.459	No	No
			C	50	1.217	6.597	Increase	5.421	No	No					
IN	Two-lane	Paved	T	14	0.047	0.567	Increase	12.167	No	No	15.524	Decrease	14.422	No	No
			C	7	1.333	19.048	Increase	14.293	No	No					
		Unpaved	T	16	1.524	29.925	Increase	19.639	No	No	-26.942	Increase	24.027	No	No
			C	18	0.201	2.350	Increase	11.691	No	No					
		Combined	T	30	1.000	10.456	Increase	10.454	No	No	-0.235	Increase	12.622	No	No
			C	25	1.120	10.197	Increase	9.104	No	No					
GA & IN	Two-lane	Paved	T	39	1.601	10.027	Increase	6.262	No	No	9.485	Decrease	8.009	No	No
			C	26	2.628	21.556	Increase	8.203	Yes	Yes					
		Unpaved	T	38	1.311	-7.657	Decrease	5.842	No	No	6.516	Decrease	7.910	No	No
			C	49	0.218	-1.221	Decrease	5.604	No	No					
		Combined	T	77	0.360	1.546	Increase	4.293	No	No	5.674	Decrease	5.737	No	No
			C	75	1.642	7.654	Increase	4.662	No	No					

T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.

Table 18. Before-after EB evaluation results for fatal and injury crashes.

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing			Statistically significant?		Safety edge effect				
						Percent change	Direction	Standard error (%)	5% level	10% level	Effect (%)	Direction	Standard error (%)	5% level	10% level
GA	Two-lane	Paved	T	25	1.592	19.899	Increase	12.499	No	No	10.959	Decrease	13.779	No	No
			C	19	2.244	34.656	Increase	15.446	Yes	Yes					
		Unpaved	T	22	0.232	2.761	Increase	11.887	No	No	-15.555	Increase	17.687	No	No
			C	31	1.243	-11.072	Decrease	8.907	No	No					
		Combined	T	47	1.346	11.647	Increase	8.651	No	No	-5.982	Increase	11.462	No	No
			C	50	0.676	5.345	Increase	7.905	No	No					
IN	Two-lane	Paved	T	14	0.736	-18.579	Decrease	25.239	No	No	44.993	Decrease	21.492	Yes	Yes
			C	7	1.359	48.020	Increase	35.335	No	No					
		Unpaved	T	16	1.340	-35.945	Decrease	26.829	No	No	43.548	Decrease	26.137	No	No
			C	18	0.598	13.469	Increase	22.521	No	No					
		Combined	T	30	1.339	-24.947	Decrease	18.633	No	No	40.939	Decrease	17.167	Yes	Yes
			C	25	1.403	27.078	Increase	19.294	No	No					
GA & IN	Two-lane	Paved	T	39	1.295	14.685	Increase	11.337	No	No	16.528	Decrease	11.919	No	No
			C	26	2.633	37.393	Increase	14.199	Yes	Yes					
		Unpaved	T	38	0.087	-0.961	Decrease	11.012	No	No	-6.361	Increase	15.147	No	No
			C	49	0.827	-6.884	Decrease	8.328	No	No					
		Combined	T	77	0.924	7.328	Increase	7.93	No	No	1.667	Decrease	9.780	No	No
			C	75	1.246	9.148	Increase	7.341	No	No					

T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.

Table 19. Before-after EB evaluation results for PDO crashes.

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing			Statistically significant?		Safety edge effect				
						Percent change	Direction	Standard error (%)	5% level	10% level	Effect (%)	Direction	Standard error (%)	5% level	10% level
GA	Two-lane	Paved	T	25	0.975	9.276	Increase	9.511	No	No	2.554	Decrease	15.183	No	No
			C	19	0.837	12.140	Increase	14.502	No	No					
		Unpaved	T	22	2.886	-20.980	Decrease	7.271	Yes	Yes	24.281	Decrease	10.078	Yes	Yes
			C	31	0.437	4.359	Increase	9.963	No	No					
		Combined	T	47	1.150	-6.764	Decrease	5.881	No	No	13.201	Decrease	8.607	No	No
			C	50	0.899	7.416	Increase	8.249	No	No					
IN	Two-lane	Paved	T	14	0.287	4.045	Increase	14.108	No	No	6.579	Decrease	18.450	No	No
			C	7	0.710	11.372	Increase	16.024	No	No					
		Unpaved	T	16	1.898	47.501	Increase	25.033	No	Yes	-50.902	Increase	33.486	No	No
			C	18	0.160	-2.254	Decrease	14.046	No	No					
		Combined	T	30	1.449	18.175	Increase	12.540	No	No	-12.894	Increase	16.531	No	No
			C	25	0.440	4.678	Increase	10.631	No	No					
GA & IN	Two-lane	Paved	T	39	0.995	7.860	Increase	7.901	No	No	3.845	Decrease	11.632	No	No
			C	26	1.127	12.173	Increase	10.803	No	No					
		Unpaved	T	38	1.469	-10.599	Decrease	7.215	No	No	12.795	Decrease	9.898	No	No
			C	49	0.309	2.518	Increase	8.150	No	No					
		Combined	T	77	0.185	-0.995	Decrease	5.364	No	No	7.100	Decrease	7.601	No	No
			C	75	1.007	6.572	Increase	6.529	No	No					

T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.

Table 20. Before-after EB evaluation results for total run-off-road crashes.

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing			Statistically significant?		Safety edge effect				
						Percent change	Direction	Standard error (%)	5% level	10% level	Effect (%)	Direction	Standard error (%)	5% level	10% level
GA	Two-lane	Paved	T	25	3.375	27.777	Increase	8.230	Yes	Yes	13.721	Decrease	9.010	No	No
			C	19	3.956	48.097	Increase	12.158	Yes	Yes					
		Unpaved	T	22	0.102	0.718	Increase	7.049	No	No	9.080	Decrease	8.652	No	No
			C	31	1.487	10.777	Increase	7.248	No	No					
		Combined	T	47	2.594	14.006	Increase	5.400	Yes	Yes	7.872	Decrease	6.406	No	No
			C	50	3.766	23.747	Increase	6.306	Yes	Yes					
IN	Two-lane	Paved	T	14	3.152	63.675	Increase	20.201	Yes	Yes	8.183	Decrease	15.844	No	No
			C	7	3.639	78.263	Increase	21.505	Yes	Yes					
		Unpaved	T	16	3.408	105.593	Increase	30.982	Yes	Yes	-46.895	Increase	27.796	No	Yes
			C	18	2.502	39.959	Increase	15.968	Yes	Yes					
		Combined	T	30	4.573	78.116	Increase	17.083	Yes	Yes	-13.484	Increase	14.389	No	No
			C	25	4.391	56.952	Increase	12.969	Yes	Yes					
GA & IN	Two-lane	Paved	T	39	4.522	34.710	Increase	7.675	Yes	Yes	14.177	Decrease	7.593	No	Yes
			C	26	5.351	56.962	Increase	10.645	Yes	Yes					
		Unpaved	T	38	1.631	11.534	Increase	7.071	No	No	4.786	Decrease	8.094	No	No
			C	49	2.581	17.140	Increase	6.640	Yes	Yes					
		Combined	T	77	4.496	23.514	Increase	5.230	Yes	Yes	6.315	Decrease	5.654	No	No
			C	75	5.576	31.840	Increase	5.710	Yes	Yes					

T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.

Table 21. Before-after EB evaluation results for fatal and injury run-off-road crashes.

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing: Percent change	Direction	Standard error (%)	Statistically significant?: 5% level	10% level	Safety edge effect: Effect (%)	Direction	Standard error (%)	5% level	10% level
GA	Two-lane	Paved	T	25	3.036	46.712	Increase	15.384	Yes	Yes	19.175	Decrease	12.659	No	No
			C	19	3.856	81.517	Increase	21.142	Yes	Yes					
		Unpaved	T	22	1.891	28.134	Increase	14.877	No	Yes	-18.058	Increase	18.139	No	No
			C	31	0.784	8.535	Increase	10.892	No	No					
		Combined	T	47	3.529	37.878	Increase	10.733	Yes	Yes	-3.609	Increase	11.192	No	No
			C	50	3.295	33.075	Increase	10.037	Yes	Yes					
IN	Two-lane	Paved	T	14	0.086	-2.553	Decrease	29.761	No	No	46.332	Decrease	20.632	Yes	Yes
			C	7	1.931	81.574	Increase	42.252	No	Yes					
		Unpaved	T	16	0.140	6.109	Increase	43.637	No	No	-12.464	Increase	51.101	No	No
			C	18	0.309	-5.651	Decrease	18.313	No	No					
		Combined	T	30	0.018	0.440	Increase	24.694	No	No	16.402	Decrease	23.965	No	No
			C	25	1.137	20.146	Increase	17.714	No	No					
GA & IN	Two-lane	Paved	T	39	2.877	39.851	Increase	13.853	Yes	Yes	23.123	Decrease	11.053	Yes	Yes
			C	26	4.323	81.916	Increase	18.950	Yes	Yes					
		Unpaved	T	38	1.877	26.499	Increase	14.120	No	Yes	-20.037	Increase	17.137	No	No
			C	49	0.573	5.383	Increase	9.388	No	No					
		Combined	T	77	3.407	33.764	Increase	9.911	Yes	Yes	-2.622	Increase	10.228	No	No
			C	75	3.469	30.346	Increase	8.748	Yes	Yes					

T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.

Table 22. Before-after EB evaluation results for PDO run-off-road crashes.

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing			Statistically significant?		Safety edge effect				
						Percent change	Direction	Standard error (%)	5% level	10% level	Effect (%)	Direction	Standard error (%)	5% level	10% level
GA	Two-lane	Paved	T	25	1.821	18.575	Increase	10.200	No	Yes	5.160	Decrease	14.498	No	No
			C	19	1.587	25.026	Increase	15.770	No	No					
		Unpaved	T	22	1.286	-10.527	Decrease	8.185	No	No	20.225	Decrease	10.451	No	Yes
			C	31	1.158	12.156	Increase	10.494	No	No					
		Combined	T	47	0.535	3.462	Increase	6.472	No	No	11.524	Decrease	8.673	No	No
			C	50	1.929	16.938	Increase	8.779	No	Yes					
IN	Two-lane	Paved	T	14	3.154	82.392	Increase	26.120	Yes	Yes	-3.538	Increase	21.327	No	No
			C	7	2.922	76.160	Increase	26.061	Yes	Yes					
		Unpaved	T	16	3.396	131.099	Increase	38.606	Yes	Yes	-31.229	Increase	30.365	No	No
			C	18	2.699	76.104	Increase	28.193	Yes	Yes					
		Combined	T	30	4.549	99.719	Increase	21.920	Yes	Yes	-12.878	Increase	17.414	No	No
			C	25	3.999	76.934	Increase	19.240	Yes	Yes					
GA & IN	Two-lane	Paved	T	39	3.323	32.288	Increase	9.718	Yes	Yes	7.374	Decrease	11.235	No	No
			C	26	3.108	42.820	Increase	13.778	Yes	Yes					
		Unpaved	T	38	0.657	5.574	Increase	8.485	No	No	16.029	Decrease	9.550	No	No
			C	49	2.548	25.727	Increase	10.096	Yes	Yes					
		Combined	T	77	2.976	19.201	Increase	6.452	Yes	Yes	10.162	Decrease	7.404	No	No
			C	75	3.995	32.684	Increase	8.181	Yes	Yes					

T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.

Table 23. Before-after EB evaluation results for total drop-off-related crashes.

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing			Statistically significant?		Safety edge effect				
						Percent change	Direction	Standard error (%)	5% level	10% level	Effect (%)	Direction	Standard error (%)	5% level	10% level
GA	Two-lane	Paved	T	25	3.817	32.758	Increase	8.582	Yes	Yes	10.293	Decrease	9.405	No	No
			C	19	3.930	47.991	Increase	12.210	Yes	Yes					
		Unpaved	T	22	0.591	4.334	Increase	7.328	No	No	9.130	Decrease	8.698	No	No
			C	31	1.970	14.817	Increase	7.522	No	Yes					
		Combined	T	47	3.250	18.272	Increase	5.623	Yes	Yes	6.603	Decrease	6.522	No	No
			C	50	4.115	26.633	Increase	6.472	Yes	Yes					
IN	Two-lane	Paved	T	14	3.681	86.217	Increase	23.425	Yes	Yes	8.759	Decrease	15.949	No	No
			C	7	4.202	104.093	Increase	24.772	Yes	Yes					
		Unpaved	T	16	4.374	193.003	Increase	44.122	Yes	Yes	-79.564	Increase	34.036	Yes	Yes
			C	18	3.357	63.175	Increase	18.820	Yes	Yes					
		Combined	T	30	5.509	117.38	Increase	21.305	Yes	Yes	-19.733	Increase	15.389	No	No
			C	25	5.386	81.554	Increase	15.141	Yes	Yes					
GA & IN	Two-lane	Paved	T	39	5.191	42.320	Increase	8.153	Yes	Yes	12.586	Decrease	7.803	No	No
			C	26	5.657	62.812	Increase	11.104	Yes	Yes					
		Unpaved	T	38	2.489	18.854	Increase	7.574	Yes	Yes	4.455	Decrease	8.189	No	No
			C	49	3.450	24.396	Increase	7.070	Yes	Yes					
		Combined	T	77	5.564	31.039	Increase	5.578	Yes	Yes	5.587	Decrease	5.739	No	No
			C	75	6.428	38.794	Increase	6.035	Yes	Yes					

T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.

Table 24. Before-after EB evaluation results for fatal and injury drop-off-related crashes.

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing: Percent change	Change in crash frequency: Direction	Change in crash frequency: Standard error (%)	Statistically significant? 5% level	Statistically significant? 10% level	Safety edge effect: Effect (%)	Safety edge effect: Direction	Safety edge effect: Standard error (%)	Safety edge effect: 5% level	Safety edge effect: 10% level
GA	Two-lane	Paved	T	25	3.082	48.356	Increase	15.691	Yes	Yes	15.135	Decrease	13.441	No	No
			C	19	3.639	74.815	Increase	20.560	Yes	Yes					
		Unpaved	T	22	2.068	31.810	Increase	15.383	Yes	Yes	-18.357	Increase	18.246	No	No
			C	31	1.014	11.366	Increase	11.214	No	No					
		Combined	T	47	3.683	40.587	Increase	11.019	Yes	Yes	-5.202	Increase	11.444	No	No
			C	50	3.317	33.635	Increase	10.139	Yes	Yes					
IN	Two-lane	Paved	T	14	1.727	120.288	Increase	69.662	No	Yes	42.488	Decrease	22.855	No	Yes
			C	7	3.073	283.030	Increase	92.115	Yes	Yes					
		Unpaved	T	16	1.038	77.468	Increase	74.600	No	No	38.503	Decrease	28.727	No	No
			C	18	3.208	188.581	Increase	58.789	Yes	Yes					
		Combined	T	30	2.037	105.168	Increase	51.641	Yes	Yes	36.972	Decrease	18.615	No	Yes
			C	25	4.473	225.519	Increase	50.414	Yes	Yes					
GA & IN	Two-lane	Paved	T	39	3.473	53.546	Increase	15.419	Yes	Yes	21.596	Decrease	11.453	No	Yes
			C	26	4.604	95.839	Increase	20.818	Yes	Yes					
		Unpaved	T	38	2.255	34.086	Increase	15.115	Yes	Yes	-5.230	Increase	15.186	No	No
			C	49	2.381	27.422	Increase	11.516	Yes	Yes					
		Combined	T	77	4.106	44.481	Increase	10.833	Yes	Yes	4.676	Decrease	9.672	No	No
			C	75	4.980	51.568	Increase	10.356	Yes	Yes					

T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.

Table 25. Before-after EB evaluation results for PDO drop-off-related crashes.

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing: Percent change	Direction	Standard error (%)	Statistically significant?: 5% level	10% level	Safety edge effect: Effect (%)	Direction	Standard error (%)	5% level	10% level
GA	Two-lane	Paved	T	25	2.281	24.794	Increase	10.870	Yes	Yes	2.550	Decrease	15.169	No	No
			C	19	1.698	28.059	Increase	16.524	No	No					
		Unpaved	T	22	0.826	-7.063	Decrease	8.556	No	No	20.631	Decrease	10.466	No	Yes
			C	31	1.550	17.095	Increase	11.032	No	No					
		Combined	T	47	1.194	8.149	Increase	6.827	No	No	10.829	Decrease	8.786	No	No
			C	50	2.307	21.283	Increase	9.224	Yes	Yes					
IN	Two-lane	Paved	T	14	3.242	81.224	Increase	25.055	Yes	Yes	-2.553	Increase	20.262	No	No
			C	7	3.085	76.713	Increase	24.863	Yes	Yes					
		Unpaved	T	16	4.122	216.618	Increase	52.557	Yes	Yes	-131.652	Increase	50.289	Yes	Yes
			C	18	1.922	36.678	Increase	19.087	No	Yes					
		Combined	T	30	5.032	118.845	Increase	23.618	Yes	Yes	-40.967	Increase	20.594	No	Yes
			C	25	3.600	55.246	Increase	15.347	Yes	Yes					
GA & IN	Two-lane	Paved	T	39	3.695	37.481	Increase	10.143	Yes	Yes	5.319	Decrease	11.529	No	No
			C	26	3.217	45.205	Increase	14.052	Yes	Yes					
		Unpaved	T	38	1.390	12.718	Increase	9.148	No	No	7.890	Decrease	10.369	No	No
			C	49	2.330	22.373	Increase	9.601	Yes	Yes					
		Combined	T	77	3.730	25.534	Increase	6.845	Yes	Yes	4.435	Decrease	7.789	No	No
			C	75	3.926	31.360	Increase	7.988	Yes	Yes					

T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.

The safety edge effect shown in the results tables is the ratio between the before-to-after change in crash frequency for the treatment sites and the before-to-after change in crash frequency for the comparison sites. This formulation of the safety effect was derived from the multiplicative nature of crash modification factors (CMFs), as shown in equation 3 and equation 4:

$$CMF_{Resurfacing+SafetyEdge} = CMF_{Resurfacing} CMF_{SafetyEdge} \quad (3)$$

or

$$CMF_{SafetyEdge} = \frac{CMF_{Resurfacing+SafetyEdge}}{CMF_{Resurfacing}} = \frac{CMF_{Treatment}}{CMF_{Comparison}} \quad (4)$$

The before-to-after percent change in crash frequency can be converted to a CMF for this calculation by dividing by 100 and adding a value of 1. Similarly, the final CMF for the safety edge can be converted back to a percent change by subtracting the ratio from 1 and multiplying by 100. When the increase in crashes with resurfacing was greater at the comparison sites than at the treatment sites, an indication that the safety edge treatment was effective, the safety edge effect is shown as a positive value. A precision estimate of the ratio was calculated and used to generate a confidence interval of the ratio. Confidence intervals excluding the value 1 indicate statistical significance. For instance, the safety edge effect for Georgia two-lane roadways with paved shoulders shown in table 17 is calculated by first converting the before-to-after changes to CMFs and then taking the ratio: (1+13.12/100)/(1+22.60/100) = 1.1312/1.2260 = 0.927. This CMF represents a (1-0.927)*100 = 7.73 percent decrease in crashes. Since both confidence intervals (i.e., 7.73±(9.60)*1.645 and 7.73±(9.60)*1.96, where 1.645 and 1.96 are critical confidence level values) contain the value 1, the estimate of the safety edge effect is not significant.

The EB results indicate that for all two-lane sites in Georgia and Indiana, the safety edge effect was 5.7 percent for total crashes, 6.3 percent for run-off-road crashes, and 5.6 percent for drop-off-related crashes. While none of these results is statistically significant, they do show a small, consistent benefit of the provision of the safety edge on rural two-lane highways.

When the results are examined separately for the two shoulder types (sites with paved shoulders having widths of 4 ft or less and sites with unpaved shoulders) the use of the safety edge shows more benefit for paved shoulder sites than for unpaved shoulder sites. The safety edge effect for sites with paved shoulders is 9.5 percent for total crashes, 14.2 percent for run-off-road crashes, and 12.6 percent for drop-off-related crashes. The results for run-off road crashes are statistically significant at the 10 percent significance level, but the result for total crashes and drop-off related crashes are not statistically significant. For sites with unpaved shoulders, the safety edge effect was 6.5 percent for total crashes, 4.8 percent for run-off-road crashes, and 4.5 percent for drop-off-related crashes. None of these results is significant.

The expectation was that the use of the safety edge treatment would produce larger benefits on highways with unpaved shoulders, since potential drop-offs at such sites are closer to the travel lanes than on highways with paved shoulders and therefore are expected to be driven over more frequently. However, the sites with unpaved shoulders in both States had much lower ADT than the sites with paved shoulders, and the lower numbers of crashes in the before and after resurfacing periods undoubtedly affected the effectiveness estimates.

In considering the States individually, Georgia sites showed a safety edge effect of 6.8 percent for total crashes, 7.9 percent for run-off-road crashes, and 6.6 percent for drop-off-related crashes. None of the results were statistically significant. Indiana sites had safety edge effects of -0.2 percent for total crashes, -13.5 percent for run-off-road crashes, and -19.7 percent for drop-off-related crashes. The negative results are not statistically significant at the 10 percent significance level. The results for Indiana sites were affected by very low numbers of crashes in the before period.

Overall results for the EB evaluation are summarized in table 26 and compared to interim results obtained from analyses conducted 1 and 2 years after resurfacing. The analysis for data including 3 years after resurfacing, which are presented in this section of the report, includes additional comparisons because shoulder types and the two States were combined and compared. Fifty-six of the 81 results for year 3 showed positive safety edge effects; however, only 11 of these positive safety effects were statistically significant. While 25 of the observed effects were negative (e.g., comparison sites had fewer crashes than treatment sites), only 4 of these results were statistically significant.

Table 26. Summary of safety effects from year 3, year 2, and year 1 results for before-after EB safety evaluations.

Direction of safety effect	Statistically significant safety effect?	Number of cases		
		Year 3 analysis results	Year 2 analysis results	Year 1 analysis results
Positive	Yes	11	8	2
Positive	No	45	14	13
Negative	Yes	4	7	6
Negative	No	21	7	15
	Total	81	36	36

The magnitude of the effects also changed with the addition of the year 3 data. The safety effects from the year 3 evaluation were smaller and less variable than the year 1 or year 2 results. The overall impact of the safety edge was expected to be small, since drop-off-related crashes are usually only a small percentage of the total non-intersection crashes on rural roads. The year 3 results presented above follow this trend and therefore are considered more reliable than the earlier results. However, in some cases the smaller magnitude of the safety edge effect makes it more difficult for the effect to be statistically significant.

Total crashes on all sites mainly increased; some of this increase may be due to a resurfacing effect that was very evident in the year 1 results but less so in later years.

The year 3 evaluation results presented above vary in magnitude and statistical significance. The overall evaluation results for total crashes in Georgia and Indiana combined show an average safety edge treatment effect of 5.7 percent. In other words, the sites treated with the safety edge appear to have lower crash frequencies after resurfacing than sites not treated with the safety edge. Although not statistically significant, this seems to be the most appropriate overall effectiveness measure for the safety edge treatment from the EB evaluation. The lack of statistical significance for this result is not surprising given the small magnitude of the effect.

Two trends were evident in the EB analysis of run-off-road and drop-off-related crashes. First, the safety edge treatment generally appears to have had a positive effect on safety for all site types except for sites with unpaved shoulders in Indiana. This variability in results has not been fully explained. Second, the negative safety edge effects for Indiana sites with unpaved shoulders may be explained by low frequencies of drop-off-related crashes on comparison sites in the period before resurfacing. The safety edge effect was statistically significant only for Indiana sites with unpaved shoulders (negative effect).

Georgia sites with paved shoulders showed safety edge treatment effects of approximately 14 percent for run-off-road crashes and 10 percent for drop-off-related crashes. Indiana sites with unpaved shoulders had safety edge effects of -31 to -47 percent for run-off-road crashes and -45 to -80 percent for drop-off-related crashes, and these effects were statistically significant. When data from both States were combined, the safety edge treatment effects for paved shoulders were 14 percent for run-off-road crashes and 12.6 percent for drop-off-related crashes. The effect for run-off-road crashes was statistically significant at the 10 percent significance level. The treatment effects for sites with unpaved shoulders were 5 percent for run-off-road crashes and 4.5 percent for drop-off-related crashes. These small, non-significant effects are probably influenced strongly by the Indiana sites with unpaved shoulders.

The effects for run-off-road and drop-off-related crashes are larger than the effects for total crashes in absolute magnitude but vary in sign and statistical significance. These evaluation results for run-off-road and drop-off-related crashes appear less stable, and thus less reliable, than the results for total crashes. Although not statistically significant, the single most reliable estimate of the effectiveness of the safety edge treatment is the 5.7 percent reduction in total crashes observed for two-lane highways in the combined data for sites with both paved and unpaved shoulders in both Georgia and Indiana (see the last row in table 17).

There are several potential biases and limitations that may influence these results, including the following:

- There were some observed differences between treatment and comparison sites for the period before resurfacing which could confound the analysis results (see sections 3.1 and 4.3.1).
- The sites with unpaved shoulders, where the safety edge treatment was expected to be most effective, also had the lowest crash frequencies. This increased the variability in the data and made the statistical test less powerful.

4.3.3 Cross-Sectional Analysis

A cross-sectional analysis of the crash data for the period after resurfacing at the treatment and comparison sites was conducted to directly compare the safety performance. This cross-sectional analysis is analogous to the analysis of safety differences for the period before resurfacing reported in section 4.3.1 but serves a different purpose. In this analysis, any observed difference in safety performance between the treatment and comparison sites is interpreted as an effect of the safety edge treatment. This interpretation should be made cautiously because, as noted in sections 3 and 4.3.1, there are other differences between the treatment and comparison sites that may affect the comparison.

The cross-sectional comparison of data for the period after resurfacing was conducted using analysis of covariance to assess the statistical significance of the treatment versus comparison site effects. This analysis was conducted for each State/roadway type/shoulder type combination with PROC GENMOD in SAS®.[3] Traffic volume and site type (treatment versus comparison) were the main factors of interest in the analysis. Lane width was also considered but was not found to be statistically significant. The analysis was conducted with the same negative binomial modeling techniques described in the discussion of SPFs in section 4.2.

The safety edge treatment effect and its standard error were calculated for each target crash type and adjusted for any covariates. The results are presented in table 27. The significance and *p*-value for the treatment versus comparison site effects are also provided.

Where blank lines are shown in the table, the regression model did not converge, so no model could be developed. Table 27 shows that there were 44 models that converged for the final analysis. This is an improvement on the year 1 and year 2 analysis, for which only 20 and 35 models converged, respectively. Thus, as additional years of data have become available, more models have been obtained in the cross-sectional analysis. Table 27 shows that the crash frequencies for the treatment sites after resurfacing were generally lower than for the comparison sites, indicating that the safety edge treatment was effective. Statistically significant results for the safety edge effect (treatment versus comparison sites) were obtained for 19 of the 44 models shown in the table. In 15 of these cases, the safety performance of the treatment sites was better than the comparison sites, indicating that the safety edge was effective. However, in four cases (three of which were on two-lane highways with unpaved shoulders in Georgia), the safety performance of the comparison sites was better than the treatment sites.

In summary, the cross-sectional analysis results are similar to the results of the EB analysis, suggesting that the safety edge treatment is effective in reducing crashes for sites with paved shoulders and for sites in Indiana with unpaved shoulders. However, results for sites in Georgia with unpaved shoulders did not show that the safety edge was effective in reducing crashes.

The potential biases and limitations of this analysis are as follows:

- There were some observed differences between treatment and comparison sites for the period before resurfacing which could confound the analysis results (see sections 3.1 and 4.3.1).
- The sites with unpaved shoulders, where the safety edge treatment would be expected to be most effective, had the lowest crash frequencies, which increased the variability in the data and made the statistical test less powerful.
- The cross-sectional approach does not explicitly compensate for regression to the mean.

Table 27. Cross-sectional analysis of safety edge treatment effect for the period after resurfacing.

State	Roadway type	Shoulder type	Crash type and severity level	Number of site-years	Intercept	AADT effect				Treatment effect				Dispersion parameter	R^2_{LR}%	Safety edge effect[2] (%)
						Coefficient	Standard error	*p*-Value	Statistically significant?[1]	Coefficient	Standard error	*p*-Value	Statistically significant?[1]			
GA	Multilane	Paved	TOT	51	-13.212	1.542	0.309	0.000	Yes	-0.655	0.305	0.032	Yes	0.282	48.4	48.1
			FI	51	-12.940	1.360	0.332	0.000	Yes	-0.293	0.257	0.254	No	0.027	30.4	25.4
			PDO	51	-14.627	1.656	0.372	0.000	Yes	-0.703	0.345	0.042	Yes	0.404	44.0	50.5
			rorTOT	51	-19.840	2.114	0.329	0.000	Yes	-0.946	0.201	0.000	Yes	0.010	66.5	61.2
			rorFI	51	-15.748	1.562	0.391	0.000	Yes	-0.410	0.244	0.092	Yes	0.010	20.3	33.6
			rorPDO	51	-23.547	2.462	0.308	0.000	Yes	-1.280	0.240	0.000	Yes	0.010	61.8	72.2
			doTOT	51	-19.432	2.029	0.446	0.000	Yes	-0.882	0.219	0.000	Yes	0.010	48.8	58.6
			doFI	51	-18.509	1.841	0.380	0.000	Yes	-0.610	0.121	0.000	Yes	0.010	23.6	45.7
			doPDO	51	-20.271	2.061	0.552	0.000	Yes	-1.130	0.354	0.001	Yes	0.010	34.5	67.7
	Two-lane	Paved	TOT	132	-8.695	1.104	0.121	0.000	Yes	0.111	0.183	0.545	No	0.178	51.0	-11.7
			FI	132	-7.501	0.880	0.182	0.000	Yes	-0.197	0.264	0.457	No	0.273	27.4	17.8
			PDO	132	-11.162	1.306	0.125	0.000	Yes	0.414	0.193	0.032	Yes	0.136	49.6	-51.2
			rorTOT	132	-7.654	0.902	0.161	0.000	Yes	-0.120	0.260	0.645	No	0.279	30.3	11.3
			rorFI	132	-5.201	0.546	0.197	0.006	Yes	-0.497	0.355	0.161	No	0.453	11.5	39.2
			rorPDO	132	-12.208	1.322	0.216	0.000	Yes	0.342	0.328	0.298	No	0.283	29.3	-40.8
			doTOT	132	-8.244	0.927	0.163	0.000	Yes	-0.153	0.301	0.611	No	0.287	25.9	14.2
			doFI	132	-5.844	0.582	0.193	0.003	Yes	-0.368	0.383	0.337	No	0.589	8.7	30.8
			doPDO	132	-14.467	1.518	0.276	0.000	Yes	0.328	0.415	0.428	No	0.209	24.9	-38.9
		Unpaved	TOT	159	-10.116	1.253	0.173	0.000	Yes	0.581	0.225	0.010	Yes	0.555	37.0	-78.7
			FI	159	-8.599	0.959	0.182	0.000	Yes	0.415	0.226	0.066	Yes	0.267	24.3	-51.5
			PDO	159	-12.683	1.498	0.199	0.000	Yes	0.594	0.274	0.030	Yes	0.683	34.0	-81.1
			rorTOT	159	-7.229	0.799	0.169	0.000	Yes	0.341	0.222	0.125	No	0.270	17.9	-40.6
			rorFI	159	-8.063	0.834	0.193	0.000	Yes	0.275	0.265	0.301	No	0.217	14.4	-31.6
			rorPDO	159	-8.374	0.840	0.177	0.000	Yes	0.365	0.255	0.152	No	0.262	12.0	-44.0
			doTOT	159	-7.422	0.773	0.196	0.000	Yes	0.379	0.262	0.149	No	0.301	14.2	-46.0
			doFI	159	-8.725	0.882	0.202	0.000	Yes	0.297	0.257	0.248	No	0.128	14.0	-34.6
			doPDO	159	-8.048	0.728	0.243	0.003	Yes	0.411	0.344	0.231	No	0.402	6.8	-50.9

See notes at end of table.

Table 27. Cross-sectional analysis of safety edge treatment effect for the period after resurfacing—Continued.

State	Roadway type	Shoulder type	Crash type and severity level	Number of site-years	Intercept	AADT effect: Coefficient	AADT effect: Standard error	AADT effect: *p*-Value	AADT effect: Statistically significant?[1]	Treatment effect: Coefficient	Treatment effect: Standard error	Treatment effect: *p*-Value	Treatment effect: Statistically significant?[1]	Dispersion parameter	R^2_{LR}%	Safety edge effect[2] (%)
IN	Two-lane	Paved	TOT	63												
			FI	63	-1.982	0.117	0.647	0.856	No	-0.819	0.582	0.159	No	0.853	4.2	55.9
			PDO	63												
			rorTOT	63												
			rorFI	63												
			rorPDO	63												
			doTOT	63												
			doFI	63	-13.163	1.184	3.132	0.705	No	-1.599	0.729	0.028	Yes	0.010	3.0	79.8
			doPDO	63												
		Unpaved	TOT	102	-4.887	0.543	0.256	0.034	Yes	-0.069	0.211	0.742	No	0.653	7.4	6.7
			FI	102	-5.650	0.493	0.313	0.115	No	-1.215	0.492	0.013	Yes	0.757	9.4	70.3
			PDO	102	-5.657	0.594	0.269	0.027	Yes	0.206	0.231	0.373	No	0.697	6.1	-22.9
			rorTOT	102	-3.429	0.273	0.396	0.491	No	-0.864	0.394	0.028	Yes	0.527	8.7	57.9
			rorFI	102	-3.926	0.219	0.399	0.583	No	-1.689	0.610	0.006	Yes	0.247	10.2	81.5
			rorPDO	102	-4.619	0.358	0.499	0.473	No	-0.486	0.417	0.244	No	0.972	3.4	38.5
			doTOT	102	-5.486	0.488	0.363	0.178	No	-1.206	0.389	0.002	Yes	0.320	11.1	70.1
			doFI	102	-9.490	0.869	0.355	0.014	Yes	-1.970	1.029	0.056	Yes	0.010	9.3	86.0
			doPDO	102	-4.672	0.327	0.525	0.534	No	-0.990	0.407	0.015	Yes	0.718	5.4	62.8
NY	Two-lane	Paved	TOT	18	-3.595	0.510	0.186	0.006	Yes	-0.278	0.273	0.307	No	0.117	28.4	24.3
			FI	18	-9.373	1.040	0.134	0.000	Yes	0.092	0.144	0.525	No	0.010	57.9	-9.6
			PDO	18	-2.241	0.311	0.281	0.268	No	-0.440	0.405	0.277	No	0.214	16.9	35.6
			rorTOT	18	-4.255	0.480	0.174	0.006	Yes	-0.128	0.271	0.638	No	0.010	28.5	12.0
			rorFI	18	-9.553	1.035	0.101	0.000	Yes	0.004	0.135	0.976	No	0.010	48.7	-0.4
			rorPDO	18												
			doTOT	18												
			doFI	18												
			doPDO	18												

[1] At the 0.10 level.
[2] Percent difference between treatment and comparison sites.
TOT = total crashes (all severity levels combined).
FI = fatal–and–injury crashes.
PDO = property–damage-only crashes.
ror = run-off-road crashes.
do = drop-off-related crashes.
Note: Blank cells represent models that did not converge.

4.3.4 Analysis of Shifts in the Crash Severity Distribution

An analysis was conducted to assess whether the safety edge treatment affected the proportion of severe crashes for specific crash types. This analysis compared fatal and injury crashes as a proportion of total crashes in the periods before and after resurfacing for each State/roadway type/shoulder type combination. Results of this analysis are presented in table 28. The fatal and injury crash proportions were evaluated for run-off-road crashes, drop-off-related crashes, and all crash types combined. These comparisons were made by estimating the mean difference in proportions and its confidence interval across all sites at a 10 percent significance level.

Table 28. Comparison of proportions of fatal and injury crashes before and after resurfacing.

Crash type	State	Roadway type	Shoulder type	Site type	Average before proportion	Average after proportion	Estimated average difference	Number of sites	Estimated mean difference	Lower 90% confidence limit	Upper 90% confidence limit	Significant at the 0.10 level?
TOT	GA	Multilane	Paved	T	0.362	0.397	0.035	10	0.088	–0.115	0.208	No
				C	0.353	0.370	0.017	6	–0.024	–0.272	0.334	No
		Two-lane	Paved	T	0.276	0.246	–0.030	15	–0.030	–0.132	0.054	No
				C	0.414	0.444	0.031	13	0.042	–0.167	0.296	No
			Unpaved	T	0.209	0.476	0.267	20	0.238	0.088	0.480	Yes
				C	0.384	0.317	–0.067	24	–0.025	–0.151	0.085	No
			All	T	0.245	0.354	0.109	35	0.099	0.006	0.216	Yes
				C	0.395	0.366	–0.030	37	–0.009	–0.122	0.095	No
	IN	Two-lane	Paved	T	0.116	0.154	0.038	8	0.007	–0.172	0.286	No
				C	0.222	0.165	–0.058	6	–0.034	–0.242	0.069	No
			Unpaved	T	0.111	0.088	–0.023	7	–0.166	–0.276	0.218	No
				C	0.233	0.271	0.038	14	0.044	–0.042	0.165	No
			All	T	0.113	0.119	0.005	15	–0.047	–0.188	0.190	No
				C	0.230	0.241	0.011	20	0.017	–0.072	0.106	No
	NY	Two-lane	Paved	T	0.507	0.334	–0.172	3	–0.181			No Test
				C	0.407	0.219	–0.188	3	–0.188			No Test
	All	Two-lane	Paved	T	0.239	0.221	–0.018	26	–0.044	–0.116	0.045	No
				C	0.367	0.354	–0.013	22	–0.032	–0.150	0.108	No
			Unpaved	T	0.168	0.313	0.145	27	0.156	0.022	0.350	Yes
				C	0.329	0.300	–0.028	38	0.008	–0.083	0.079	No
			All	T	0.205	0.265	0.059	53				No
				C	0.343	0.320	–0.023	60				No
ROR	GA	Multilane	Paved	T	0.340	0.459	0.119	9	0.168	–0.083	0.357	No
				C	0.378	0.154	–0.224	6	–0.250	–0.400	–0.143	Yes
		Two-lane	Paved	T	0.331	0.234	–0.097	17	–0.148	–0.297	0.035	No
				C	0.386	0.361	–0.025	11	–0.035	–0.467	0.321	No
			Unpaved	T	0.309	0.491	0.182	14	0.250	0.021	0.542	Yes
				C	0.339	0.366	0.026	19	0.065	–0.126	0.250	No
			All	T	0.321	0.355	0.034	31	0.035	–0.125	0.200	No
				C	0.357	0.364	0.007	30	0.024	–0.142	0.214	No

See notes at end of table.

Table 28. Comparison of proportions of fatal and injury crashes before and after resurfacing—Continued.

Crash type	State	Roadway type	Shoulder type	Site type	Average before proportion	Average after proportion	Estimated average difference	Number of sites	Estimated mean difference	Lower 90% confidence limit	Upper 90% confidence limit	Significant at the 0.10 level?
ROR	IN	Two-lane	Paved	T	0.063	0.139	0.077	5	0.179	–0.171	0.750	No
				C	0.486	0.193	–0.293	6	–0.317	–0.708	0.000	No
			Unpaved	T	0.207	0.096	–0.111	8	–0.333	–0.667	0.313	No
				C	0.367	0.413	0.046	11	0.042	–0.294	0.387	No
			All	T	0.140	0.116	–0.024	13	–0.108	–0.333	0.333	No
				C	0.400	0.351	–0.049	17	–0.113	–0.317	0.173	No
	NY	Two-lane	Paved	T	0.685	0.519	–0.166	3	–0.156			No Test
				C	0.628	0.635	0.007	3	–0.023			No Test
	All	Two-lane	Paved	T	0.267	0.223	–0.044	25	–0.097	–0.229	0.065	No
				C	0.435	0.349	–0.086	20	–0.133	–0.367	0.100	No
			Unpaved	T	0.266	0.325	0.059	22	0.089	–0.110	0.333	No
				C	0.350	0.383	0.034	30	0.061	–0.097	0.217	No
			All	T	0.267	0.271	0.005	47	–0.011	–0.134	0.122	No
				C	0.381	0.370	–0.011	50	–0.008	–0.142	0.117	No
DO	GA	Multilane	Paved	T	0.410	0.526	0.116	9	0.167	–0.083	0.333	No
				C	0.401	0.186	–0.216	6	–0.250	–0.458	–0.057	Yes
		Two-lane	Paved	T	0.416	0.313	–0.103	14	–0.200	–0.455	0.089	No
				C	0.399	0.308	–0.091	12	–0.152	–0.500	0.250	No
			Unpaved	T	0.305	0.562	0.257	17	0.375	0.104	0.563	Yes
				C	0.285	0.355	0.070	18	0.151	–0.089	0.333	No
			All	T	0.364	0.430	0.066	31	0.100	–0.075	0.292	No
				C	0.328	0.337	0.009	30	0.000	–0.199	0.250	No
	IN	Two-lane	Paved	T	0.000	0.071	0.071	1	1.000			No Test
				C	0.238	0.097	–0.141	2	–0.492			No Test
			Unpaved	T	0.141	0.063	–0.078	4	–0.438	–1.000	1.000	No
				C	0.435	0.289	–0.146	11	–0.338	–0.583	0.125	No
			All	T	0.075	0.067	–0.008	5	0.000	–1.000	1.000	No
				C	0.380	0.236	–0.144	13	–0.375	–0.554	0.000	Yes
	NY	Two-lane	Paved	T	0.667	0.000	–0.667	2	–1.000			No Test
				C	0.667	0.167	–0.500	2	–0.750			No Test
	All	Two-lane	Paved	T	0.295	0.210	–0.085	17	–0.211	–0.472	0.078	No
				C	0.388	0.243	–0.145	16	–0.300	–0.550	0.000	Yes
			Unpaved	T	0.236	0.352	0.116	21	0.250	0.000	0.508	No
				C	0.340	0.331	–0.009	29	–0.003	–0.217	0.183	No
			All	T	0.267	0.277	0.010	38	0.000	–0.181	0.250	No
				C	0.358	0.298	–0.060	45	–0.113	–0.289	0.028	No

TOT = Total crashes.
ROR = Run-off-road crashes.
DO = Drop-off-related crashes.
T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.
Note: Blank cells indicate that the test of proportions could not be conducted or that the category had fewer than four sites.

These evaluations were performed with the Wilcoxon signed-rank test, a nonparametric test that does not require that the differences being considered follow a normal distribution. The Wilcoxon signed-rank test was programmed in SAS® using the algorithm developed for the FHWA SafetyAnalyst software.[(8)] The primary measures of interest presented in table 28 for differences in proportion of fatal and injury crashes are as follows:

- Average proportion of fatal and injury crashes before resurfacing.
- Average proportion of fatal and injury crashes after resurfacing.
- Simple average difference in proportions (after-before).
- Number of sites included in the analysis.
- Estimated median before-after effect.
- Lower confidence limit of median before-after effect.
- Upper confidence limit of median before-after effect.
- Summary of statistical significance.

The estimated average treatment effect is the difference between the proportions for the periods before and after resurfacing based only on those sites where the difference is not zero. Since the Wilcoxon signed-rank test uses only those sites with an observed non-zero change in the proportion of fatal and injury crashes, it estimates the median rather than the mean. Consequently, the test results are less influenced by extreme changes in proportions. Cases in which the test of proportions could not be conducted are left blank in the table.

A negative estimated median difference indicates that the proportion of fatal and injury crashes decreased. If the number of sites was less than four, no test was conducted.

The proportion of severe crashes after resurfacing was lower than the proportion of severe crashes before resurfacing in 31 out of 58 cases shown in table 28. Thirteen of the 31 positive results were for sites resurfaced with the safety edge treatment, and 18 were for sites resurfaced without the safety edge treatment. Only 4 of the 58 comparisons of severity proportions were statistically significant; all 4 of these cases were comparison sites. Overall, it appears that the proportion of severe crashes was reduced from before to after resurfacing, but only a few of the results were statistically significant, and there is no apparent difference in the shift in severity distributions between resurfacing with and without the safety edge treatment.

CHAPTER 5. ESTIMATED COST OF THE SAFETY EDGE TREATMENT

This chapter presents the analysis results for the cost of the safety edge treatment. Section 5.1 discusses an analysis of costs for both treatment and comparison resurfacing contracts, and section 5.2 presents another method for determining the cost of the safety edge.

5.1 COMPARISON OF OVERALL COSTS OF RESURFACING PROJECTS

Since the safety edge treatment adds a wedge of asphalt to each edge of the roadway, it is expected to add cost to a resurfacing project. Costs of resurfacing both treatment and comparison sites were obtained from each of the participating States after the resurfacing project was completed and project accounts were finalized. The cost items obtained for each project included the engineer's estimate, the contract cost or price bid for the project by the winning bidder, and the cost per ton of the hot-mix asphalt (HMA) concrete used to resurface the roadway and form the safety edge.

The Georgia data set included 28 resurfacing projects (15 treatment and 13 comparison sites) and 345 mi of roadway. A summary of the project costs for Georgia is shown in table 29. Costs per mile of safety edge resurfacing versus non-safety edge resurfacing were found to be $110,000 versus $140,000.

Table 29. Summary of Georgia resurfacing project costs (2005).

Cost item	Weighted average cost		Nonweighted average cost	
	Safety edge sites	Comparison sites	Safety edge sites	Comparison sites
Engineer's estimate ($ million/mi)	$2.650	$1.353	$3.222	$1.272
Contract cost ($ million/mi)	$1.306	$1.353	$1.183	$1.268
HMA resurfacing cost ($/ton)	$45.730	$43.050	$49.210	$42.970
HMA resurfacing cost ($ million/mi)	—	—	$0.110	$0.140

— Not applicable.

The Indiana data set included 16 resurfacing projects (8 treatment and 8 comparison sites) and 165 mi of roadway. A summary of the project costs for Indiana is shown in table 30. Costs per mile of safety edge resurfacing versus non-safety edge resurfacing were found to be $140,000 versus $150,000.

Table 30. Summary of Indiana resurfacing project costs (2005).

Cost item	Weighted average cost		Nonweighted average cost	
	Safety edge sites	Comparison sites	Safety edge sites	Comparison sites
Engineer's estimate ($ million/mi)	$1.878	$1.766	$1.748	$1.691
Contract cost ($ million/mi)	$1.505	$1.419	$1.407	$1.388
HMA resurfacing cost ($/ton)	$38.200	$35.510	$38.600	$35.650
HMA resurfacing cost ($ million/mi)	—	—	$0.140	$0.150

— Not applicable.

The New York data set included six resurfacing projects (three treatment and three comparison sites) and 25 mi of roadway. A summary of the project costs for New York is shown in table 31. Costs per mile of safety edge resurfacing versus non-safety edge resurfacing were found to be $30,000 versus $40,000. Costs for New York projects are substantially less than Indiana and Georgia. The HMA costs were generally higher in Indiana and Georgia than in New York, but it is also possible that the New York projects differed in scope from those in Indiana and Georgia.

Table 31. Summary of New York resurfacing project costs (2005).

Cost item	Weighted average cost		Nonweighted average cost	
	Safety edge sites	Comparison sites	Safety edge sites	Comparison sites
Engineer's estimate ($ million/mi)	$0.368	$0.881	$0.354	$0.737
Contract cost ($ million/mi)	$0.106	$0.145	$0.108	$0.143
HMA resurfacing cost ($/ton)	$40.290	$49.180	$40.670	$51.710
HMA resurfacing cost ($ million/mi)	—	—	$0.030	$0.040

— Not applicable.

The cost analyses for resurfacing with the safety edge treatment as compared to resurfacing projects on similar roads without the safety edge treatment were reviewed collectively and individually. A summary of the resurfacing costs for all three States combined is shown in table 32. Collectively, the cost of resurfacing with the safety edge treatment was found to be slightly less than without the safety edge treatment. Earlier analysis of the yield of coverage on safety edge and non-safety edge sites in Georgia found only a very small difference in the amount of area covered per ton of asphalt.

Table 32. Summary of combined Georgia, Indiana, and New York resurfacing project costs (2005).

Cost item	Weighted average cost		Nonweighted average cost	
	Safety edge sites	Comparison sites	Safety edge sites	Comparison sites
Engineer's estimate ($ million/mi)	$1.632	$1.333	$1.775	$1.233
Contract cost ($ million/mi)	$0.973	$0.973	$0.899	$0.933
HMA resurfacing cost ($/ton)	$41.407	$42.578	$42.830	$43.445
HMA resurfacing cost ($ million/mi)	—	—	$0.096	$0.110

— Not applicable.

Some advocates of the safety edge treatment maintain that incorporating the treatment in resurfacing projects has little, if any, added cost because the asphalt used is merely reformed to create the safety edge treatment. The results summarized in table 32 can be interpreted as consistent with this hypothesis. However, construction practices vary between contractors and highway agencies, and while the amount of asphalt used for the safety edge treatment may be very small, it is unrealistic to assume there is no additional cost to implement this treatment. The next section presents an alternative approach to estimating the additional cost per mile of the safety edge treatment.

5.2 COST OF SAFETY EDGE TREATMENT BASED ON AMOUNT OF ASPHALT USED

An alternative method to determine the cost of the safety edge treatment is to compute the amount of asphalt used to provide the treatment and multiply this quantity by a typical bid cost per ton of HMA for that specific project.

Figure 5 shows a typical triangular cross section for the safety edge treatment. The safety edge treatment is shown with a cross slope of 30 degrees, which is consistent with current practice. The cost per mile for the safety edge treatment on both sides of the road based on the cross section shown in figure 5 can be estimated using equation 5.

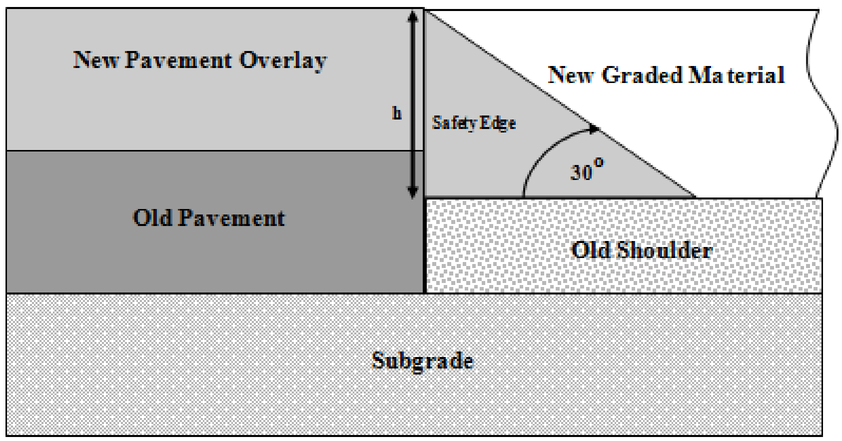


Figure 5. Diagram. Typical cross section for the safety edge treatment on one side of the road.

$$CC_{SE} = \frac{(A)(L)(D)(C)}{(2000)} \qquad (5)$$

Where:

CC_{SE} = cost for application of the safety edge treatment ($ per mi)

A = area of the safety edge treatment cross section (ft^2) $[= 0.5\,(h/12)\;\frac{h/\tan 30°}{12}\;]$

h = height of safety edge treatment (inches)

L = length of safety edge treatment (ft)

D = HMA density ($1b/ft^3$)

C = HMA cost ($/ton)

The height of the safety edge treatment (*h*) is estimated to range from 1.5 to 3.0 inches, based on the assumption that a 1.5-inch overlay will be placed and that the shoulder will be leveled between 0 and 1.5 inches below the elevation of the pavement existing before resurfacing.

The length of the safety edge treatment for a 1.0-mi road section would be 2.0 mi or 10,560 ft for both sides of the road combined.

The density of the HMA for the safety edge treatment is estimated to be 100 1b/ft^3. This is less than the maximum density of compacted asphalt because the safety edge treatment is not compacted as an overlay course would be.

The cost of HMA has increased since the 2005 costs shown in table 29 through table 32. HMA costs vary substantially between regions of the United States. Based on discussions with several highway agencies, a representative current price for HMA is $75 per ton.

Applying equation 5 to the values discussed above, the cost for a safety edge treatment 1.5 inches high would be $536 per mi. The cost for a safety edge treatment 3.0 inches high would be $2,145 per mi. Thus, a reasonable range of costs for the safety edge treatment is $536–2,145 per mi.

CHAPTER 6. BENEFIT-COST ANALYSIS

This chapter presents the results of a benefit-cost analysis of the safety edge treatment based on the results in this report. Section 6.1 presents the overall approach for determining benefit-cost estimates, section 6.2 documents the components of the analysis, and section 6.3 discusses the results of the benefit-cost analysis.

6.1 BENEFIT-COST ANALYSIS APPROACH

The benefit-cost ratio for the safety edge treatment has been determined according to equation 6:

$$B/C = \frac{(N_{FI} E_{SE} C_{FI} + N_{PDO} E_{SE} C_{PDO})(P/A, i\%, n)}{CC_{SE}} \qquad (6)$$

Where:

B/C = benefit-cost ratio

N_{FI} = number of fatal and injury crashes per mile per year before application of the safety edge treatment

N_{PDO} = number of PDO crashes per mile per year before application of the safety edge treatment

E_{SE} = effectiveness (percent reduction in crashes) for application of the safety edge treatment

C_{FI} = cost savings per crash for fatal and injury crashes reduced

C_{PDO} = cost savings per crash for PDO crashes reduced

(P/A, *i*, n) = uniform series present worth factor

i = minimum attractive rate of return (discount rate), expressed as a proportion (i.e., *i* = 0.04, for a discount rate of 4 percent)

n = service life of safety edge treatment (years)

CC_{SE} = cost for application of the safety edge treatment (dollars per mile)

6.2 COMPONENTS OF THE BENEFIT-COST ANALYSIS

The following sections document the components of the benefit-cost computation, including crash frequencies, treatment effectiveness, crash costs, service life, minimum attractive rate of return, uniform series present worth factor, and treatment cost.

6.2.1 Crash Frequencies

Crash frequencies per mile per year were estimated for the benefit-cost analysis using the SPFs presented in section 4.2. Only two-lane highway sites were considered because no treatment effectiveness measure was found for multilane highway sites. Both Georgia and Indiana SPFs were used because each State has an SPF and because using the individual State SPFs constitutes a sensitivity analysis of the results. The location of the SPFs used in the benefit-cost analysis are shown in table 33.

Table 33. SPFs used in benefit-cost analysis.

State	Roadway type	Shoulder type	Crash type and security level	Table
Georgia	Two-lane highway	Paved	All crashes	10
Georgia	Two-lane highway	Paved	F&I crashes	10
Georgia	Two-lane highway	Paved	PDO crashes	10
Indiana	Two-lane highway	Paved	All crashes	11
Indiana	Two-lane highway	Paved	F&I crashes	11
Indiana	Two-lane highway	Paved	PDO crashes	11
Georgia	Two-lane highway	Unpaved	All crashes	10
Georgia	Two-lane highway	Unpaved	F&I crashes	10
Georgia	Two-lane highway	Unpaved	PDO crashes	10
Indiana	Two-lane highway	Unpaved	All crashes	11
Indiana	Two-lane highway	Unpaved	F&I crashes	11
Indiana	Two-lane highway	Unpaved	PDO crashes	11

F&I = Fatal and injury.
PDO = Property-damage-only.

The computation of crash frequencies was performed as illustrated in the following example of Georgia two-lane highways with paved shoulders. This example illustrates the computation of crash frequencies per mile per year for highways with a traffic volume of 1,000 vehicles per day.

SPF for total crashes from table 10:
N_{TOT} = exp (-8.921 + 1.108 ln (1,000)) = 0.282 crashes per mi per year

SPF for fatal and injury crashes from table 10:
N_{FI} = exp (-7.818 + 0.853 ln (1,000)) = 0.146 crashes per mi per year

SPF for PDO crashes from table 10:
N_{PDO} = exp (-11.414 + 1.349 ln (1,000)) = 0.123 crashes per mi per year

Since the sum of N_{FI} (0.146) and N_{PDO} (0.123) is less than N_{TOT} (0.282), the values of N_{FI} and N_{PDO} are adjusted so that this sum is equal to N_{TOT}, as follows:

$$N_{FI}\text{ (adjusted)} = 0.282 \left(\frac{0.146}{0.146+0.123}\right) = 0.153 \text{ crashes per mi per year}$$

$$N_{PDO}\text{ (adjusted)} = 0.282 \left(\frac{0.123}{0.146+0.123}\right) = 0.129 \text{ crashes per mi per year}$$

6.2.2 Treatment Effectiveness

Based on the results of the EB evaluation presented in section 4.3.2, the crash reduction effectiveness of the safety edge treatment is 5.7 percent. Continuing the computational example for Georgia two-lane highways with paved shoulders and a traffic volume of 1,000 vehicles per day, the crash reduction from the safety edge treatment would be estimated as follows:

For fatal and injury crashes:
0.153 (0.057) = 0.008721 crashes reduced per mi per year

For PDO crashes:
0.129 (0.057) = 0.007353 crashes reduced per mi per year

6.2.3 Crash Costs

The estimated crash costs used in this analysis are based on those currently used in SafetyAnalyst, as follows:

- Fatal crash = $5,800,000.
- A injury crash = $402,000.
- B injury crash = $80,000.
- C injury crash = $42,000.
- PDO crash = $4,000.[8]

The costs are based on the latest published FHWA values.[10] The weighted average cost of a fatal and injury crash (assuming 1 percent fatal crashes, 9 percent A injury crashes, 50 percent B injury crashes, and 40 percent C injury crashes) is $150,980 per crash. Based on these crash costs, the estimated annual crash reduction benefits for the example presented above are as follows:

0.008721 (150,980) + (.007353) (4,000) = $1,346 per mi

6.2.4 Service Life

The service life of the safety edge treatment is estimated to be 7 years, the same as the service life of a typical pavement resurfacing project.

6.2.5 Minimum Attractive Rate of Return

The minimum attractive rate of return for this analysis is estimated to be 4 percent. This value is currently used in SafetyAnalyst and is representative of the real, long-term cost of capital (i.e., not including inflation).[8]

6.2.6 Uniform Series Present Worth Factor

The uniform series present worth factor is applied to convert the annual crash reduction benefits to a present value. This factor is determined as shown in equation 7:

$$(P/A,\ i,\ n) = \frac{(1+i)^n - 1}{i(1+i)^n} \tag{7}$$

The uniform series present worth factor for a minimum attractive rate of return of 4 percent and a service life of 7 years is determined as follows:

$$(P/A,\ 4\%,\ 7) = \frac{(1+0.04)^7 - 1}{0.04(1+0.04)^7} = 6.002$$

6.2.7 Treatment Cost

The cost of the safety edge treatment is estimated as falling in the range of $536 to 2,145 per mi for both sides of the road combined, as explained in section 5.2.

6.2.8 Benefit Cost Ratio

The value of the benefit-cost ratio is computed using equation 6. For the computational example previously presented, the maximum benefit-cost ratio (estimated for the minimum treatment cost of $536 per mi) is determined as follows:

$$B/C = \frac{(1{,}346)(6.002)}{536} = 15.07$$

The minimum benefit-cost ratio for the same case (estimated for the maximum treatment cost of $2,145 per mi) is determined as follows:

$$B/C = \frac{(1{,}346)(6.002)}{2{,}145} = 3.77$$

The result indicates that the safety edge treatment provides at least $3 in benefits for each dollar spent on the treatment and possibly as much as $15 in benefits for each dollar spent on the treatment depending on the thickness of the safety edge treatment provided. This example addresses sites with a traffic volume of 1,000 vehicles per day. Larger benefit-cost ratios would be expected for sites with higher traffic volumes.

6.3 BENEFIT-COST ANALYSIS RESULTS

The results of the benefit-cost analysis are summarized in table 34 through table 37 for application of the safety edge treatment to four types of roadways.

Table 34. Benefit-cost analysis for application of safety edge treatment on Georgia two-lane roadways with paved shoulders.

AADT (vehicles/day)	1,000	5,000	10,000	15,000	20,000
Crash Frequencies					
Total crashes per mile per year	0.282	1.675	3.611	5.659	7.784
F&I crashes per mile per year	0.146	0.575	1.039	1.469	1.877
PDO crashes per mile per year	0.123	1.079	2.748	4.748	6.999
F&I crashes per mile per year (adjusted)	0.153	0.583	0.991	1.337	1.646
PDO crashes per mile per year (adjusted)	0.129	1.093	2.620	4.322	6.138
Safety Benefits—Number of Crashes Reduced					
F&I crashes reduced per mile per year	0.009	0.033	0.056	0.076	0.094
PDO crashes reduced per mile per year	0.007	0.062	0.149	0.246	0.350
Safety Benefits—Dollars					
F&I crash reduction benefits per year ($)	1,314	5,015	8,528	11,505	14,165
PDO crash reduction benefits per year ($)	29	249	597	986	1,399
Total crash reduction benefits per year ($)	1,344	5,264	9,126	12,491	15,565
Present value of total benefits per year ($)	8,065	31,597	54,773	74,972	93,421
Treatment Cost					
Minimum cost of safety edge treatment ($ per mile)	536	536	536	536	536
Maximum cost of safety edge treatment ($ per mile)	2,145	2,145	2,145	2,145	2,145
Benefit-Cost Ratio					
Minimum benefit-cost ratio	3.8	14.7	25.5	35.0	43.6
Maximum benefit-cost ratio	15.0	59.0	102.2	139.9	174.3

F&I = Fatal and injury.
PDO = Property-damage-only.

Table 35. Benefit-cost analysis for application of safety edge treatment on Indiana two-lane roadways with paved shoulders.

AADT (veh/day)	1,000	5,000	10,000	15,000	20,000
Crash Frequencies					
Total crashes per mile per year	0.664	2.175	3.626	4.888	6.043
F&I crashes per mile per year	0.158	0.444	0.694	0.900	1.082
PDO crashes per mile per year	0.542	1.722	2.832	3.789	4.659
F&I crashes per mile per year (adjusted)	0.150	0.446	0.713	0.938	1.139
PDO crashes per mile per year (adjusted)	0.514	1.729	2.912	3.950	4.904
Safety Benefits—Number of Crashes Reduced					
F&I crashes reduced per mile per year	0.009	0.025	0.041	0.053	0.065
PDO crashes reduced per mile per year	0.029	0.099	0.166	0.225	0.280
Safety Benefits—Dollars					
F&I crash reduction benefits ($)	1,291	3,841	6,138	8,072	9,804
PDO crash reduction benefits ($)	117	394	664	901	1,118
Total crash reduction benefits ($)	1,408	4,235	6,802	8,973	10,922
Present value of total benefits ($)	8,453	25,419	40,824	53,856	65,553
Treatment Cost					
Minimum cost of safety edge treatment (per mile)	536	536	536	536	536
Maximum cost of safety edge treatment (per mile)	2,145	2,145	2,145	2,145	2,145
Benefit-Cost Ratio					
Minimum benefit-cost ratio	3.9	11.9	19.0	25.1	30.6
Maximum benefit-cost ratio	15.8	47.4	76.2	100.5	122.3

F&I = Fatal and injury.
PDO = Property-damage-only.

Table 36. Benefit-cost analysis for application of safety edge treatment on Georgia two-lane roadways with unpaved shoulders.

AADT (veh/day)	1,000	5,000	10,000	15,000	20,000
Crash Frequencies					
Total crashes per mile per year	0.377	1.822	3.588	5.335	7.068
F&I crashes per mile per year	0.144	0.673	1.307	1.927	2.538
PDO crashes per mile per year	0.226	1.151	2.320	3.496	4.676
F&I crashes per mile per year (adjusted)	0.147	0.672	1.293	1.896	2.487
PDO crashes per mile per year (adjusted)	0.231	1.150	2.296	3.439	4.581
Safety Benefits—Number of Crashes Reduced					
F&I crashes reduced per mile per year	0.008	0.038	0.074	0.108	0.142
PDO crashes reduced per mile per year	0.013	0.066	0.131	0.196	0.261
Safety Benefits—Dollars					
F&I crash reduction benefits ($)	1,263	5,782	11,126	16,314	21,403
PDO crash reduction benefits ($)	53	262	523	784	1,045
Total crash reduction benefits ($)	1,316	6,044	11,649	17,098	22,447
Present value of total benefits ($)	7,898	36,277	69,920	102,624	134,730
Treatment Cost					
Minimum cost of safety edge treatment (per mile)	536	536	536	536	536
Maximum cost of safety edge treatment (per mile)	2,145	2,145	2,145	2,145	2,145
Benefit-Cost Ratio					
Minimum benefit-cost ratio	3.7	16.9	32.5	47.8	62.8
Maximum benefit-cost ratio	14.7	67.7	130.4	191.5	251.4

F&I = Fatal and injury.
PDO = Property-damage-only.

Table 37. Benefit-cost analysis for application of safety edge treatment on Indiana two-lane roadways with unpaved shoulders.

AADT (veh/day)	1,000	5,000	10,000	15,000	20,000
Crash Frequencies					
Total crashes per mile per year	0.409	1.263	2.053	2.728	3.338
F&I crashes per mile per year	0.118	0.235	0.317	0.376	0.426
PDO crashes per mile per year	0.336	1.027	1.662	2.202	2.689
F&I crashes per mile per year (adjusted)	0.106	0.236	0.329	0.398	0.456
PDO crashes per mile per year (adjusted)	0.302	1.028	1.725	2.330	2.882
Safety Benefits—Number of Crashes Reduced					
F&I crashes reduced per mile per year	0.006	0.013	0.019	0.023	0.026
PDO crashes reduced per mile per year	0.017	0.059	0.098	0.133	0.164
Safety Benefits—Dollars					
F&I crash reduction benefits ($)	916	2,027	2,827	3,428	3,926
PDO crash reduction benefits ($)	69	234	393	531	657
Total crash reduction benefits ($)	985	2,261	3,221	3,959	4,583
Present value of total benefits ($)	5,914	13,572	19,331	23,762	27,507
Treatment Cost					
Minimum cost of safety edge treatment (per mile)	536	536	536	536	536
Maximum cost of safety edge treatment (per mile)	2,145	2,145	2,145	2,145	2,145
Benefit-Cost Ratio					
Minimum benefit-cost ratio	2.8	6.3	9.0	11.1	12.8
Maximum benefit-cost ratio	11.0	25.3	36.1	44.3	51.3

F&I = Fatal and injury.
PDO = Property-damage-only.

For each State and roadway type, benefit-cost analyses were performed for traffic volumes ranging from 1,000 to 20,000 vehicles per day. The overall results of the benefit-cost analysis are shown in figure 6 and figure 7.

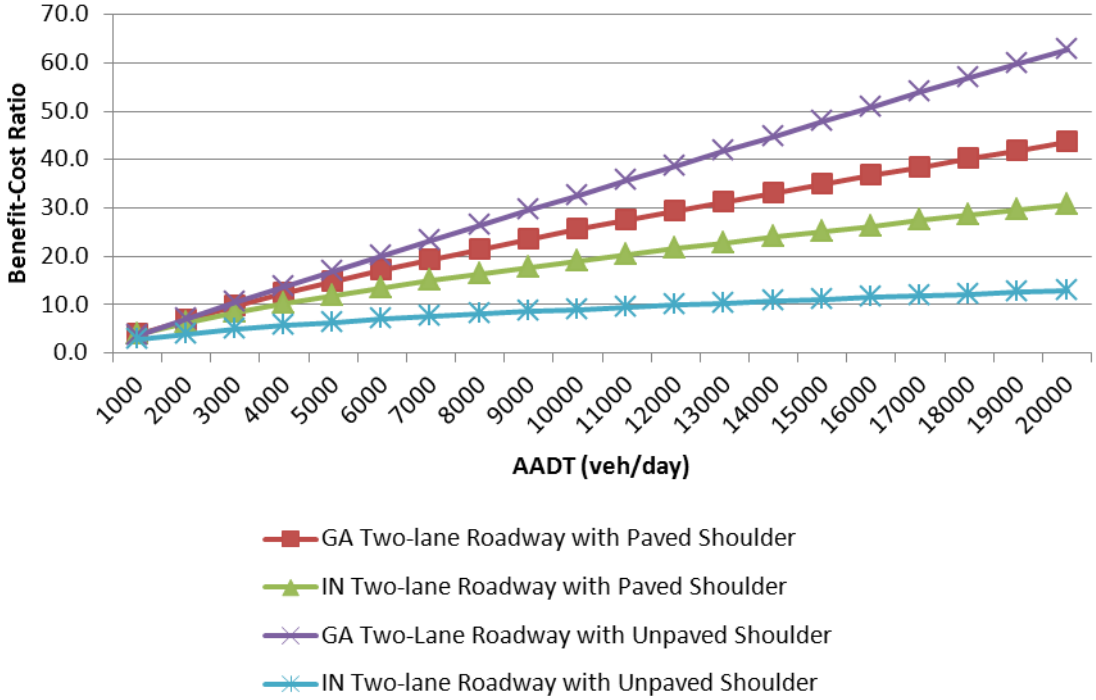


Figure 6. Graph. Minimum benefit-cost ratios for the safety edge treatment as a function of AADT.

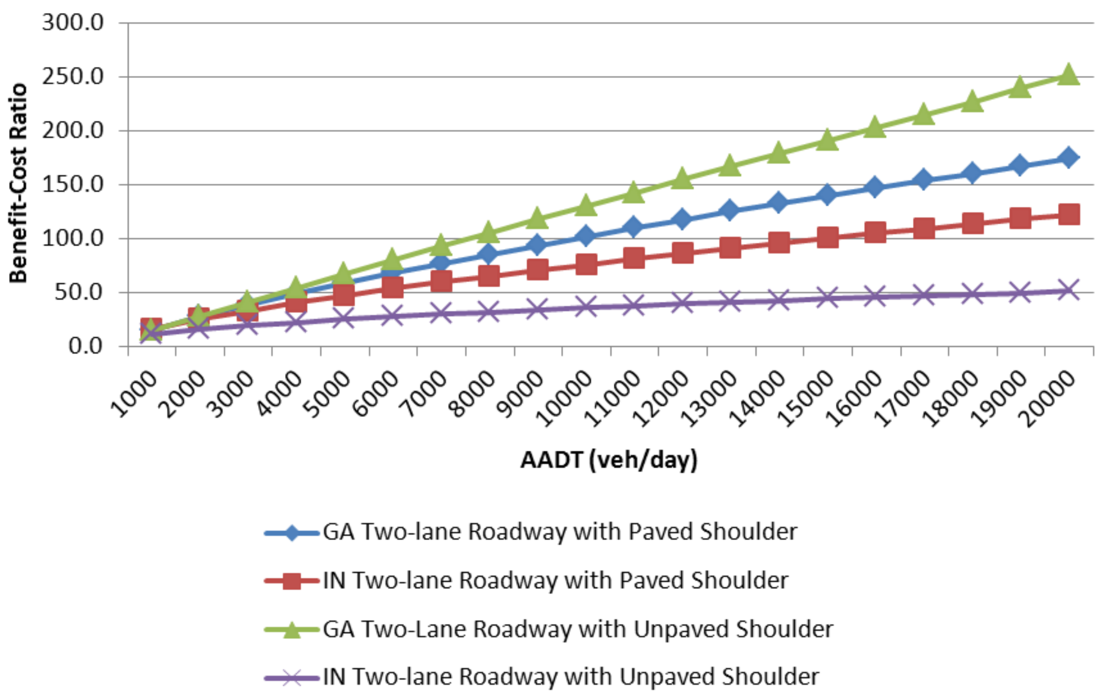


Figure 7. Graph. Maximum benefit-cost ratios for the safety edge treatment as a function of AADT.

For two-lane highways with paved shoulders, application of the safety edge treatment has minimum benefit-cost ratios ranging from 3.8 to 43.6 for Georgia conditions and from 3.9 to 30.6 for Indiana conditions. For two-lane highways with unpaved shoulders, the minimum benefit-cost ratios for the safety edge treatment range from 3.7 to 62.8 for Georgia conditions and 2.8 to 12.8 for Indiana conditions. In all these cases, the maximum benefit-cost ratios are at least four times the minimum benefit-cost ratios.

These results suggest that the safety edge treatment is highly cost-effective under a broad range of conditions. Even though there is uncertainty in the treatment effectiveness estimate, the safety edge treatment is likely to be a good safety investment in most situations, especially for roadways with higher volume levels, where higher crash frequencies are expected.

CHAPTER 7. CONCLUSIONS

Conclusions from the analysis of pavement-edge drop-off field measurements and crash data, based on 3 years of data for the period after resurfacing and installation of the safety edge treatment, are as follows:

- The EB evaluation for the safety edge treatment with 3 years of crash data for the period after resurfacing found that 56 of the 81 comparisons showed a positive safety effect for the safety edge treatment. However, only 11 of these comparisons were statistically significant, which may be due in part to the small magnitude of the safety edge effect.

- The EB evaluation results indicated that the best estimate of effectiveness of the safety edge treatment for all two-lane highway sites in two States is an approximately 5.7 percent reduction in total crashes. While this result was not statistically significant, the evaluation results obtained for total crashes were nearly always in the positive direction. The results of separate evaluations for fatal and injury crashes and PDO crashes were too variable to draw conclusions.

- Benefit-cost analysis based on the estimated 5.7 percent crash reduction effectiveness found that the safety edge treatment is so inexpensive that it is highly cost-effective for application in a broad range of conditions on two-lane highways. Computed minimum values for benefit-cost ratios ranged from 4 to 44 for two-lane highways with paved shoulders and from 4 to 63 for two-lane highways with unpaved shoulders. The benefit-cost ratios are generally higher with increasing traffic volume and where the cost of installing the safety edge treatment is lower.

- The cost of adding the safety edge treatment to a resurfacing project is minimal. Comparisons of overall project costs and overall costs of HMA resurfacing material did not show an increase for resurfacing projects with the safety edge when compared to normal resurfacing projects without the safety edge. However, computations based on the volume of asphalt required to form the safety edge suggested that the cost of the safety edge treatment is approximately $536–2,145 per mi for application to both sides of the roadway.

- Resurfacing with or without the safety edge treatment was found to decrease the proportion of drop-off-heights exceeding 2 inches, at least in the short term. However, there is little evidence that resurfacing with the safety edge treatment creates more high drop-offs than resurfacing without the safety edge treatment. Data for drop-off heights showed that the proportion of drop-offs on both treatment and comparison sites increased in the second and third years after resurfacing. There is no evidence that the safety edge treatment sites have more high drop-offs than comparison sites that did not have the safety edge treatment.

- Evaluation results for the effect of the safety edge treatment on run-off-road crashes and drop-off-related crashes on two-lane highways were variable and inconsistent. More sites and higher crash frequencies are needed to obtain consistent, statistically significant results. Two trends were evident in the EB analysis of run-off-road and drop-off-related crashes. First, the safety edge treatment generally appears to have a positive effect on safety for all site types except for sites with unpaved shoulders in Indiana. This variability in results has not yet been fully explained. Second, however, the negative safety edge effects for Indiana sites with unpaved shoulders may be explained by low frequencies of drop-off-related crashes on comparison sites in the period before resurfacing.

- There were not enough sites at which the safety edge treatment was applied on rural multilane highways to obtain meaningful evaluation results. However, the physical role of the safety edge treatment is no different on multilane highways than on two-lane highways. Results of the cross-sectional analysis, while not definitive, suggested that the safety edge treatment is effective on multilane highways.

- An increase in total crashes for the first 12–30 months after resurfacing has been noted in previous studies of the effect of resurfacing on crashes.(4) The observed increase in crash frequency for the period immediately after resurfacing may have resulted from this effect. The use of 3 years of crash data after resurfacing resulted in more realistic estimates of the safety effectiveness of the safety edge than analysis using 1–2 years of data.

- A test of the proportion of fatal and injury crashes after resurfacing indicated that the proportion of fatal and injury crashes decreased significantly after resurfacing. However, there was no apparent shift in crash severity distributions between sites that were resurfaced with and without the safety edge treatment.

- Resurfacing appears to increase crash frequencies, at least in the short term, and to reduce crash severities. Incorporating the safety edge treatment in a resurfacing project appears to reduce crash frequencies slightly but to have no effect on crash severities.

CHAPTER 8. RECOMMENDATIONS

The following recommendations can be made based on the results of the research presented in this report:

- The safety edge treatment is suitable for use by highway agencies under a broad range of conditions on two-lane highways. While the evaluation results for total crashes were not statistically significant, there is no indication that the effect of the safety edge treatment on total crashes is other than positive.

- That the overall effectiveness of the safety edge treatment found in this study was not statistically significant is not surprising given that the magnitude of that safety effect appears to be small (i.e., approximately 5.7 percent). However, the safety edge treatment is so inexpensive that its application under most conditions appears to be highly cost-effective. The effect of the safety edge treatment would be cost-effective for two-lane highways with traffic volumes over 1,000 vehicles per day even if its effectiveness were 2 percent rather than 5.7 percent.

- The cost-effectiveness of the safety edge treatment increases with increasing traffic volumes. For roads with higher traffic volumes, the safety edge treatment is highly cost-effective.

APPENDIX A. IDENTIFICATION OF DROP-OFF-RELATED CRASHES

All crashes obtained from participating agencies were screened, and crashes that were not relevant to the study were excluded. All remaining crashes were then classified into whether one or more of the involved vehicles ran off the road. Then, each run-off-road crash was classified as to whether it was potentially related to a pavement-edge drop-off. Differences in accident reporting between agencies led to individualized classification criteria for each agency. The classification criteria and data elements used for each agency are described in table 38.

Table 38. Classification criteria for crashes.

Classification	Georgia	Indiana	New York
Excluded crashes	Intersection and intersection-related	Intersection and intersection-related	Intersection and intersection-related and Non-reportable crashes and non-injury crashes (with less than $1,000 in property damage to any vehicle) since these crashes were not available for all years
Run-off-road crashes	If harmful event included a roadside object or If location of impact was off the roadway	If any vehicle collided with a roadside object or If manner of collision was ran-off-road or If primary factor was ran-off-road right or ran-off-road left	If accident type involved a roadside object or If location of first harmful event was off the roadway or If second event for any vehicle involved a roadside object
Drop-off-related crashes	If crash road type was defective shoulders or "holes, deep ruts, bumps" or If driver contributing factor indicated driver lost control	If primary factor was overcorrecting/over-steering	If contributing factor for any involved vehicle was defective shoulder

APPENDIX B. PAVEMENT-EDGE DROP-OFF DATA COLLECTION METHODOLOGY

This appendix presents the methodology used to collect field measurements for pavement-edge drop-offs.

SELECTION OF DATA COLLECTION LOCATIONS

Several data collection locations were selected within each resurfacing project site to obtain field measurements of pavement-edge drop-offs. Data collection locations were generally 2–4 mi apart. There were typically three to four data collection locations within each site, depending on the overall site length.

Each data collection location was predefined as being a specified distance, in whole miles, from the start of the site. Then, to remove bias from the data collection process, a random offset was added to the predefined distance. This random offset, selected separately for each data location, was 0.1–0.9 mi, in increments of 0.1 mi. The location defined by the predefined distance plus the offset was used as the starting point for data collection. Field data collection personnel were given discretion to move the starting point if the measurement location was clearly not representative of the roadway as a whole or if sight distance was too limited for measurements to be made safely. Data were not collected at a selected location if recent maintenance had occurred or if weather did not permit data to be collected safely or accurately.

FIELD MEASUREMENTS

Roadway characteristics were recorded at the selected starting point, and pavement-edge drop-off height was measured every 52 ft on both sides of the roadway over a 0.1-mi interval beginning at the starting point. A field data collection form is illustrated in figure 8. The data collection intervals are illustrated in figure 9. The measurements illustrated in the figure were repeated at intervals of 2–4 mi along the roadway, as previously described.

The roadway characteristics recorded at each data collection starting point included the following:

- Speed limit.
- Pavement type.
- Shoulder type.
- Shoulder grade.
- Shoulder width.
- Lane cross-slope.
- Lane width.
- Pavement edge drop-off shape.
- Grade.

Pavement Edge Drop-off Data Collection

County & State: ________________________ **Date:** __________________

Site: _______________ **Milepost:** __________ **(Page ___ of ___)**

Weather Condition: sunny partly cloudy overcast

Main St. (include gov and local names): _______________________________________

Begin cross-street: ____

End cross-street: ____

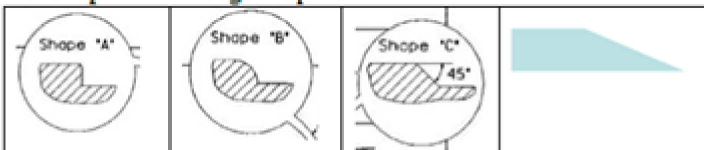
Speed Limit: ___________ **Orientation:** N / S E / W

Pavement Type: Asphalt Concrete

Shoulder Type:

asphalt	concrete	gravel	earth	mixed / varies
N / S / E / W	N / S / E / W	N / S / E / W	N / S / E / W	N / S / E / W

Circle pavement edge shape:



Sharp break-off or concrete	overlay, may be more jagged	Wedge in place	Safety Edge	Other (draw)
N / E S / W	N / E S / W	N / E S / W	N / E S / W	N / E S / W

random start point (mi)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9

	Grade (%)	Width (ft)
N or E Shoulder		
S or W Shoulder		
N or E Lane		
S or W Lane		
Road Grade (if sig)		up / down

Horizontal Curve left right none

Vertical crest sag none

Initial Grade ______ up down

Final Grade ______ up down

Roadside Rating ______

Additional Comments:

Dist from Start Pt	N / E	S / W
0 (ft)		
52 (ft)		
104 (ft)		
156 (ft)		
208 (ft)		
260 (ft)		
312 (ft)		
364 (ft)		
416 (ft)		
468 (ft)		
520 (ft)		

Figure 8. Illustration. Sample data collection form.

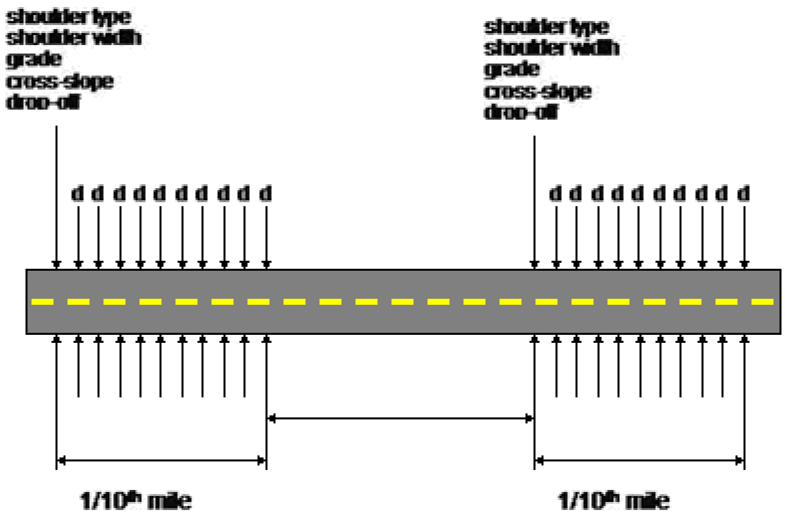


Figure 9. Illustration. Data collection intervals.

SHOULDER TYPE AND WIDTH

Shoulder types were generally recorded as paved, gravel, or earth. When a mixture of shoulder types was found (i.e., a composite shoulder), the width of paved shoulder beyond the edge of the traveled way was recorded and the presence of the other shoulder type was noted.

DROP-OFF SHAPE

Drop-off shapes are shown in the data collection form in figure 8. Shapes A, B, and C are defined in other literature.[2] Most shapes correspond to A, B, or C. Shape A typically corresponds to the edge of concrete pavement. The likely cause of such drop-offs is settling of the concrete pavement. Shape A may also occur when asphalt pavement breaks. Shape B is the most common shape for drop-offs at the edge of an asphalt pavement. It is the shape that occurs from a typical overlay. Shape C corresponds to the safety wedge. It is recorded when the edge shape is angled at approximately 45 degrees and appears to be intentionally shaped at that angle. Other drop-off shapes were also recorded when present.

LANE WIDTH AND PAVEMENT WIDTH

Both pavement widths (i.e., traveled way width) and lane widths were measured. Lane widths were measured from the edge of the lane to the painted centerline of the roadway. Where no centerline was present, the lane width was calculated as half of the total pavement width. Where pavement extended less than 4 inches beyond the pavement edge line, it was included in the lane width. Where pavement extended more than 4 inches beyond the pavement edge line, it was treated as a paved shoulder.

DROP-OFF HEIGHT

Drop-off height was measured to the nearest 0.125 inch since most measuring tools measure in 0.125-inch increments. Additionally, measurement tools marked with 0.125-inch increments are easier to read consistently than those marked with 0.1-inch increments. It is assumed that a tire could catch on just a few inches of drop-off, even if shoulder material is at grade beyond that distance. Therefore, drop-off height was measured approximately 4 inches from the edge of the pavement for shape A and 4 inches from the base of the pavement for shapes B and C (see figure 10).

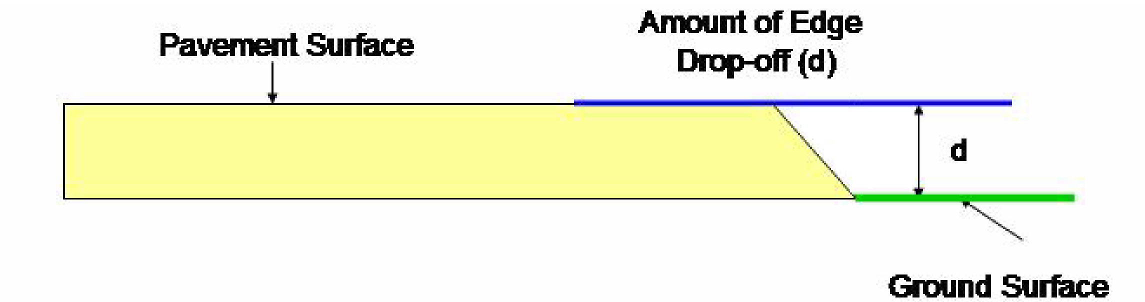


Figure 10. Illustration. Measurement of drop-off perpendicular to pavement surface.

Drop-off height was measured by placing a level across the top of the pavement surface so that it hung over the shoulder. A ruler was then used to measure the vertical distance between the shoulder and the level at the appropriate location. Drop-off height was measured from the ground to the base of the level, as shown in figure 11.

Figure 11. Photo. Measurement of pavement-edge drop-off height.

Pavement-edge drop-off height was not measured at driveways or minor intersections if they coincided with a planned data collection point. If a driveway or intersection was located at a data collection point along a segment, data collectors recorded that information and moved to the next data collection point.

APPENDIX C. SCATTER PLOTS OF ACCIDENTS AND AADT

Figure 12 through figure 16 are scatter plots of crashes (per mile per year) and traffic volume (log basis) that were used to determine the appropriateness of modeling assumptions. In general, these plots show a positive relationship between crashes and traffic volume (i.e., crashes increase with increasing volume). Also, distributions for comparison, treatment, and reference sites appropriately overlap each other and do not contain extreme outliers.

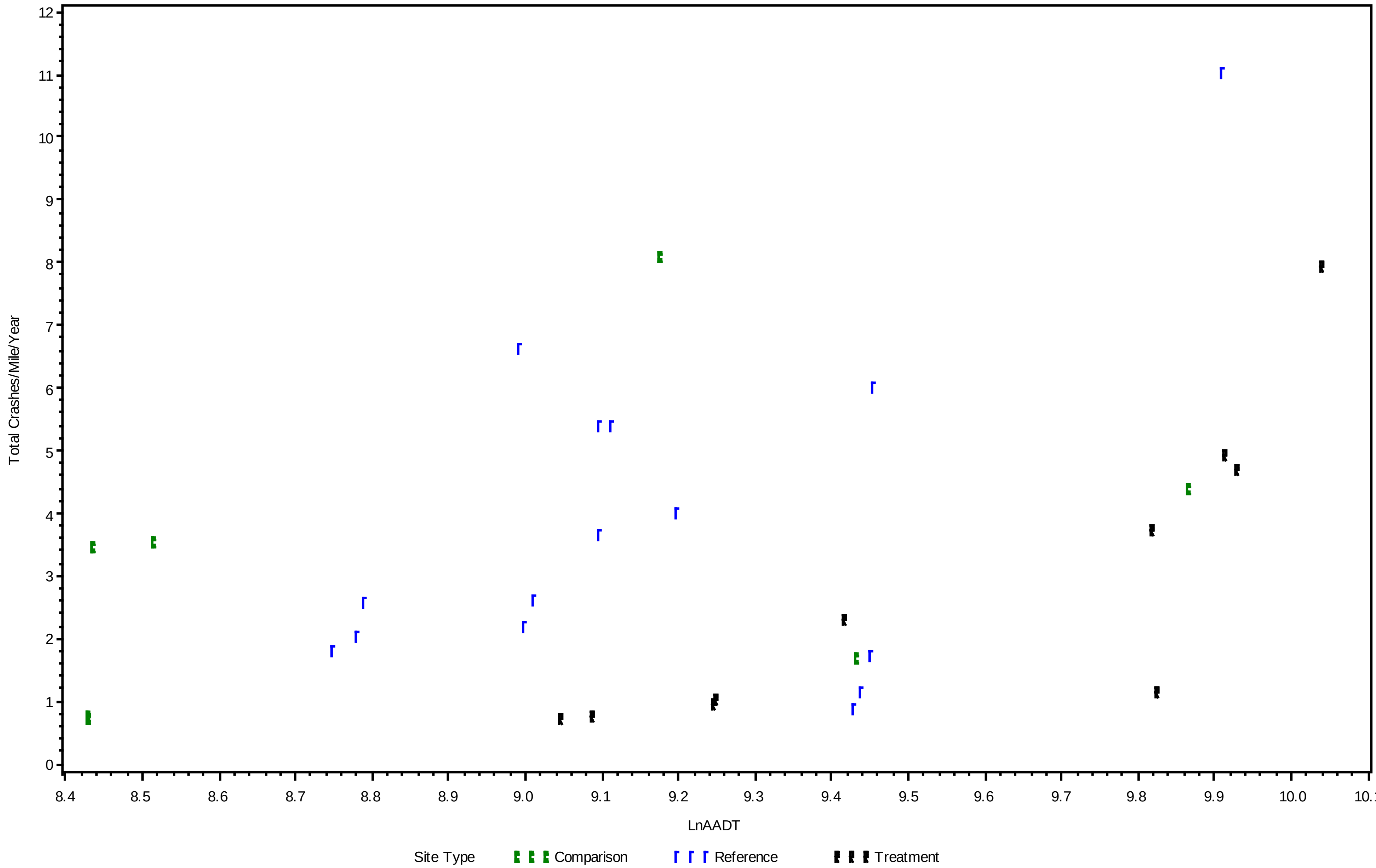


Figure 12. Graph. Georgia multilane roadway with paved shoulder.

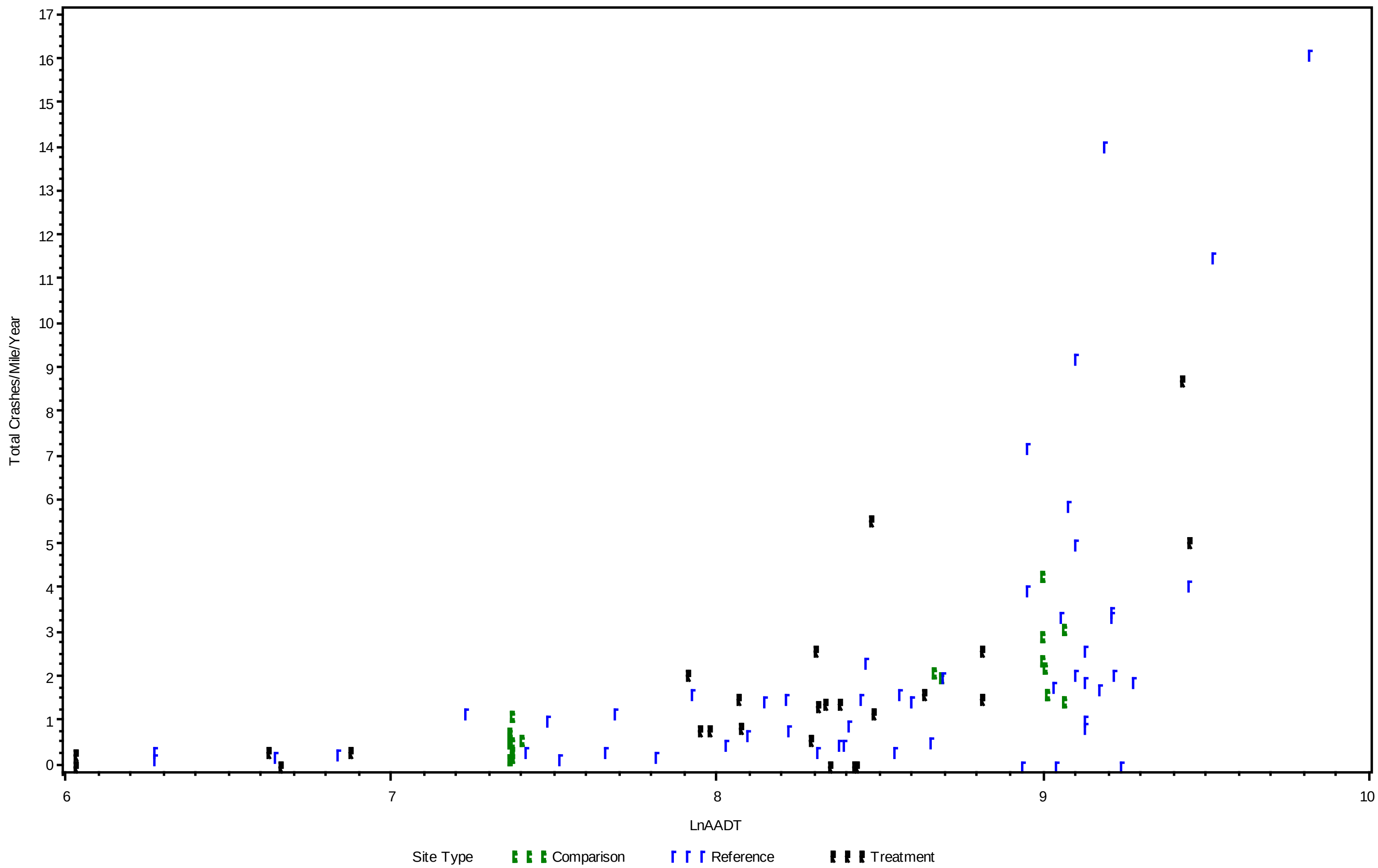


Figure 13. Graph. Georgia two-lane roadway with paved shoulder.

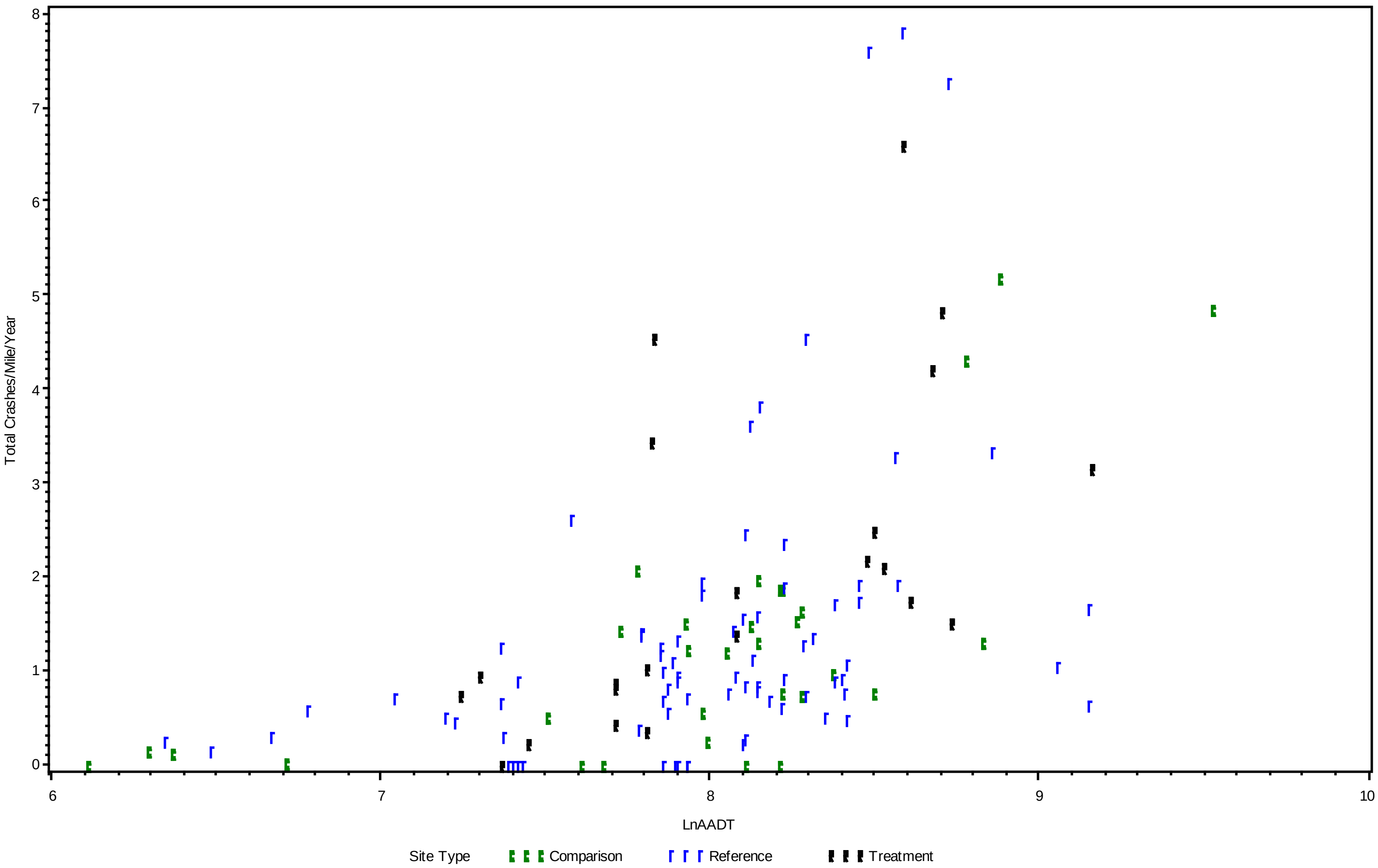


Figure 14. Graph. Georgia two-lane roadway with unpaved shoulder.

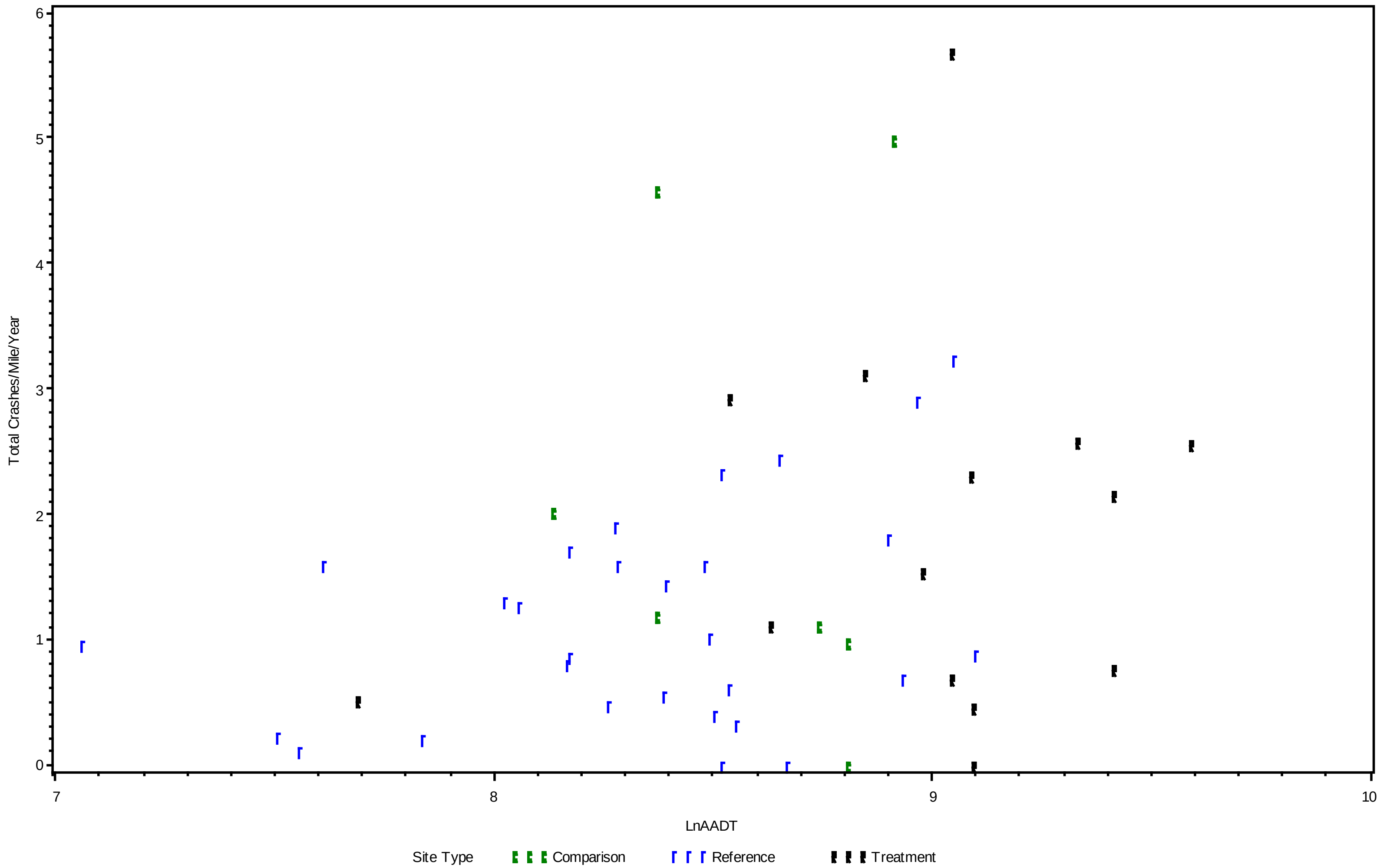


Figure 15. Graph. Indiana two-lane roadway with paved shoulder.

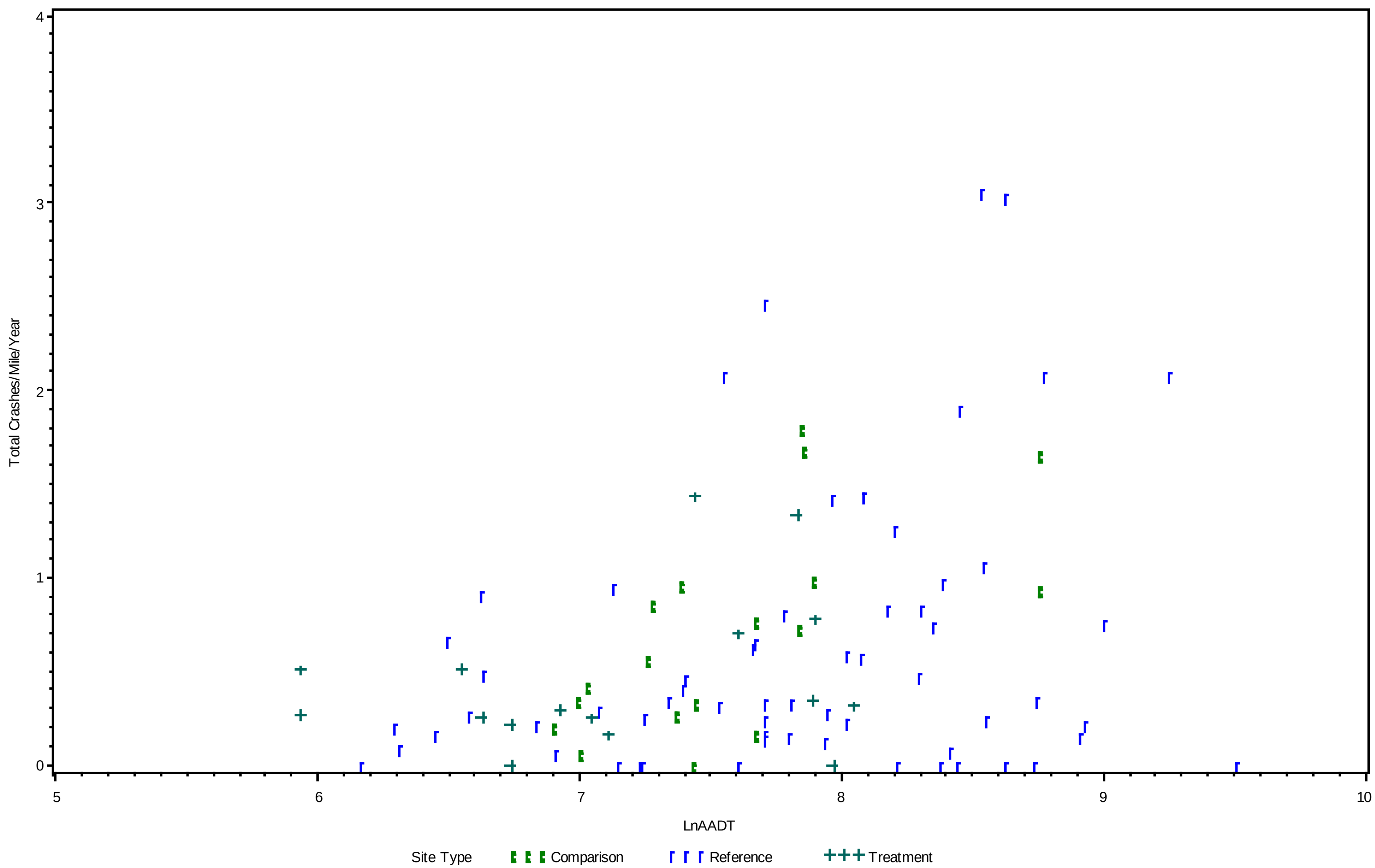


Figure 16. Graph. Indiana two-lane roadway with unpaved shoulder.

REFERENCES

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

2. Zimmer, R.A. and Ivey, D.L. (1983). "Pavement Edges and Vehicle Stability—A Basis for Maintenance Guidelines," *Transportation Research Record 946,* 48–56, Transportation Research Board, Washington, DC.

3. SAS Institute, Inc. (2008). *SAS/STAT® 9.2 User's Guide*, Cary, NC.

4. Hauer, E., Terry, D., and Griffith, M.S. (1994). "Effect of Resurfacing on Safety of Two-Lane Rural Roads in New York State," *Transportation Research Record 1467,* 30–37, Transportation Research Board, Washington, DC.

5. Hughes, W.E., Prothe, L.M., and McGee, H.W. (2001). *Impacts of Resurfacing Projects With and Without Additional Safety Improvements,* NCHRP Research Results Digest 255, Transportation Research Board, Washington, DC.

6. Hauer, E. (1997). *Observational Before-After Studies in Road Safety,* Pergamon/Elsevier Science, Inc., Tarrytown, NY.

7. Hauer, E., Harwood, D.W., Council, F.M., and Griffith, M.S. (2002). "Estimating Safety by the Empirical Bayes Method: A Tutorial," *Transportation Research Record 1784,* 126–131, Transportation Research Board, Washington, DC.

8. American Association of State Highway and Transportation Officials (2010). "SafetyAnalyst," Washington, DC. Accessed online: March 1, 2011. (http://www.safetyanalyst.org)

9. Hollander, M. and Wolfe, D.A. (1973). *Nonparametric Statistical Methods*. John Wiley & Sons, Inc., New York, NY.

10. U.S. Department of Transportation. (2008). *Revised Departmental Guidance: Treatment of the Value of Preventing Fatalities and Injuries in Preparing Economic Analyses,* Washington, DC. Accessed online: March 1, 2011. (http://ostpxweb.dot.gov/policy/reports/080205.htm)

HRDS-20/04-11(300)E