Midwest Research Institute

Safety Evaluation of the Safety Edge Treatment

Draft Final Report

For
University of North Carolina
Highway Safety Research Center

Federal Highway Administration
Office of Safety Research and Development

MRI Project No. 110495.1.001

April 2010

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For
University of North Carolina
Highway Safety Research Center
Chapel Hill, North Carolina 27599

Federal Highway Administration
Office of Safety Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101

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Preface

The work reported herein was performed under Subcontract 5-55697, Task Order 1, between the University of North Carolina—Chapel Hill (UNC-CH) and Midwest Research Institute (MRI), as part of the prime contract, "Development, Operation, and Maintenance of Highway Safety Information System (HSIS-V), between UNC-CH and the FHWA. This final report was prepared by Mr. Jerry L. Graham, Ms. Karen R. Richard, and Mr. Douglas W. Harwood. MRI looks forward to comments on this report from FHWA and UNC-CH.

MIDWEST RESEARCH INSTITUTE

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Section 1. Background and Research Objectives

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

1.1 Purpose of the Safety Edge Treatment

Two-lane rural highways often 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 0.3 to 1.2 m (1 to 4 ft.) If roadway maintenance forces do not keep material against the pavement edge, a pavement-shoulder drop-off may form. The drop-off height can vary from less than 25 mm (1 inch) to 152 mm (6 inches) or more, even though maintenance performance standards usually require maintenance when the drop-off exceeds 38 to 51 mm (1.5 to 2 inches) (*1*).

When a vehicle leaves the traveled way and encounters a pavement-shoulder drop-off, it may be difficult for the driver to return safely to the traveled way. As the driver attempts to steer back onto the roadway, the side of the tire may scrub along the drop-off, resisting the driver's attempts to steer and make a smooth reentry to the roadway. This resistance often leads to driver over-correction with a greater steering angle than desired to remount the drop-off. When the tire does remount the drop-off, the increased tire angle may "slingshot" the vehicle across the road, resulting in a collision with other traffic or 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 formed at a sloped angle of less than 45 degrees to lessen the resistance of the tire to remounting the drop-off (see Figure 1). The lessened resistance is intended to allow a more controlled reentry onto the traveled way.

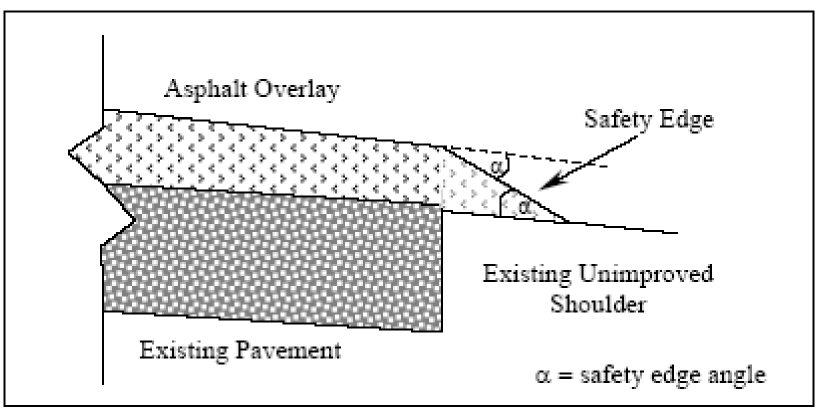

Figure 1. Safety Edge Detail

Selected highway agencies have begun to use the safety edge treatment as part of 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

Four state highway agencies have joined with FHWA in a pooled-fund study to implement and evaluate the safety edge treatment in conjunction with pavement resurfacing projects. The participating highway agencies are 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 extends over a three-year period. This final report presents the evaluation results for the three years after implementation of the treatment. Year 1 and Year 2 interim reports were prepared for the first and second year after implementation of the safety edge treatment (*2,3*). This final report discusses the entire three-year study.

The primary objective of the evaluation is to quantify the safety effectiveness of the safety edge treatment. An evaluation was performed to determine whether provision of 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 target crash types that can be expected from the provision of the safety edge treatment. Other objectives of the study are 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 uses the safety effectiveness evaluation results and project cost data to define the types of roadways and traffic volume levels for which provision of the safety edge treatment would be cost effective. Full details of the evaluation plan were presented in final work plan submitted to FHWA in May 2006 (*4*).

The project scope includes two-lane rural roads with no paved shoulder and with a paved shoulder no wider than 1.2 m (4 ft). Multilane roads with paved shoulders no wider than 1.2 m (4 ft) are also studied.

1.3 Summary of Evaluation Plan

The evaluation plan for the safety edge treatment is based on three 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 a *reference* sites).

This final report is based on data for the characteristics and performance of the treatment, comparison, and reference sites during the period before the treatment and comparison sites were resurfaced and for three years after resurfacing. Data collected and analyzed in this report includes field measurements of drop-offs present on the treated sites before, and during the three years after resurfacing; crash records for two to five years before the site was resurfaced and three years after resurfacing; traffic volumes and road characteristics for each site, and the date and cost of resurfacing of 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 three 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 three years after resurfacing. Two statistical approaches were used to analyze these data: (1) a before-after comparison using Empirical Bayes (EB) method 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.

For use in the before-after EB analysis to estimate the safety performance of the safety edge treatment, 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. All of the target crashes for the safety evaluation exclude at-intersection and intersection-related crashes, since the safety edge treatment is targeted primarily at nonintersection crashes.

Safety measures used as dependent variables for this report include the frequencies of total nonintersection 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 presented in the report, and findings are presented concerning the cost-effectiveness of the safety edge treatment.

1.4 Organization of This Report

The remainder of this report is organized as follows. Section 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. Section 3 presents the analysis results for the field measurements of pavement edge drop-offs. Section 4 presents the safety effectiveness evaluation. Section 5 presents project cost comparisons for sites resurfaced with and without the safety edge. Section 6 presents the benefit-cost economic analysis, Section 7 presents conclusions drawn from the analysis results, and Section 8 presents recommendations based on results of the three-year evaluation.

Section 2.
Project Database

Evaluation of the safety edge treatment requires 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 section of the report 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 site: 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); and sites that were similar to the treatment and comparison sites but were not resurfaced (referred to as *reference* sites).

Treatment sites were selected by the three participating states from among the sites considered for their normal resurfacing program for the year 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 Georgia Department of Transportation made a policy decision to include the safety edge treatment in all resurfacing projects let in April 2005 or thereafter. The treatment sites for this evaluation were drawn from among the projects let 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, a decision was reached to focus the analysis on three types of roadway segments:

- Rural multilane roadways with paved shoulders with widths of 1.2 m (4 ft) or less
- Rural two-lane roadways with paved shoulders with widths of 1.2 m (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 that did not receive the safety edge treatment. In Georgia, the comparison sites were resurfacing projects that were let to contract prior to April 2005 and, thus, before the date on which the Georgia Department of Transportation implemented 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 are located in the same highway districts as the treatment sites, so they are located in the same geographical area within the state.

Reference sites in each participating state include sites that had not been resurfaced during the study period before resurfacing of the treatment and comparison sites and were not expected to be resurfaced during the entire three-year study period. The reference sites include 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 as the length of treated sites in the state and often larger. Reference sites were chosen from the same highway districts as the treatment sites, so they are located in the same geographical area of the state. Input from district engineers was sought to ensure that the reference sites were similar to the treatment sites in that area. No reference sites were selected in New York because the reference sites are 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 can be included in other planned 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 includes 415 sites: 261 in Georgia, 148 in Indiana, and 6 in New York. The individual sites ranged in length from 0.2 to 41.5 km (0.1 to 25.8 mi). The total length of all segments considered in the study was 1,102 km (685 mi) in Georgia, 827 km (514 mi) in Indiana, and 40 km (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[a]	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

[a] Site types:
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 includes 90 sites, with a total length of 340 km (211 mi), at which the safety edge treatment was implemented. This includes 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 386 km (240 mi) and 240 reference sites with a total length of 1,245 km (774 mi).

2.2 Data Collection

A substantial amount of data has been collected and assembled into a database for consideration in the analysis phase of this study. The data collected include data for the period before resurfacing of the treatment and comparison sites and for three 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 includes the following data elements: location on the agency's highway system, project construction dates, and basic roadway characteristics. The basic roadway characteristics obtained include: 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 from 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 includes all nonintersection 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 is desirable to limit the evaluation to specific target crash types that are most likely affected by the implementation of safety edge treatment. If the crash data for both the before and after periods include crash types that could not conceivably be affected by the safety edge treatment, then this “noise” could introduce unnecessary variability into the crash counts that may 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, at the same time, the more restrictive the crash type definition used, the smaller the crash counts available for analysis; smaller crash counts make 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/shoulder edge drop-offs by Council (*5*) and Hallmark et al. (*1*). These studies identified five scenarios (crash sequences) under which over-steering may occur resulting in a crash related to a pavement edge drop-off. This report assumes that only these types of crashes and no other would be affected by provision of the safety edge.

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

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

Of course, head-on crashes may involve a vehicle that crossed the centerline without first running off the road; such head-on crashes have not been classified as drop-off-related nor treated as target crashes.

The target crash types described above represent ***potential*** drop-off-related crashes, defined as precisely as possible without obtaining and reviewing individual hard-copy police crash forms. Past research by Council (*5*) that 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 crashes.

Since the above methodology represents a narrow interpretation of drop-off-related crashes, it is also recommended that crashes which show evidence of a vehicle leaving the road or run-off-the-road crashes be included, such as:

- 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 (could be in road or 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 include 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:

- 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., also including PDO crashes) were also considered because the larger crash sample size including, PDO crashes may make it easier to detect statistically significant improvement effects. Although it is more desirable to consider only PDO crashes that are sufficiently severe that at least one of the involved vehicles is towed from the crash scene, since PDO tow-away crashes are more consistently reported than other PDO crashes, this exclusion was not applied in this study as only one of the participating states (Indiana) identified tow-away crashes in their data.

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

Indiana was only able to provide reference-point (i.e., milepost) information, as well as 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 Nonintersection Crash Data for Study Sites

State	Roadway type	Shoulder type	Site type[a]	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[b]: 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	1999 to 2004	2006 to 2008	25.5	250	58	12
			C	7	1999 to 2004	2006 to 2008	21.3	234	55	25
			R	29	1999 to 2004	2006 to 2008	101.3	646	176	59
		Unpaved	T	16	1999 to 2004	2006 to 2008	58.0	169	59	16
			C	18	1999 to 2004	2006 to 2008	71.2	287	145	73
			R	64	1999 to 2004	2006 to 2008	237.0	810	260	96
			Combined	148	1999 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

[a] Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge
R = Reference sites not resurfaced

[b] Does not include at-intersection or intersection-related crashes.

Table 3. Summary of Fatal-and-Injury Nonintersection Crash Data for Study Sites

State	Roadway type	Shoulder type	Site type[a]	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[b]: 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	1999 to 2004	2006 to 2008	25.5	37	14	3
			C	7	1999 to 2004	2006 to 2008	21.3	57	20	7
			R	29	1999 to 2004	2006 to 2008	101.3	129	73	29
		Unpaved	T	16	1999 to 2004	2006 to 2008	58.0	31	18	5
			C	18	1999 to 2004	2006 to 2008	71.2	83	58	32
			R	64	1999 to 2004	2006 to 2008	237.0	141	91	35
			Combined	148	1999 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

[a] Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge
R = Reference sites not resurfaced

[b] Does not include at-intersection or intersection-related crashes.

2.2.3 Traffic Volumes

Annual average daily traffic volume (AADT) 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 highways sites with paved shoulders in Georgia. For these sites, the AADT ranges are 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.

2.2.4 Lane Width

Lane widths ranged from 2.7 to 4.0 m (9 to 13 ft) across all sites and states, with the majority of lanes being 3.6 m (12 ft) wide. The distribution of lane width is summarized in Table 5 by state and site type. The variability in lane width is most evident for the unpaved shoulder type, so it was decided to include this variable in modeling efforts for these sites.

2.2.5 Field Drop-Off Measurements

Field visits were made to each treatment and comparison site to collect pavement edge drop-off measurements, as well as additional geometric design variables. Field measurements of pavement edge drop-offs were made before resurfacing and during each of the three years after resurfacing. However, some of the project sites were resurfaced before field visits could be made which prevented this supplemental data collection before resurfacing at some sites. The types of data collected and the methodology for collecting these data are documented in Appendix B.

Table 4. Summary of Traffic Volume Data for Study Sites

State	Roadway type	Shoulder type	Site type[a]	Number of sites	Site length (mi)	AADT (veh/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	1224.6	310	3,682	3,712	23,825

[a] Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge
R = Reference sites not resurfaced

Table 5. Summary of Lane Widths for Study Sites

State	Road type	Shoulder type	Site type	Number of sites	Site length (mi)	Lane width		
						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

Section 3.
Preliminary Analysis Results for Field Measurements of Pavement Edge Drop-Offs

This section 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 is effective in minimizing the development of pavement edge drop-offs in the period after resurfacing. Both of these analyses are discussed in this section.

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 of this report. 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 below.

3.1 Comparison of Pavement Edge Drop-Off Measurements for Treatment and Comparison Sites in the Period 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 that exceed 51 mm (2 in). This criterion was used based on research indicating that pavement edge drop-off heights that exceed 51 mm (2 in) 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 that exceed 51 mm (2 in) 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 software (*6*). 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 over 51 mm (2 in) 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 odds ratio could not be determined by maximum likelihood due to small sample size, complete separation of responses between factors [(i.e., when all observations for one site type are above 51 mm (2 inches) and all observations for the other site type are below 51 mm (2 inches), quasicomplete separation in responses (i.e., nearly complete separation), or overlapping responses (i.e., identical responses for each site type)], then an exact test was performed and a median unbiased estimate of the odds ratio is provided.

The results of this analysis for each state, roadway type, shoulder type, and treatment type combination, including the frequency and proportion of measurements above 51 mm (2 inches), the odds ratio point estimate, the odds ratio confidence interval, and 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 have a greater probability of experiencing drop-offs above 51 mm (2 inches) than treatment sites.

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 are relatively well matched in terms of shoulder conditions in the period before resurfacing. By contrast, for Georgia sites on two-lane highways with paved shoulders, evidence suggests that there is a statistically significant chance that comparison sites have greater proportions at drop-offs above 51 mm (2 inches).

For Indiana sites on two-lane highways with paved shoulders, there is a greater proportion of extreme drop-off heights for the comparison sites than for the treatment sites in the period before resurfacing, although it is not statistically significant. The opposite is 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 are not perfectly matched in terms of shoulder conditions in the period before resurfacing. For Indiana, this difference is 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 Pavement Edge Drop-Off Measurements for Treatment and Comparison Sites Between the Periods Before and After Resurfacing

The field measurement data for pavement edge drop-offs were initially reviewed by state, roadway type, shoulder type, and treatment type. For each study period, Table 7 presents summary descriptive statistics for these measures. Histograms for a sample of

Table 6. Comparison of the Proportions of Drop-Off Heights That Exceed 2 inches Between the Treatment and Comparison Sites for the Period Before Resurfacing

State	Roadway type	Shoulder type	Site type	Drop-off heights that exceed 2 inches: Number	Drop-off heights that exceed 2 inches: Proportion	Odds ratio point estimate	Lower confidence limit	Upper confidence limit	Statistically significant at 0.05 level?
GA	Multilane	Paved	T	2	0.07				
			C	5	0.06	0.909	0.184	6.596	N
	Two-lane	Paved	T	10	0.03				
			C	25	0.14	4.591	2.211	10.259	Y
		Unpaved	T	23	0.09				
			C	29	0.13	1.557	0.876	2.799	N
IN	Two-lane	Paved	T	6	0.04				
			C	10	0.10	2.519	0.902	7.642	N
		Unpaved	T	150	0.39				
			C	53	0.22	0.423	0.291	0.608	Y
NY	Two-lane	Paved	T	36	0.38				
			C	0	0.00	0.028	0.000	1.620	N[b]

[a] Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge
[b] Indicates that median unbiased estimate was used.

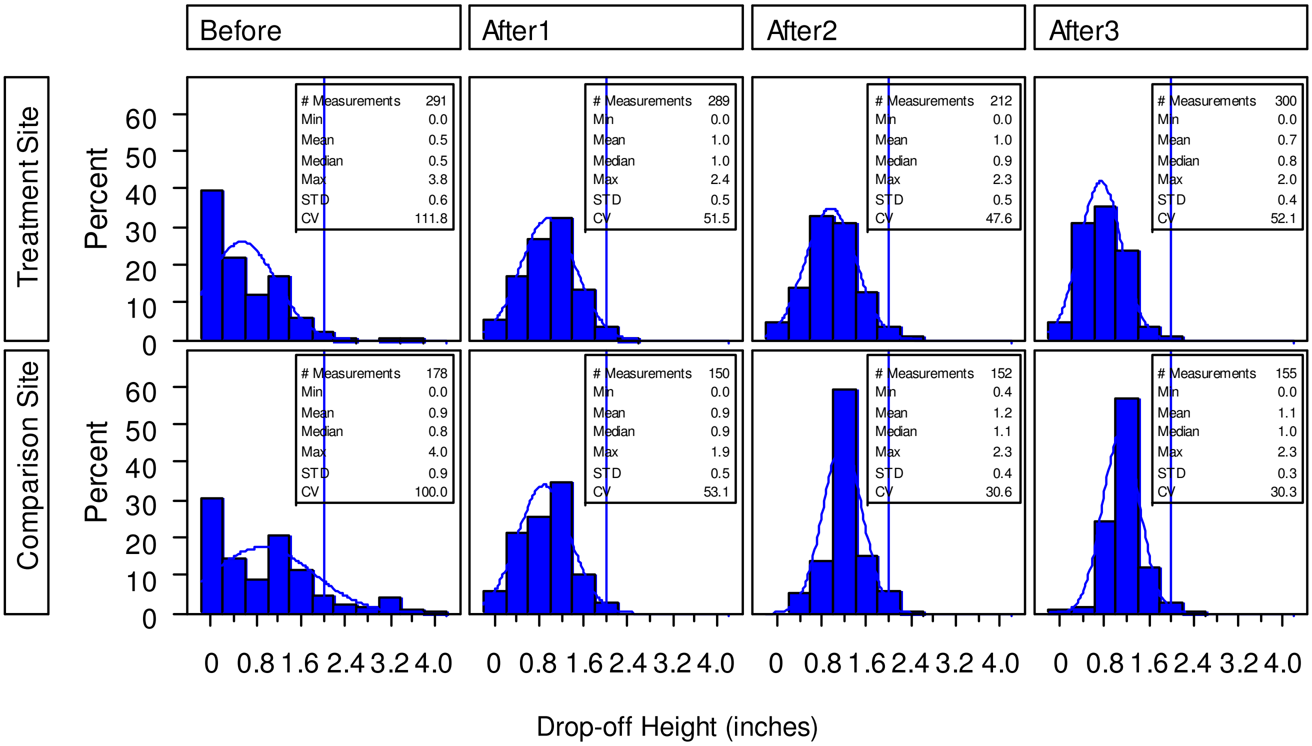

Figure 2. Drop-off Measurement Distributions for Two-Lane Highways With Paved Shoulders in Georgia

Figure 3. Exposed Safety Edge

Table 7. Summary of Pavement Edge Drop-Off Height Measurements

State	Road type	Shoulder type	Site type	Before resurfacing							After resurfacing						
				Number of measure-ments	Drop-off height (inches)						Number of measure-ments	Drop-off height (inches) (Year1)					
					Minimum	Mean	Median	Maximum	Standard deviation	Coefficient of variation %		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							After resurfacing						
				Number of measure-ments	Drop-off height (inches) (Year 2)						Number of measure-ments	Drop-off height (inches) (Year3)					
					Minimum	Mean	Median	Maximum	Standard deviation	Coefficient of variation %		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

the distributions in Figure 2 shows the impact of resurfacing for both treatment and comparison sites.

There appear to be differences in construction practices between the states. For some of the treatment sites in Indiana and New York, the shoulder materials were not pulled up, and therefore the safety edge was exposed. An example of this condition is shown in the photograph in Figure 3. This may also partially explain why 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 the before resurfacing and each of the first two years after resurfacing, but increased again following the second year after resurfacing.

To formally assess whether the safety edge treatment is effective in minimizing pavement/shoulder 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 that exceed 51 mm (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 that exceed 51 mm (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 period one 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 vs. After Year 1, After Year 1 vs. After Year 2, After Year 2 vs. After Year 3, and Before vs. After Year 3 have been summarized.

For Before vs. After Year 1, an odds ratio point estimate less than 1.0 indicates that After Year 1 has more drop-off heights that exceeds 51 mm (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 above 51 mm (2 inches), than the sites in the period before resurfacing. Also, the three cases when After Year 1 had more drop-off exceeding 51 mm (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.

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.

Table 8. Comparison of the Proportions of Drop-Off Heights That Exceed 2 inches for the Treatment and Comparison Sites Between the Periods Before and After Resurfacing

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 AfterY1 vs Before	0.06	0.06	1.05	0.28	3.92	N
			C	Period AfterY2 vs Before	0.03	0.06	1.80	0.43	8.99	N
			C	Period AfterY3 vs Before	0.08	0.06	0.73	0.21	2.39	N
			C	Period AfterY1 vs AfterY2	0.06	0.03	0.59	0.12	2.46	N
			C	Period AfterY1 vs AfterY3	0.06	0.08	1.44	0.44	5.03	N
			C	Period AfterY2 vs AfterY3	0.03	0.08	2.45	0.66	11.68	N
			T	Period AfterY1 vs Before	0.07	0.07	0.98	0.13	5.35	N
			T	Period AfterY2 vs Before	0.08	0.07	0.86	0.12	4.25	N
			T	Period AfterY3 vs Before	0.09	0.07	0.70	0.10	3.27	N
			T	Period AfterY1 vs AfterY2	0.07	0.08	1.15	0.29	4.83	N
			T	Period AfterY1 vs AfterY3	0.07	0.09	1.40	0.38	5.72	N
			T	Period AfterY2 vs AfterY3	0.08	0.09	1.22	0.35	4.44	N
	Two-lane	Paved	C	Period AfterY1 vs Before	0	0.14	infinity	12.13	infinity	Y
			C	Period AfterY2 vs Before	0.05	0.14	3.38	1.49	8.70	Y
			C	Period AfterY3 vs Before	0.03	0.14	6.17	2.33	21.32	Y
			C	Period AfterY1 vs AfterY2	0	0.05	infinity	3.24	infinity	Y
			C	Period AfterY1 vs AfterY3	0	0.03	infinity	1.60	infinity	Y
			C	Period AfterY2 vs AfterY3	0.05	0.03	0.55	0.14	1.86	N
			T	Period AfterY1 vs Before	0.03	0.03	1.11	0.44	2.83	N
			T	Period AfterY2 vs Before	0.02	0.03	1.85	0.61	6.82	N
			T	Period AfterY3 vs Before	0	0.03	10.64	2.02	195.83	Y
			T	Period AfterY1 vs AfterY2	0.03	0.02	0.60	0.16	1.86	N
			T	Period AfterY1 vs AfterY3	0.03	0	0.10	0.01	0.56	Y
			T	Period AfterY2 vs AfterY3	0.02	0	0.17	0.01	1.19	N
		Unpaved	C	Period AfterY1 vs Before	0.06	0.13	2.36	1.36	4.10	Y
			C	Period AfterY2 vs Before	0.1	0.13	1.29	0.78	2.12	N
			C	Period AfterY3 vs Before	0.08	0.13	1.68	0.99	2.84	N
			C	Period AfterY1 vs AfterY2	0.06	0.1	1.83	1.11	3.04	Y
			C	Period AfterY1 vs AfterY3	0.06	0.08	1.40	0.83	2.38	N
			C	Period AfterY2 vs AfterY3	0.1	0.08	0.77	0.48	1.23	N
			T	Period AfterY1 vs Before	0.03	0.09	2.73	1.28	6.34	Y
			T	Period AfterY2 vs Before	0.13	0.09	0.62	0.35	1.10	N
			T	Period AfterY3 vs Before	0.09	0.09	0.99	0.53	1.85	N
			T	Period AfterY1 vs AfterY2	0.03	0.13	4.39	2.13	9.99	Y
			T	Period AfterY1 vs AfterY3	0.03	0.09	2.76	1.28	6.46	Y
			T	Period AfterY2 vs AfterY3	0.13	0.09	0.63	0.35	1.12	N
IN	Two-lane	Paved	C	Period AfterY1 vs Before	0.17	0.10	0.58	0.25	1.24	N
			C	Period AfterY2 vs Before	0.27	0.10	0.31	0.13	0.66	Y
			C	Period AfterY3 vs Before	0.14	0.10	0.70	0.30	1.52	N
			C	Period AfterY1 vs AfterY2	0.17	0.27	1.88	1.01	3.53	Y
			C	Period AfterY1 vs AfterY3	0.17	0.14	0.83	0.43	1.57	N
			C	Period AfterY2 vs AfterY3	0.27	0.14	0.44	0.23	0.83	Y

Table 8. Comparison of the Proportions of Drop-Off Heights That Exceed 2 inches for the Treatment and Comparison Sites Between the Periods Before and After Resurfacing (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?
			T	Period AfterY1 vs Before	0.00	0.04	infinity	3.18	infinity	Y
IN	Two-lane	Paved	T	Period AfterY2 vs Before	0.01	0.04	8.58	1.44	163.10	Y
IN	Two-lane	Paved	T	Period AfterY3 vs Before	0.02	0.04	2.86	0.74	13.75	N
IN	Two-lane	Paved	T	Period AfterY1 vs AfterY2	0.00	0.01	infinity	0.15	infinity	N
IN	Two-lane	Paved	T	Period AfterY1 vs AfterY3	0.00	0.02	infinity	0.94	infinity	N
IN	Two-lane	Paved	T	Period AfterY2 vs AfterY3	0.01	0.02	3.00	0.38	60.92	N
IN	Two-lane	Unpaved	C	Period AfterY1 vs Before	0.11	0.22	2.21	1.37	3.61	Y
IN	Two-lane	Unpaved	C	Period AfterY2 vs Before	0.16	0.22	1.48	0.95	2.31	N
IN	Two-lane	Unpaved	C	Period AfterY3 vs Before	0.14	0.22	1.68	1.07	2.64	Y
IN	Two-lane	Unpaved	C	Period AfterY1 vs AfterY2	0.11	0.16	1.49	0.91	2.46	N
IN	Two-lane	Unpaved	C	Period AfterY1 vs AfterY3	0.11	0.14	1.32	0.80	2.18	N
IN	Two-lane	Unpaved	C	Period AfterY2 vs AfterY3	0.16	0.14	0.88	0.56	1.40	N
IN	Two-lane	Unpaved	T	Period AfterY1 vs Before	0.28	0.39	1.65	1.22	2.24	Y
IN	Two-lane	Unpaved	T	Period AfterY2 vs Before	0.42	0.39	0.88	0.66	1.18	N
IN	Two-lane	Unpaved	T	Period AfterY3 vs Before	0.30	0.39	1.52	1.12	2.06	Y
IN	Two-lane	Unpaved	T	Period AfterY1 vs AfterY2	0.28	0.42	1.86	1.37	2.54	Y
IN	Two-lane	Unpaved	T	Period AfterY1 vs AfterY3	0.28	0.30	1.09	0.79	1.49	N
IN	Two-lane	Unpaved	T	Period AfterY2 vs AfterY3	0.42	0.30	0.58	0.43	0.79	Y
NY	Two-lane	Paved	C	Period AfterY1 vs Before	0.02	0	-infinity	-infinity	3.18	N
NY	Two-lane	Paved	C	Period AfterY2 vs Before	0.12	0	-infinity	-infinity	0.37	Y
NY	Two-lane	Paved	C	Period AfterY3 vs Before	0.18	0	-infinity	-infinity	0.23	Y
NY	Two-lane	Paved	C	Period AfterY1 vs AfterY2	0.02	0.12	5.70	1.44	37.92	Y
NY	Two-lane	Paved	C	Period AfterY1 vs AfterY3	0.02	0.18	9.07	2.44	58.83	Y
NY	Two-lane	Paved	C	Period AfterY2 vs AfterY3	0.12	0.18	1.59	0.67	3.89	N
NY	Two-lane	Paved	T	Period AfterY1 vs Before	0.18	0.38	2.79	1.39	5.84	Y
NY	Two-lane	Paved	T	Period AfterY2 vs Before	0.27	0.38	1.68	0.88	3.26	N
NY	Two-lane	Paved	T	Period AfterY3 vs Before	0.27	0.38	1.72	0.91	3.30	N
NY	Two-lane	Paved	T	Period AfterY1 vs AfterY2	0.18	0.27	1.66	0.78	3.63	N
NY	Two-lane	Paved	T	Period AfterY1 vs AfterY3	0.18	0.27	1.62	0.77	3.52	N
NY	Two-lane	Paved	T	Period AfterY2 vs AfterY3	0.27	0.27	0.98	0.49	1.98	N

For After Year 1 vs. After Year 2, an odds ratio point estimate greater than 1.0 indicates that the second year after resurfacing has more drop-off heights that exceeds 51 mm (2 inches) than the first year after resurfacing. Since there were more drop-off heights greater than 51 mm (2 inches) in After Year 2, as compared to After Year 1, in 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 greater than 51 mm (2 inches) were statistically significant at the 5-percent significance level.

For After Year 2 vs. After Year 3, an odds ratio point estimate greater than 1.0 indicates that the third year after resurfacing has more drop-off heights that exceeds 51 mm (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 51 mm (2 in), there appears to be minimal deterioration of the shoulder condition in the third year after resurfacing.

The data for drop-off heights in the before period were compared to drop-off height data for After Year 3 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 the After Year 3 has more drop-off heights that exceeds 51 mm (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 in 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 provides an advantage in the preventive development of drop-offs. The results of this analysis are given in Table 9. Odds ratio values above 1.0 indicate that comparison sites have more drop-off heights above 51 mm (2 inches) than treatment sites.

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 resurfaced with the safety edge had fewer drop-offs for sites with paved shoulders. 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. Overall, these results taken together appear to be 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 and that resurfacing with the safety edge treatment may be no more effective than resurfacing without the safety edge treatment in reducing the proportion of extreme drop-off heights over time.

Table 9. Comparison of the Proportions of Drop-off Heights That Exceed 2 inches Between the 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	N
			T	5	0.08				
	Two-lane	Paved	C	6	0.04	1.034	0.341	2.922	N
			T	9	0.04				
		Unpaved	C	38	0.08	0.796	0.476	1.349	N
			T	27	0.1				
IN	Two-lane	Paved	C	21	0.14	10.332	3.470	44.394	Y
			T	3	0.02				
		Unpaved	C	41	0.14	0.384	0.256	0.567	Y
			T	112	0.3				
NY	Two-lane	Paved	C	10	0.12	0.382	0.161	0.858	Y

Section 4. Analysis Results for Safety Evaluation

This section presents analysis results for the safety evaluation. The section presents the 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 Empirical Bayes (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 have been 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 is 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 towards ("regress towards") the mean value over time. That is, if an observation in one year is unusually high, then the observation in the following year will nearly always be lower, returning to the mean (and vice versa). 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 is a concern, but is lessened by the availability of three 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 to 30 months after resurfacing (*7*). However, a more recent, larger study in NCHRP Project 17-9(2) (*8*) 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. 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.

To address the safety effect of resurfacing as well as the confounding effect of resurfacing and the safety edge treatment, the study design was developed in the following ways. First, the study period after resurfacing was selected to be three 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 evaluate 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 are being considered. Differences in 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 (*9, 10*). The specific version of the EB technique used in this evaluation was that developed for the FHWA *SafetyAnalyst* software tools (*11*). 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 approach, it is typical for data to be collected at sites where the safety edge treatment was 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 countermeasure was installed. Data from this reference group of sites (i.e., where no countermeasure was installed) are used to create safety performance functions (SPFs) which are then used together 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 resurfaced sites (i.e., treatment and comparison sites) is key 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 before treatment 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 an estimate of the effectiveness of (1) resurfacing with the safety edge (treatment sites), and (2) resurfacing only (comparison sites), separately 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 difference between the two measures of effectiveness (i.e., comparison–treatment). 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 is anticipated that the effectiveness measure being sought for the safety edge treatment will be relatively small since it is expected that the safety edge treatment will affect only certain crash types and will have the greatest impact on two-lane highways with no paved shoulders. Most such sites have relatively low traffic volume and are, therefore, not expected to have a high frequency of run-off-the-road and drop-off-related crashes**.**

The EB-based before-after comparison approach 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 approach 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, then 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 predicted crash frequencies of the sites for the period after resurfacing with the safety edge treatment to those resurfaced without the safety edge treatment. Site type (i.e., treatment vs. comparison which represents resurfacing with or without safety edge treatment) 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 Wilcoxin Signed Rank test

(*11*), 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.

4.2 Safety Performance Functions

This section documents the safety performance functions (SPFs) and the 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 expected 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 period after implementation of the treatment 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—for severity levels—total and fatal-and-injury crashes. Thus, a total of six dependent variables were considered for three target crash types and two crash severity levels. Traffic volume and lane width were the only independent variables considered in SPFs. Separate models were developed for Georgia and Indiana for each of the three classifications of roadways identified early in this report:

- Rural multilane highways with paved shoulders with widths of 1.2 m (4 ft or less)
- Rural two-lane highways with paved shoulders with widths of 1.2 m (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 following functional forms:

$$N = \exp\,(a + b\ \ln AADT) \qquad \textbf{(1)}$$

$$N = \exp\,(a + b\ \ln AADT + cLW) \qquad \textbf{(2)}$$

where:

N = predicted number of target crashes per mile per year
AADT = average daily traffic volume (veh/day) for the roadway segment

LW = lane width for the roadway segment
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 ADT values were average 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 also produced an estimate of the overdispersion parameter, or 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 re-fit assuming a constant value. Both methods were accomplished with the GENMOD procedure of SAS (*6*).

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 Tables 10 and 11 for Georgia and Indiana, respectively. 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 and fatal and injury crash SPFs are illustrated in Figures 4 and 5.

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
Property-damage-only 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
Property-damage-only 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
Property-damage-only 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

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
Property-damage-only 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
Property-damage-only 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
Property-damage-only 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

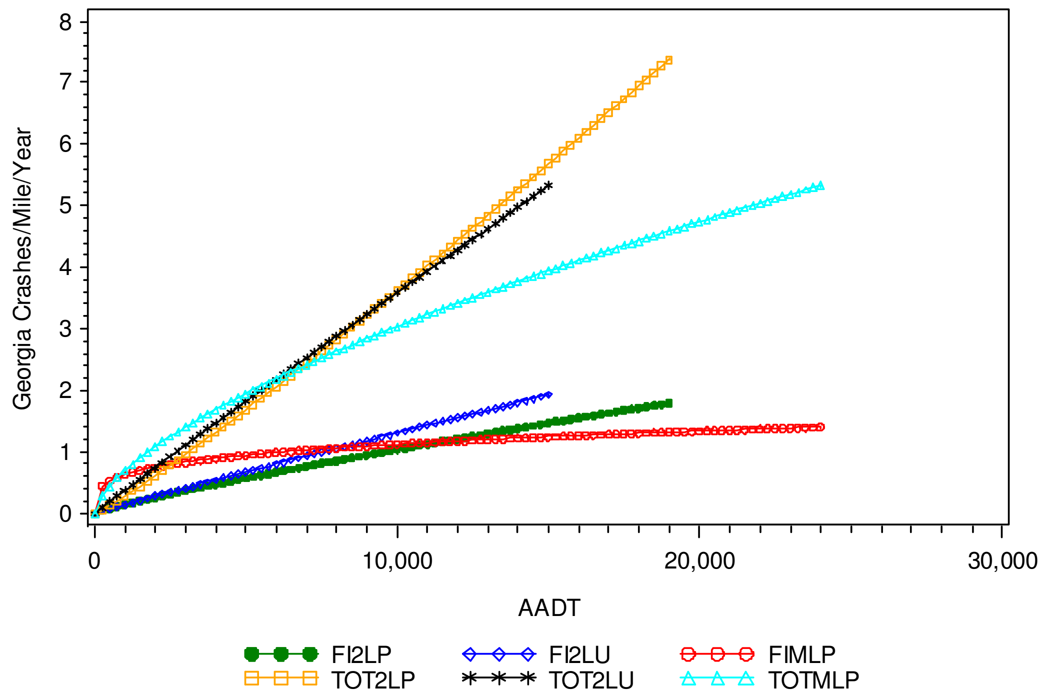

Figure 4. Comparison of Georgia SPFs by Crash Severity and Roadway and Shoulder Type

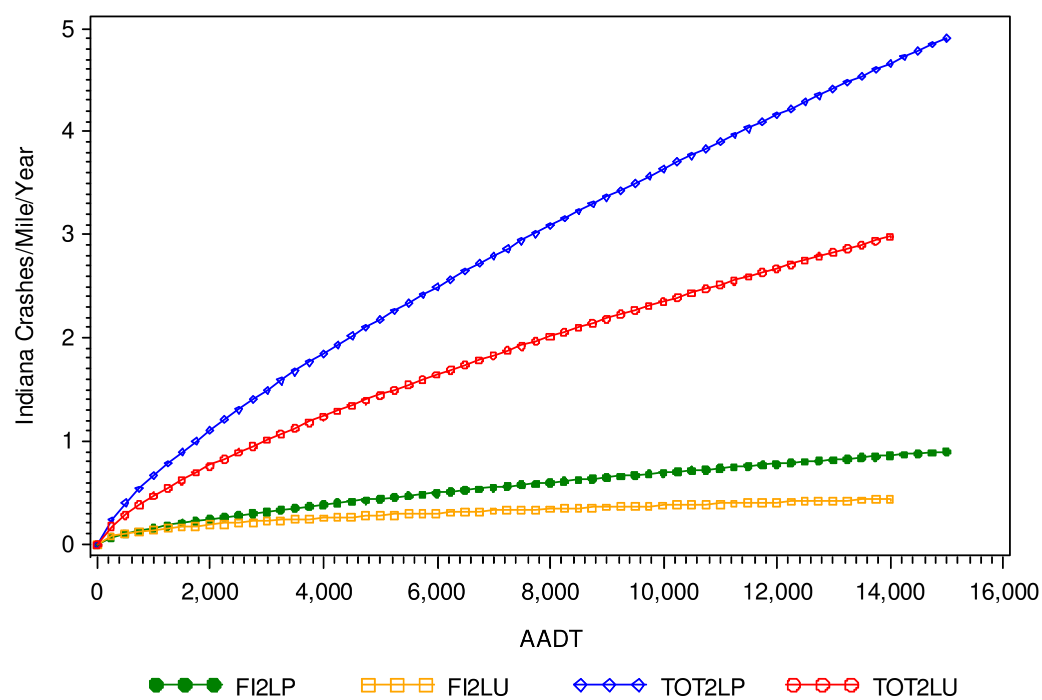

Figure 5. Comparison of Indiana SPFs by Crash Severity and Roadway and Shoulder Type

As noted above, the proportion of run-off-road and drop-off-related crashes, developed from reference sites, were 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

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 Tables 13 and 14 for Georgia and Indiana respectively.

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	1.705	1.814	1.920	1.706	1.966	2.160	1.799	1.782
		FI	1.590	1.908	1.669	2.032	2.068	2.076	1.692	1.663
		PDO	1.792	1.789	2.084	1.547	1.932	2.229	1.882	1.867
Two-lane	Paved	Total	1.927	2.138	2.057	2.320	2.185	2.285	2.222	2.180
		FI	2.209	2.336	2.360	2.625	2.667	2.718	2.578	2.453
		PDO	1.759	1.999	1.861	2.110	1.898	2.021	1.987	1.992
	Unpaved	Total	2.314	2.094	2.104	2.515	2.513	2.642	2.093	2.404
		FI	2.457	2.391	2.002	2.624	3.105	2.857	2.415	2.744
		PDO	2.233	1.920	2.165	2.451	2.166	2.517	1.905	2.209
Run-off-road crashes										
Multilane	Paved	Total	1.688	1.993	2.075	1.583	1.953	1.746	1.711	1.457
		FI	2.044	2.217	2.225	2.234	2.522	2.157	1.850	1.878
		PDO	1.664	2.078	2.236	1.330	1.814	1.695	1.821	1.363
Two-lane	Paved	Total	2.868	3.311	2.677	3.290	3.061	3.596	3.371	3.169
		FI	3.344	3.027	3.104	3.789	3.721	4.233	3.674	3.515
		PDO	2.510	3.541	2.353	2.910	2.560	3.112	3.127	2.901
	Unpaved	Total	2.752	2.696	2.755	3.024	3.343	3.230	2.625	2.979
		FI	2.840	2.937	2.081	3.106	3.496	3.089	2.774	3.164
		PDO	2.508	2.307	3.261	2.773	3.005	3.185	2.330	2.625
Drop-off-related crashes										
Multilane	Paved	Total	1.828	1.931	1.999	1.950	1.840	1.790	2.051	1.374
		FI	1.609	2.293	1.722	1.956	1.728	2.194	1.950	1.502
		PDO	2.056	1.546	2.280	1.937	1.952	1.353	2.144	1.234
Two-lane	Paved	Total	2.827	3.286	2.647	3.186	3.118	3.659	3.360	3.382
		FI	3.264	2.850	3.171	3.602	3.834	4.077	3.782	3.990
		PDO	2.386	3.724	2.121	2.758	2.404	3.222	2.916	2.763
	Unpaved	Total	2.828	2.642	2.887	3.146	3.522	3.582	3.020	3.309
		FI	3.050	3.088	2.084	3.009	3.597	3.578	3.401	3.535
		PDO	2.497	2.034	3.841	3.261	3.363	3.524	2.487	2.962

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	2.323	2.349	1.440	1.502	0.799	0.957
		FI	2.344	2.564	1.162	1.491	0.876	0.834
		PDO	2.361	2.340	1.538	1.534	0.794	1.006
	Unpaved	Total	3.763	2.995	1.864	1.645	1.083	0.786
		FI	2.884	3.161	1.485	1.486	0.906	0.576
		PDO	3.978	2.910	1.954	1.672	1.122	0.839
Run-off-road crashes								
Two-lane	Paved	Total	3.027	2.592	1.680	1.526	0.841	1.377
		FI	3.521	3.048	1.357	1.808	1.133	1.247
		PDO	2.893	2.452	1.918	1.437	0.721	1.503
	Unpaved	Total	3.044	2.618	1.451	1.100	0.848	0.538
		FI	2.695	3.299	1.594	1.411	0.735	0.490
		PDO	3.164	2.231	1.353	0.924	0.889	0.552
Drop-off-related crashes								
Two-lane	Paved	Total	2.748	2.614	1.785	1.189	1.192	1.908
		FI	1.862	1.840	0.923	1.105	0.742	0.742
		PDO	2.624	2.395	2.002	0.799	1.206	2.413
	Unpaved	Total	4.109	3.306	1.732	1.733	1.657	0.792
		FI	4.242	3.314	2.215	1.478	1.291	0.737
		PDO	4.033	3.310	1.425	1.902	1.896	0.830

4.3 Safety Evaluations

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

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 key 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 differs in the period before resurfacing, this may influence the comparison of treatment and comparison sites in the period after resurfacing.

Initial comparisons were made by examination of scatter plots of crashes and traffic volumes (crashes per mile per year vs. lnAADT). Ideal plots would contain no discernable differences between treatment and comparison sites as well as no extreme points. Separation of the data points between the two groups may indicate a potential concern in the subsequent analyses. Also, 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 also inhibit crash analysis of the treatment and comparison groups. Inspection of these plots with data from Year 3 showed an improvement in the plots from Year 1 and Year 2.

Yearly total crash and target crash distributions were also present 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, as well as between site types. Additionally, potential concerns for the crash analysis to be performed may be identified if the period after resurfacing is also included. Specifically, a regression-to-the-mean or resurfacing effect may be identified.

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 ideally be compared to the average of several years for the period after resurfacing. Therefore, if the after-period data is 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 is lower than the before period average, then the treatment effect will be a decrease in crash frequency. Examination of these graphs indicated that the after period year was 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 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, 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 the SAS software package (*6*), assuming a negative binomial crash distribution. 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 Tables 15 and 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 procedure. Regression coefficients with their standard errors are shown in the tables for each independent variable, including AADT and the treatment vs. 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.

Results from the analysis of EB-adjusted crash frequencies in Table 15 show that there tend to be significant differences between treatment and comparison site crash frequencies for Georgia sites with unpaved shoulders in the period before resurfacing. In these differences, comparison sites that had unpaved shoulders had lower crash rates than treatment sites. There also appears to be some evidence of differences in drop-off-related and run-off-road crashes for Georgia paved shoulder locations. Similarly, Indiana unpaved shoulder locations are different for drop-off-related crashes. These differences 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 is to be expected since EB-adjusted crashes are smoothed by the SPF model predictions, which causes smaller differences and less variation, 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, 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 Section 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 as the drop-off analysis indicated. That is, if drop-offs were more prevalent, then the sites had more crashes and vice versa. Similarly, two-lane highway sites with paved shoulders in Georgia had comparison sites with a significantly higher probability of having more high drop-offs, and the crash analysis showed comparison sites have more crashes, although the result was nonsignificant.

Table 15. Evaluation of Treatment vs. 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				Lane width effect				Treatment vs. comparison site effect				Dispersion parameter	R^2_{LR}%
						Coefficient	Standard error	p-value	Statistically significant?	Coefficient	Standard error	p-value	Statistically significant?	Coefficient	Standard error	p-value	Statistically significant?		
GA	Multilane	Paved	TOT	102	-3.794	0.558	0.139	0.000	Y					-0.510	0.440	0.246	N	0.242	29.4
			FI	102	-2.025	0.237	0.165	0.150	N					-0.407	0.394	0.302	N	0.050	8.7
			PDO	102	-5.792	0.728	0.167	0.000	Y					-0.544	0.516	0.292	N	0.289	34.2
			rorTOT	102	-4.699	0.515	0.197	0.009	N					-0.146	0.223	0.512	N	0.010	7.6
			rorFI	102	-3.285	0.281	0.179	0.117	N					-0.269	0.191	0.160	N	0.010	23.9
			rorPDO	102	-7.093	0.704	0.203	0.001	Y					-0.055	0.271	0.838	N	0.010	9.5
			doTOT	102	-3.247	0.347	0.182	0.057	Y					-0.058	0.198	0.770	N	0.010	14.8
			doFI	102	-2.825	0.222	0.143	0.120	N					-0.090	0.160	0.574	N	0.010	25.1
			doPDO	102	-5.030	0.467	0.218	0.032	Y					-0.030	0.240	0.899	N	0.010	16.9
	Two-lane	Paved	TOT	264	-11.713	1.440	0.089	0.000	Y					0.142	0.177	0.423	N	0.010	53.2
			FI	264	-11.002	1.289	0.109	0.000	Y					-0.120	0.164	0.464	N	0.010	30.4
			PDO	264	-13.251	1.525	0.095	0.000	Y					0.341	0.236	0.148	N	0.010	47.3
			rorTOT	264	-5.404	1.091	0.113	0.000	Y	-0.313	0.101	0.002	Y	-0.271	0.159	0.090	Y	0.010	22.2
			rorFI	264	-5.088	1.023	0.141	0.000	Y	-0.332	0.106	0.002	Y	-0.325	0.176	0.065	Y	0.010	4.7
			rorPDO	264	-7.195	1.100	0.101	0.000	Y	-0.254	0.143	0.076	Y	-0.179	0.182	0.324	N	0.010	14.6
			doTOT	264	-7.203	1.205	0.126	0.000	Y	-0.278	0.081	0.001	Y	-0.326	0.152	0.032	Y	0.010	16.4
			doFI	264	-6.801	1.164	0.135	0.000	Y	-0.318	0.116	0.006	Y	-0.365	0.190	0.055	Y	0.010	1.1
			doPDO	264	-11.799	1.212	0.118	0.000	Y					-0.124	0.131	0.346	N	0.010	11.3
		Unpaved	TOT	318	-8.207	1.023	0.102	0.000	Y					0.606	0.161	0.000	Y	0.010	59.9
			FI	318	-7.859	0.902	0.119	0.000	Y					0.238	0.154	0.122	N	0.010	39.8
			PDO	318	-9.337	1.062	0.072	0.000	Y					0.956	0.195	0.000	Y	0.010	57.5
			rorTOT	318	-7.210	0.833	0.096	0.000	Y					0.367	0.165	0.026	Y	0.010	38.0
			rorFI	318	-6.529	0.698	0.102	0.000	Y					0.201	0.145	0.166	N	0.010	22.9
			rorPDO	318	-9.259	0.944	0.089	0.000	Y					0.628	0.219	0.004	Y	0.010	29.9
			doTOT	318	-7.289	0.806	0.098	0.000	Y					0.285	0.153	0.062	Y	0.010	30.9
			doFI	318	-6.166	0.624	0.110	0.000	Y					0.203	0.138	0.142	N	0.010	15.9
			doPDO	318	-10.544	1.046	0.126	0.000	Y					0.453	0.206	0.028	Y	0.010	21.4

[a] Crash types and severity levels:
- 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

[b] At the 0.20 level.

Table 15. Evaluation of Treatment vs. Comparison Site Effect for the Period Before Resurfacing Using EB-Adjusted Crash Frequencies (Continued)

State	Roadway type	Shoulder type	Crash type and severity level	Number of site-years	Intercept	AADT effect				Lane width effect				Treatment vs. comparison site effect				Dispersion parameter	R^2_{LR}%
						Coefficient	Standard error	p-value			Standard error	p-value	Statistically significant?	Coefficient	Standard error	p-value	Statistically significant?		
IN	Two-lane	Paved	TOT	42	-10.642	1.394	0.066	0.000	Y					-0.486	0.288	0.092	Y	0.176	11.5
			FI	42	-21.857	2.639	0.234	0.000	Y					-0.941	0.362	0.009	Y	0.010	11.2
			PDO	42															0.0
			rorTOT	42	-3.740	0.396	0.271	0.145	N					-0.038	0.225	0.867	N	0.010	3.5
			rorFI	42	-4.948	0.472	0.113	0.000	Y					-0.090	0.127	0.479	N	0.010	31.4
			rorPDO	42															
			doTOT	42															
			doFI	42	-4.614	0.310	0.060	0.000	Y					-0.200	0.215	0.353	N	0.010	33.1
			doPDO	42															
		Unpaved	TOT	68	-0.756	0.757	0.222	0.001	Y	-0.455	0.107	0.000	Y	0.113	0.264	0.669	N	0.151	42.6
			FI	68	-1.978	0.475	0.167	0.005	Y	-0.223	0.068	0.001	Y	-0.116	0.210	0.580	N	0.010	4.7
			PDO	68	-1.404	1.070	0.291	0.000	Y	-0.672	0.158	0.000	Y	0.321	0.307	0.296	N	0.323	38.3
			rorTOT	68	0.129	0.558	0.209	0.008	Y	-0.457	0.105	0.000	Y	-0.067	0.233	0.774	N	0.010	37.3
			rorFI	68	0.376	0.314	0.123	0.011	Y	-0.343	0.046	0.000	Y	-0.035	0.141	0.806	N	0.010	0.4
			rorPDO	68	-2.553	1.239	0.435	0.004	Y	-0.804	0.301	0.008	Y	-0.025	0.463	0.957	N	0.627	21.6
			doTOT	68	-1.474	0.250	0.106	0.019	Y	-0.146	0.074	0.047	Y	-0.404	0.183	0.028	Y	0.010	5.4
			doFI	68	-1.785	0.168	0.058	0.004	Y	-0.127	0.044	0.004	Y	-0.250	0.114	0.029	Y	0.010	28.1
			doPDO	68	-2.436	0.326	0.189	0.084	Y	-0.173	0.134	0.196	Y	-0.586	0.327	0.073	Y	0.010	2.2

[a] Crash types and severity levels:
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

[b] At the 0.20 level.

Table 16. Evaluation of Treatment vs. Comparison Site Effect for the Period Before Resurfacing Using Observed Crash Frequencies

State	Roadway type	Shoulder type	Crash type and severity level[a]	Number of site-years	Intercept	AADT effect: Coefficient	AADT effect: Standard error	AADT effect: p-value	AADT effect: Statistically significant[b]	Lane width effect: Coefficient	Lane width effect: Standard error	Lane width effect: p-value	Lane width effect: Statistically significant[b]	Treatment vs. comparison site effect: Coefficient	Treatment vs. comparison site effect: Standard error	Treatment vs. comparison site effect: p-value	Treatment vs. comparison site effect: Statistically significant[b]	Dispersion parameter	R^2_{LR}%
GA	Multilane	Paved	TOT	102	-9.014	1.128	0.282	0.000	Y					-0.878	0.505	0.082	Y	0.378	27.7
			FI	102	-7.293	0.812	0.288	0.005	Y					-0.826	0.516	0.109	N	0.338	10.1
			PDO	102	-10.881	1.286	0.321	0.000	Y					-0.885	0.527	0.093	Y	0.505	27.3
			rorTOT	102	-7.749	0.822	0.268	0.002	Y					-0.295	0.225	0.188	N	0.015	15.0
			rorFI	102	-7.005	2.654	0.660	0.288	Y					-0.547	0.259	0.035	Y	0.010	5.6
			rorPDO	102	-9.207	3.372	0.911	0.353	Y					-0.119	0.282	0.672	N	0.010	16.2
			doTOT	102	-8.374	2.175	0.844	0.229	Y					-0.355	0.180	0.048	Y	0.010	11.9
			doFI	102	-8.785	2.656	0.809	0.287	Y					-0.442	0.221	0.046	Y	0.010	5.0
			doPDO	102	-9.387	3.466	0.884	0.364	Y					-0.304	0.272	0.264	N	0.010	7.6
	Two-lane	Paved	TOT	264	-8.045	0.982	0.130	0.000	Y					0.222	0.176	0.207	N	0.247	35.7
			FI	264	-7.646	0.852	0.143	0.000	Y					-0.121	0.152	0.426	N	0.018	21.3
			PDO	264	-10.106	1.147	0.139	0.000	Y					0.447	0.200	0.025	Y	0.436	30.8
			rorTOT	264	-3.346	0.666	0.121	0.000	Y	-0.220	0.161	0.172	Y	-0.231	0.206	0.261	N	0.166	13.9
			rorFI	264	-1.188	0.465	0.156	0.003	Y	-0.303	0.161	0.059	Y	-0.593	0.229	0.010	Y	0.073	7.2
			rorPDO	264	-8.299	0.834	0.118	0.000	Y					0.110	0.203	0.587	N	0.360	10.8
			doTOT	264	-6.541	0.673	0.173	0.000	Y					-0.297	0.173	0.086	Y	0.177	10.3
			doFI	264	-1.063	0.414	0.202	0.040	Y	-0.300	0.170	0.077	Y	-0.752	0.249	0.003	Y	0.173	5.7
			doPDO	264	-10.600	1.038	0.204	0.000	Y					-0.016	0.223	0.942	N	0.156	9.9
		Unpaved	TOT	318	-8.615	1.059	0.104	0.000	Y					0.610	0.174	0.000	Y	0.389	35.9
			FI	318	-8.473	0.940	0.097	0.000	Y					0.258	0.177	0.143	N	0.318	21.3
			PDO	318	-9.950	1.148	0.119	0.000	Y					0.864	0.197	0.000	Y	0.419	34.3
			rorTOT	318	-7.022	0.774	0.106	0.000	Y					0.441	0.194	0.023	Y	0.309	19.4
			rorFI	318	-7.358	0.740	0.109	0.000	Y					0.226	0.220	0.304	N	0.487	9.7
			rorPDO	318	-8.611	0.874	0.150	0.000	Y					0.653	0.228	0.004	Y	0.385	16.8
			doTOT	318	-7.106	0.736	0.132	0.000	Y					0.397	0.212	0.061	Y	0.247	15.6
			doFI	318	-6.937	0.645	0.139	0.000	Y					0.270	0.245	0.272	N	0.548	6.9
			doPDO	318	-9.469	0.922	0.188	0.000	Y					0.554	0.252	0.028	Y	0.361	12.5

[a] Crash types and severity levels:
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

[b] At the 0.20 significance level.

Table 16. Evaluation of Treatment vs. Comparison Site Effect for the Period Before Resurfacing Using Observed Crash Frequencies (Continued)

State	Roadway type	Shoulder type	Crash type and severity level[a]	Number of site-year	Intercept	AADT effect				Lane width effect				Treatment vs. comparison site effect				Dispersion parameter	R^2_{LR}%
						Coefficient	Standard error	p-value			Standard error	p-value	Statistically significant[b]	Coefficient	Standard error	p-value	Statistically significant[b]		
IN	Two-lane	Paved	TOT	42	-3.824	0.588	0.250	0.019	Y					-0.380	0.364	0.296	N	0.416	6.6
			FI	42	-7.523	0.850	0.606	0.161	N					-0.842	0.533	0.114	N	0.629	7.9
			PDO	42	-3.076	0.465	0.235	0.048	Y					-0.205	0.356	0.565	N	0.369	4.1
			rorTOT	42	-6.756	0.736	0.546	0.178	N					-0.468	0.396	0.237	N	0.446	5.1
			rorFI	42	-2.953	4.414	0.188	0.515	N					-0.830	0.457	0.069	Y	0.010	6.0
			rorPDO	42	-8.070	0.815	0.589	0.167	N					-0.092	0.432	0.831	N	0.461	5.0
			doTOT	42	-13.860	1.420	1.212	0.241	N					-0.996	0.503	0.048	Y	0.478	6.0
			doFI	42															0.0
			doPDO	42	-23.901	2.478	0.959	0.010	Y					-0.477	0.529	0.368	N	0.010	11.9
		Unpaved	TOT	68	-0.761	0.918	0.248	0.000	Y	-0.587	0.140	0.000	Y	0.188	0.297	0.525	N	0.435	35.8
			FI	68	-0.041	0.732	0.347	0.035	Y	-0.640	0.225	0.005	Y	-0.050	0.347	0.884	N	0.093	23.4
			PDO	68	-1.612	0.998	0.270	0.000	Y	-0.594	0.155	0.000	Y	0.269	0.304	0.377	N	0.527	31.5
			rorTOT	68	1.418	0.806	0.316	0.011	Y	-0.783	0.200	0.000	Y	-0.068	0.331	0.838	N	0.221	34.7
			rorFI	68	1.478	3.119	0.435	0.358	N	-0.608	0.212	0.004	Y	-0.268	0.340	0.431	N	0.010	18.7
			rorPDO	68	0.475	1.120	0.398	0.005	Y	-0.974	0.313	0.002	Y	0.091	0.365	0.804	N	0.377	29.2
			doTOT	68	1.029	0.101	0.386	0.794	N	-0.312	0.246	0.204	N	-1.107	0.596	0.063	Y	0.010	21.7
			doFI	68															0.0
			doPDO	68	-4.194	0.270	0.560	0.630	N					-1.090	0.699	0.119	N	0.584	6.4
NY	Two-lane	Paved	TOT	36	-5.328	0.674	0.085	0.000	Y					0.127	0.182	0.484	N	0.486	24.9
			FI	36	-6.943	0.766	0.113	0.000	Y					0.308	0.172	0.074	Y	0.674	19.3
			PDO	36	-5.467	0.625	0.083	0.000	Y					-0.030	0.204	0.884	N	0.813	15.7
			rorTOT	36	-4.846	0.480	0.085	0.000	Y					0.577	0.140	0.000	Y	0.243	19.6
			rorFI	36	-5.333	0.486	0.122	0.000	Y					0.643	0.175	0.000	Y	0.410	14.4
			rorPDO	36	-5.784	0.372	0.467	0.048	Y					0.475	0.1049	0.000	Y	0.010	13.0
			doTOT	36															
			doFI	36															
			doPDO	36															

[a] Crash types and severity levels:
- 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

[b] At the 0.20 significance level.

Results for Indiana sites on two-lane highways with paved shoulders are consistent with the results of the analysis of drop-off measurements, but the results for Indiana sites for 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 the period before resurfacing in Indiana for which crash data were available was only two years in duration, in comparison to a six-year duration for the period before resurfacing in Georgia. Thus, the variability of the Indiana crash frequencies would be expected to be higher. In most cases (with one exception noted above), 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 Method

An observational before-after evaluation was conducted using the EB method to estimate the safety effectiveness of the safety edge treatment. Separate before-after evaluations were conducted for resurfacing projects with safety edge (treatment sites) and resurfacing projects without the safety edge (comparison sites). Differences in these results were 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 four-year period from 2001 to 2004. The study period after resurfacing was the three-year period 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 the new driving conditions, and so the transition period during which drivers become adjusted to the resurfaced roadway 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 evaluation results.

The EB procedure was programmed and executed in the SAS software package (*6*). Effectiveness estimates and their precision estimates, along with their statistical significance, are presented for specific crash types in Tables 17 through 25.

The safety edge effect shown in the results tables is the difference between the before-to-after change in crash frequency for the comparison sites and the before-to-after change in crash frequency for the treatment sites. If the increase in crashes with resurfacing was greater at the comparison sites than at the treatment sites, this is an indication that the safety edge treatment was effective. In such cases, the safety edge effect is shown in the tables as a positive value. The estimate of the safety edge effectiveness is considered reliable only if the before-to-after changes in crash frequency for both the treatment and comparison sites are statistically significant.

Table 17. Before-After Empirical Bayes Evaluation Results for Total 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	Difference between C and T (%)	Both effects significant?
GA	Two-lane	Paved	T	25	1.521	10.839	Increase	7.125	N	N	9.112	N
			C	19	2.047	19.951	Increase	9.746	Y	Y		
		Unpaved	T	22	3.747	–20.705	Decrease	5.525	Y	Y	9.258	Y
			C	31	1.979	–11.447	Decrease	5.785	N	Y		
		Combined	T	47	1.35	–5.993	Decrease	4.439	N	N	5.358	N
			C	50	0.126	–0.635	Decrease	5.041	N	N		
IN	Two-lane	Paved	T	14	1.019	–10.949	Decrease	10.744	N	N	19.025	N
			C	7	0.624	8.076	Increase	12.95	N	N		
		Unpaved	T	16	0.76	12.931	Increase	17.025	N	N	-18.232	N
			C	18	0.49	–5.301	Decrease	10.811	N	N		
		Combined	T	30	0.305	–2.796	Decrease	9.172	N	N	3.863	N
			C	25	0.128	1.067	Increase	8.341	N	N		
GA & IN Com-bined	Two-lane	Paved	T	39	0.832	4.976	Increase	5.978	N	N	10.943	N
			C	26	2.038	15.919	Increase	7.811	Y	Y		
		Unpaved	T	38	2.999	–15.914	Decrease	5.307	Y	Y	6.028	Y
			C	49	1.936	–9.886	Decrease	5.107	N	Y		
		Combined	T	77	1.324	–5.294	Decrease	3.999	N	N	5.184	N
			C	75	0.025	–0.110	Decrease	4.318	N	N		

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Table 18. Before-After Empirical Bayes 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: Percent change	Direction	Standard error (%)	Statistically significant?: 5% level	10% level	Safety edge effect: Difference between C and T (%)	Both effects significant?
GA	Two-lane	Paved	T	25	0.085	0.887	Increase	10.476	N	N	14.766	N
			C	19	1.192	15.653	Increase	13.131	N	N		
		Unpaved	T	22	1.726	–16.555	Decrease	9.589	N	Y	–11.727	Y
			C	31	3.949	–28.282	Decrease	7.162	Y	Y		
		Combined	T	47	1.081	–7.691	Decrease	7.116	N	N	–5.467	N
			C	50	2.03	–13.158	Decrease	6.482	Y	Y		
IN	Two-lane	Paved	T	14	2.3	–41.468	Decrease	18.032	Y	Y	55.530	N
			C	7	0.519	14.062	Increase	27.118	N	N		
		Unpaved	T	16	4.778	–66.616	Decrease	13.942	Y	Y	38.608	Y
			C	18	1.976	–28.008	Decrease	14.177	N	Y		
		Combined	T	30	4.582	–52.991	Decrease	11.565	Y	Y	39.347	N
			C	25	1.051	–13.644	Decrease	12.978	N	N		
GA & IN Combined	Two-lane	Paved	T	39	0.62	–5.756	Decrease	9.284	N	N	21.375	N
			C	26	1.318	15.619	Increase	11.849	N	N		
		Unpaved	T	38	2.827	–23.754	Decrease	8.403	Y	Y	–4.409	Y
			C	49	4.402	–28.163	Decrease	6.398	Y	Y		
		Combined	T	77	2.319	–14.548	Decrease	6.275	Y	Y	1.350	Y
			C	75	2.275	–13.198	Decrease	5.802	Y	Y		

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Table 19. Before-After Empirical Bayes Evaluation Results for Property-Damage-Only 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: Difference between C and T (%)	Both effects significant?
GA	Two-lane	Paved	T	25	1.636	17.335	Increase	10.593	N	N	6.091	N
			C	19	1.389	23.426	Increase	16.868	N	N		
		Unpaved	T	22	3.213	–23.084	Decrease	7.184	Y	Y	28.831	N
			C	31	0.543	5.747	Increase	10.574	N	N		
		Combined	T	47	0.83	–5.087	Decrease	6.132	N	N	17.225	N
			C	50	1.344	12.138	Increase	9.035	N	N		
In	Two-lane	Paved	T	14	0.257	–3.424	Decrease	13.31	N	N	9.009	N
			C	7	0.361	5.585	Increase	15.486	N	N		
		Unpaved	T	16	1.944	56.408	Increase	29.02	N	Y	–47.300	N
			C	18	0.538	9.108	Increase	16.922	N	N		
		Combined	T	30	1.14	14.33	Increase	12.572	N	N	–6.642	N
			C	25	0.67	7.688	Increase	11.475	N	N		
GA & IN Com-bined	Two-lane	Paved	T	39	1.27	10.608	Increase	8.352	N	N	5.090	N
			C	26	1.359	15.698	Increase	11.548	N	N		
		Unpaved	T	38	1.627	–11.842	Decrease	7.28	N	N	18.823	N
			C	49	0.776	6.981	Increase	8.992	N	N		
		Combined	T	77	0.069	–0.381	Decrease	5.542	N	N	11.104	N
			C	75	1.507	10.723	Increase	7.116	N	N		

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Table 20. Before-After Empirical Bayes 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: Percent change	Direction	Standard error (%)	Statistically significant?: 5% level	10% level	Safety edge effect: Difference between C and T (%)	Both effects significant?
GA	Two-lane	Paved	T	25	1.729	12.479	Increase	7.218	N	Y	21.228	Y
			C	19	3.091	33.707	Increase	10.903	Y	Y		
		Unpaved	T	22	2.091	–12.721	Decrease	6.084	Y	Y	8.032	N
			C	31	0.753	–4.689	Decrease	6.224	N	N		
		Combined	T	47	0.096	–0.449	Decrease	4.697	N	N	8.675	N
			C	50	1.498	8.226	Increase	5.493	N	N		
IN	Two-lane	Paved	T	14	1.349	19.659	Increase	14.571	N	N	13.956	N
			C	7	2.09	33.615	Increase	16.081	Y	Y		
		Unpaved	T	16	2.134	46.94	Increase	21.995	Y	Y	–31.269	N
			C	18	1.193	15.671	Increase	13.136	N	N		
		Combined	T	30	2.385	29.203	Increase	12.242	Y	Y	–5.062	Y
			C	25	2.359	24.141	Increase	10.235	Y	Y		
GA & IN Com-bined	Two-lane	Paved	T	39	2.183	14.145	Increase	6.478	Y	Y	19.688	Y
			C	26	3.743	33.833	Increase	9.038	Y	Y		
		Unpaved	T	38	0.906	–5.406	Decrease	5.968	N	N	5.305	N
			C	49	0.018	–0.101	Decrease	5.649	N	N		
		Combined	T	77	1.066	4.703	Increase	4.414	N	N	7.723	N
			C	75	2.56	12.426	Increase	4.854	Y	Y		

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Table 21. Before-After Empirical Bayes 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: Difference between C and T (%)	Both effects significant?
GA	Two-lane	Paved	T	25	0.815	9.284	Increase	11.391	N	N	33.390	N
			C	19	2.594	42.674	Increase	16.453	Y	Y		
		Unpaved	T	22	0.313	–3.485	Decrease	11.116	N	N	–15.057	N
			C	31	2.277	–18.542	Decrease	8.143	Y	Y		
		Combined	T	47	0.407	3.247	Increase	7.98	N	N	–1.849	N
			C	50	0.184	1.398	Increase	7.602	N	N		
IN	Two-lane	Paved	T	14	2.669	–44.591	Decrease	16.708	Y	Y	54.941	N
			C	7	0.408	10.35	Increase	25.366	N	N		
		Unpaved	T	16	4.016	–62.254	Decrease	15.5	Y	Y	20.264	Y
			C	18	3.764	–41.99	Decrease	11.155	Y	Y		
		Combined	T	30	4.474	–51.956	Decrease	11.613	Y	Y	25.546	Y
			C	25	2.46	–26.41	Decrease	10.735	Y	Y		
GA & IN Combined	Two-lane	Paved	T	39	0.027	–0.266	Decrease	9.802	N	N	35.530	N
			C	26	2.531	35.264	Increase	13.935	Y	Y		
		Unpaved	T	38	1.261	–12.167	Decrease	9.646	N	N	–12.534	N
			C	49	3.706	–24.701	Decrease	6.665	Y	Y		
		Combined	T	77	0.842	–5.804	Decrease	6.896	N	N	0.129	N
			C	75	0.904	–5.675	Decrease	6.279	N	N		

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Table 22. Before-After Empirical Bayes Evaluation Results for Property-Damage-Only 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: Difference between C and T (%)	Both effects significant?
GA	Two-lane	Paved	T	25	1.402	14.183	Increase	10.113	N	N	11.006	N
			C	19	1.531	25.189	Increase	16.454	N	N		
		Unpaved	T	22	2.282	–17.461	Decrease	7.651	Y	Y	25.439	N
			C	31	0.758	7.978	Increase	10.532	N	N		
		Combined	T	47	0.416	–2.586	Decrease	6.218	N	N	16.779	N
			C	50	1.589	14.193	Increase	8.932	N	N		
IN	Two-lane	Paved	T	14	2.139	45.534	Increase	21.292	Y	Y	–3.236	Y
			C	7	1.941	42.298	Increase	21.79	N	Y		
		Unpaved	T	16	2.974	123.09	Increase	41.393	Y	Y	–21.854	Y
			C	18	2.629	101.24	Increase	38.504	Y	Y		
		Combined	T	30	3.562	69.622	Increase	19.546	Y	Y	–2.737	Y
			C	25	3.379	66.885	Increase	19.794	Y	Y		
GA & IN Combined	Two-lane	Paved	T	39	2.394	22.095	Increase	9.229	Y	Y	10.267	Y
			C	26	2.448	32.362	Increase	13.219	Y	Y		
		Unpaved	T	38	0.256	–2.057	Decrease	8.03	N	N	27.388	N
			C	49	2.364	25.331	Increase	10.716	Y	Y		
		Combined	T	77	1.686	10.312	Increase	6.117	N	N	18.149	N
			C	75	3.411	28.461	Increase	8.343	Y	Y		

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Table 23. Before-After Empirical Bayes 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: Percent change	Direction	Standard error (%)	Statistically significant?: 5% level	10% level	Safety edge effect: Difference between C and T (%)	Both effects significant?
GA	Two-lane	Paved	T	25	2.039	15.11	Increase	7.411	Y	Y	18.171	Y
			C	19	3.045	33.281	Increase	10.93	Y	Y		
		Unpaved	T	22	2.417	–14.442	Decrease	5.976	Y	Y	7.678	N
			C	31	1.111	–6.764	Decrease	6.089	N	N		
		Combined	T	47	0.079	–0.373	Decrease	4.713	N	N	6.910	N
			C	50	1.207	6.537	Increase	5.416	N	N		
IN	Two-lane	Paved	T	14	1.644	25.551	Increase	15.538	N	N	9.028	N
			C	7	2.121	34.579	Increase	16.302	Y	Y		
		Unpaved	T	16	2.341	53.782	Increase	22.974	Y	Y	–45.117	N
			C	18	0.702	8.665	Increase	12.348	N	N		
		Combined	T	30	2.732	35.459	Increase	12.977	Y	Y	–15.095	Y
			C	25	2.048	20.364	Increase	9.943	Y	Y		
GA & IN Combined	Two-lane	Paved	T	39	2.604	17.463	Increase	6.705	Y	Y	16.404	Y
			C	26	3.724	33.867	Increase	9.093	Y	Y		
		Unpaved	T	38	1.11	–6.554	Decrease	5.906	N	N	3.388	N
			C	49	0.578	–3.166	Decrease	5.478	N	N		
		Combined	T	77	1.256	5.614	Increase	4.469	N	N	4.618	N
			C	75	2.146	10.232	Increase	4.768	Y	Y		

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Table 24. Before-After Empirical Bayes 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	Direction	Standard error (%)	Statistically significant?: 5% level	10% level	Safety edge effect: Difference between C and T (%)	Both effects significant?
GA	Two-lane	Paved	T	25	1.088	12.92	Increase	11.871	N	N	28.561	N
			C	19	2.516	41.481	Increase	16.487	Y	Y		
		Unpaved	T	22	0.474	–5.197	Decrease	10.969	N	N	–15.034	N
			C	31	2.531	–20.231	Decrease	7.994	Y	Y		
		Combined	T	47	0.506	4.096	Increase	8.1	N	N	–4.390	N
			C	50	0.039	–0.294	Decrease	7.509	N	N		
IN	Two-lane	Paved	T	14	0.501	18.625	Increase	37.142	N	N	87.608	N
			C	7	2.148	106.23	Increase	49.457	Y	Y		
		Unpaved	T	16	1.026	–30.091	Decrease	29.324	N	N	70.598	N
			C	18	1.434	40.507	Increase	28.244	N	N		
		Combined	T	30	0.132	–3.166	Decrease	24.073	N	N	67.468	N
			C	25	2.556	64.302	Increase	25.16	Y	Y		
GA & IN Com-bined	Two-lane	Paved	T	39	1.203	13.625	Increase	11.326	N	N	37.391	N
			C	26	3.22	51.016	Increase	15.843	Y	Y		
		Unpaved	T	38	0.699	–7.223	Decrease	10.332	N	N	–5.215	N
			C	49	1.584	–12.438	Decrease	7.855	N	N		
		Combined	T	77	0.456	3.504	Increase	7.685	N	N	4.774	N
			C	75	1.131	8.278	Increase	7.321	N	N		

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Table 25. Before-After Empirical Bayes Evaluation Results for Property-Damage-Only 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: Difference between C and T (%)	Both effects significant?
GA	Two-lane	Paved	T	25	1.56	16.152	Increase	10.351	N	N	9.115	N
			C	19	1.511	25.267	Increase	16.726	N	N		
		Unpaved	T	22	2.55	–19.177	Decrease	7.521	Y	Y	24.692	N
			C	31	0.535	5.515	Increase	10.312	N	N		
		Combined	T	47	0.468	–2.914	Decrease	6.226	N	N	15.425	N
			C	50	1.413	12.511	Increase	8.855	N	N		
IN	Two-lane	Paved	T	14	1.511	26.263	Increase	17.379	N	N	–5.783	N
			C	7	1.194	20.48	Increase	17.154	N	N		
		Unpaved	T	16	2.609	78.666	Increase	30.155	Y	Y	–80.171	N
			C	18	0.109	–1.505	Decrease	13.857	N	N		
		Combined	T	30	2.82	43.334	Increase	15.364	Y	Y	–34.259	N
			C	25	0.833	9.075	Increase	10.89	N	N		
GA & IN Combined	Two-lane	Paved	T	39	2.146	19.132	Increase	8.917	Y	Y	4.494	Y
			C	26	1.957	23.626	Increase	12.074	N	Y		
		Unpaved	T	38	0.836	–6.393	Decrease	7.645	N	N	9.930	N
			C	49	0.425	3.537	Increase	8.315	N	N		
		Combined	T	77	1.114	6.534	Increase	5.868	N	N	4.888	N
			C	75	1.656	11.422	Increase	6.899	N	N		

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

The EB results indicate that for all two-lane sites in Georgia and Indiana combined the safety edge effect was +5.2 percent for total crashes, 7.7 percent for run-off-road crashes, and 4.6 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 1.2 m (4 ft) or less and sites with unpaved shoulders, the paved shoulder sites show more benefit of the use of the safety edge than for unpaved shoulders. The safety edge effect for sites with paved shoulders is 10.9 percent for total crashes, 19.7 percent for run-off-road crashes, and 16.4 percent for drop-off-related crashes. The results for run-off road and drop-off-related crashes are statistically significant at the 10 percent significance level, but the result for total crashes is not statistically significant. For sites with unpaved shoulders the safety edge effect was 6.08 percent for total crashes, 5.3 percent for run-off-road crashes and 3.4 percent for drop-off-related crashes. The result for total crashes is significant at the 10 percent significance level.

This result is somewhat unexpected, as one would expect that there are larger benefits from the use of the safety edge treatment on highways with unpaved shoulders, since potential drop-offs at such sites are closer to the travel lanes than for highways with paved shoulders and are, therefore, expected to be driven over more frequently. However, the sites with unpaved shoulders in both states have much lower ADTs than the sites with paved shoulders and the lower numbers of crashes in both the before and after resurfacing periods undoubtedly affected the effectiveness estimates.

In considering the states individually Georgia sites showed a safety edge effect of 5.4 percent for total crashes, 8.7 percent for run-off-road crashes and 6.9 percent for drop-off-related crashes. None of the results were statistically significant. Indiana sites had safety edge effects of 3.9 percent for total crashes, -5.1 percent for run-off-road crashes, and -15.1 percent for drop-off-related crashes. The negative results for run-off-road and drop-off-related crashes are 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 one and two years after resurfacing (*2, 3*). The analysis for data including three years after resurfacing, presented in this section of the report, includes additional comparisons because shoulder types and the two states were combined and compared. Fifty-nine of the 81 results for Year 3 evaluation showed positive safety edge effects; however, only 12 of these positive safety effects were statistically significant. While 22 of the observed effects were negative, e.g., comparison sites had fewer crashes than treatment sites, only 7 of these results were statistically significant.

The magnitude of the effects were 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 (*2, 3*). The overall impact of the safety edge was expected to be small, since drop-off-related crashes were 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 does make it more difficult for effect to be shown as statistically significant.

Table 26. Summary of Safety Effects From Year 3, Year 2 and Year 1 Results for Before-After Empirical Bayes 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	Y	12	8	2
Positive	N	47	14	13
Negative	Y	7	7	6
Negative	N	15	7	15
		81	36	36

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 approximately 5 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 appears 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 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. The safety edge effect was statistically significant for Georgia sites with paved shoulders, but not statistically significant for Indiana sites with paved shoulders.

Georgia sites with paved shoulders showed statistically significant safety edge treatment effects of approximately 20 percent for run-off-road and drop-off-related crashes. Indiana sites with unpaved shoulders had safety edge effects of -31 and -45 percent for run-off-road and drop-of-related crashes, respectively, but these effects were not statistically significant. When data from both states were combined, the safety edge treatment effects for paved shoulders were 20 and 16 percent for run-off-road and drop-off-related crashes, respectively. Both of these effects were statistically significant at the 10 percent significance level. The treatment effects for sites with unpaved shoulders were 5 and 3 percent for run-off-road and drop-off-related crashes, respectively. These small non-significant effects are probably influenced strongly by Indiana sites with unpaved shoulders.

The results 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 credible than the results for total crashes.

There are several potential biases and limitations that may influence these results. Specifically, these potential biases and limitations include:

- there were some observed differences between treatment and comparison sites for the period before resurfacing (see discussions in Sections 3.1 and 4.3.1) which could confound the analysis results.
- the sites with unpaved shoulders, where the safety edge treatment would be 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 evaluation of the crash data for the period after resurfacing at the treatment and comparison sites was conducted to directly compare their 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 cross-sectional 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 of this report, 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, which was used to assess the statistical significance of the treatment vs. comparison site effect. This analysis was conducted for each state/roadway type/shoulder type combination with PROC GENMOD in the SAS software package (*6*). Traffic volume and site type (treatment vs. 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 of this report.

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

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[a]	Number of site-years	Intercept	AADT effect				Treatment effect				Dispersion parameter	R^2_{LR}%	Safety edge effect[b] (%)
						Coefficient	Standard error	p-Value	Statistically significant?[b]	Coefficient	Standard error	p-Value	Statistically significant?[b]			
GA	Multilane	Paved	TOT	51	-13.212	1.542	0.309	0.000	Y	-0.655	0.305	0.032	Y	0.282	48.4	48.1
			FI	51	-12.940	1.360	0.332	0.000	Y	-0.293	0.257	0.254	N	0.027	30.4	25.4
			PDO	51	-14.627	1.656	0.372	0.000	Y	-0.703	0.345	0.042	Y	0.404	44.0	50.5
			rorTOT	51	-19.840	2.114	0.329	0.000	Y	-0.946	0.201	0.000	Y	0.010	66.5	61.2
			rorFI	51	-15.748	1.562	0.391	0.000	Y	-0.410	0.244	0.092	Y	0.010	20.3	33.6
			rorPDO	51	-23.547	2.462	0.308	0.000	Y	-1.280	0.240	0.000	Y	0.010	61.8	72.2
			doTOT	51	-19.432	2.029	0.446	0.000	Y	-0.882	0.219	0.000	Y	0.010	48.8	58.6
			doFI	51	-18.509	1.841	0.380	0.000	Y	-0.610	0.121	0.000	Y	0.010	23.6	45.7
			doPDO	51	-20.271	2.061	0.552	0.000	Y	-1.130	0.354	0.001	Y	0.010	34.5	67.7
	Two-lane	Paved	TOT	132	-8.695	1.104	0.121	0.000	Y	0.111	0.183	0.545	N	0.178	51.0	-11.7
			FI	132	-7.501	0.880	0.182	0.000	Y	-0.197	0.264	0.457	N	0.273	27.4	17.8
			PDO	132	-11.162	1.306	0.125	0.000	Y	0.414	0.193	0.032	Y	0.136	49.6	-51.2
			rorTOT	132	-7.654	0.902	0.161	0.000	Y	-0.120	0.260	0.645	N	0.279	30.3	11.3
			rorFI	132	-5.201	0.546	0.197	0.006	Y	-0.497	0.355	0.161	N	0.453	11.5	39.2
			rorPDO	132	-12.208	1.322	0.216	0.000	Y	0.342	0.328	0.298	N	0.283	29.3	-40.8
			doTOT	132	-8.244	0.927	0.163	0.000	Y	-0.153	0.301	0.611	N	0.287	25.9	14.2
			doFI	132	-5.844	0.582	0.193	0.003	Y	-0.368	0.383	0.337	N	0.589	8.7	30.8
			doPDO	132	-14.467	1.518	0.276	0.000	Y	0.328	0.415	0.428	N	0.209	24.9	-38.9
		Unpaved	TOT	159	-10.116	1.253	0.173	0.000	Y	0.581	0.225	0.010	Y	0.555	37.0	-78.7
			FI	159	-8.599	0.959	0.182	0.000	Y	0.415	0.226	0.066	Y	0.267	24.3	-51.5
			PDO	159	-12.683	1.498	0.199	0.000	Y	0.594	0.274	0.030	Y	0.683	34.0	-81.1
			rorTOT	159	-7.229	0.799	0.169	0.000	Y	0.341	0.222	0.125	N	0.270	17.9	-40.6
			rorFI	159	-8.063	0.834	0.193	0.000	Y	0.275	0.265	0.301	N	0.217	14.4	-31.6
			rorPDO	159	-8.374	0.840	0.177	0.000	Y	0.365	0.255	0.152	N	0.262	12.0	-44.0
			doTOT	159	-7.422	0.773	0.196	0.000	Y	0.379	0.262	0.149	N	0.301	14.2	-46.0
			doFI	159	-8.725	0.882	0.202	0.000	Y	0.297	0.257	0.248	N	0.128	14.0	-34.6
			doPDO	159	-8.048	0.728	0.243	0.003	Y	0.411	0.344	0.231	N	0.402	6.8	-50.9

[a] Crash types and severity levels:
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
[b] Percent difference between treatment and comparison sites.
[c] At the 0.10 level.

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[a]	Number of site-years	Intercept	AADT effect				Treatment effect				Dispersion parameter	R^2_{LR}%	Safety edge effect[b] (%)
						Coefficient	Standard error	p-Value	Statistically significant?[b]	Coefficient	Standard error	p-Value	Statistically significant?[b]			
			TOT	63												
			FI	63	-1.982	0.117	0.647	0.856	N	-0.819	0.582	0.159	N	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	N	-1.599	0.729	0.028	Y	0.010	3.0	79.8
		Paved	doPDO	63												
			TOT	102	-4.887	0.543	0.256	0.034	Y	-0.069	0.211	0.742	N	0.653	7.4	6.7
			FI	102	-5.650	0.493	0.313	0.115	N	-1.215	0.492	0.013	Y	0.757	9.4	70.3
			PDO	102	-5.657	0.594	0.269	0.027	Y	0.206	0.231	0.373	N	0.697	6.1	-22.9
			rorTOT	102	-3.429	0.273	0.396	0.491	N	-0.864	0.394	0.028	Y	0.527	8.7	57.9
			rorFI	102	-3.926	0.219	0.399	0.583	N	-1.689	0.610	0.006	Y	0.247	10.2	81.5
			rorPDO	102	-4.619	0.358	0.499	0.473	N	-0.486	0.417	0.244	N	0.972	3.4	38.5
			doTOT	102	-5.486	0.488	0.363	0.178	N	-1.206	0.389	0.002	Y	0.320	11.1	70.1
			doFI	102	-9.490	0.869	0.355	0.014	Y	-1.970	1.029	0.056	Y	0.010	9.3	86.0
IN	Two-lane	Unpaved	doPDO	102	-4.672	0.327	0.525	0.534	N	-0.990	0.407	0.015	Y	0.718	5.4	62.8
			TOT	18	-3.595	0.510	0.186	0.006	Y	-0.278	0.273	0.307	N	0.117	28.4	24.3
			FI	18	-9.373	1.040	0.134	0.000	Y	0.092	0.144	0.525	N	0.010	57.9	-9.6
			PDO	18	-2.241	0.311	0.281	0.268	N	-0.440	0.405	0.277	N	0.214	16.9	35.6
			rorTOT	18	-4.255	0.480	0.174	0.006	Y	-0.128	0.271	0.638	N	0.010	28.5	12.0
			rorFI	18	-9.553	1.035	0.101	0.000	Y	0.004	0.135	0.976	N	0.010	48.7	-0.4
			rorPDO	18												
			doTOT	18												
			doFI	18												
NY	Two-lane	Paved	doPDO	18												

[a] Crash types and severity levels:
- 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

[b] Percent difference between treatment and comparison sites.
[c] At the 0.10 level.

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 (*2,3*). Thus, as additional years of data have become available, more models are being 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. However, statistically significant results for the safety edge effect (treatment vs. 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. These results suggest 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:

- there were some observed differences between treatment and comparison sites for the period before resurfacing (see discussion in Sections 3.1 and 4.3.1) which could confound the analysis results
- the sites with unpaved shoulders, where the safety edge treatment would be expected to be most effective, also 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

4.3.4 Analysis of Shifts in the Crash Severity Distribution

An analysis was conducted to assess whether 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 significance level of 10 percent.

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 (*11*). The primary measures of interest presented in Table 28 for differences in proportion of fatal-and-injury crashes are:

- 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 non-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; 13 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.

Table 28. Comparison of Proportions of Fatal and Injury Crashes Before and After Resurfacing

Crash type[a]	State	Roadway type	Shoulder Type	Site type[b]	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
	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

Table 28. Comparison of Proportions of Fatal and Injury Crashes Before and After resurfacing (Continued)

Crash type[a]	State	Roadway type	Shoulder Type	Site type[b]	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?
				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

[a]Crash types:
TOT = Total Crashes
ROR = Run-off-road crashes
DO = Drop-off-related crashes
[b] Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Section 5. Estimated Cost of the Safety Edge Treatment

This section presents the analysis results for the cost of the safety edge treatment.

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 an additional cost to a resurfacing project. Costs of resurfacing for both treatment and comparison sites (i.e., sites resurfaced both with and without the safety edge), 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 of the cost, the contract cost or price actually bid for the project by the winning bidder, and the cost per ton of the hot-mix asphalt concrete (HMA) used to resurface the roadway and to form the safety edge.

The Georgia data set included 28 resurfacing projects (15 treatment and 13 comparison sites) and 557 km (345 mi) of roadway. A summary of the project costs for Georgia is shown in Table 29. Costs per mile of safety edge resurfacing vs. non-safety-edge resurfacing were found to be $110,000 vs. $140,000.

Table 29. Summary of Georgia Resurfacing Project Costs

	Weighted average cost		Nonweighted average cost	
Cost item	Safety edge sites	Comparison sites	Safety edge sites	Comparison
Engineer's estimate ($ million/mi)	$2.650	$1.353	$3.222	$1.272
Contract cost ($ million/mi)	$1.306	$1.353	$1.183	$1.268
HMA surfacing cost ($/ton)	$45.73	$43.05	$49.21	$42.97
HMA surfacing cost ($ million/mi)	----------	----------	$0.11	$0.14

The Indiana data set includes 16 resurfacing projects (8 treatment and 8 comparison sites) and 265 km (165 mi) of roadway. A summary of the project costs for Indiana is shown in Table 30. Costs per mile of safety edge resurfacing vs. non-safety edge resurfacing were found to be $140,000 vs. $150,000.

Table 30. Summary of Indiana Resurfacing Project Costs

Cost item	Weighted average cost		Nonweighted average cost	
	Safety edge sites	Comparison sites	Safety edge sites	Comparison
Engineer's estimate ($ million/mi)	$1.878	$1.766	$1.748	$1.691
Contract cost ($ million/mi)	$1.505	$1.419	$1.407	$1.388
HMA surfacing cost ($/ton)	$38.20	$35.51	$38.60	$35.65
HMA surfacing cost ($ million/mi)	----------	----------	$0.14	$0.15

The New York data set included 6 resurfacing projects (3 treatment and 3 comparison sites) and 40 km (25 mi) of roadway. A summary of the costs for New York projects is shown in Table 31. Costs per mile of safety edge resurfacing vs. non-safety-edge treatment were found to be $30,000 vs. $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 may differ in scope from those in Indiana and Georgia.

Table 31. Summary of New York Resurfacing Project Costs

Cost item	Weighted average cost		Nonweighted average cost	
	Safety edge	Comparison	Safety edge	Comparison
Engineer's estimate ($ million/mi)	$0.368	$0.881	$0.354	$0.737
Contract cost ($ million/mi)	$0.106	$0.145	$0.108	$0.143
HMA surfacing cost ($/ton)	$40.29	$49.18	$40.67	$51.71
HMA surfacing cost ($ million/mi)	----------	----------	$0.03	$0.04

The cost analyses for resurfacing with the safety edge treatments 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 less than without the safety edge treatment. This seems unlikely, so it seems possible that the projects without the safety edge treatment may have differed in scope from the projects with the safety edge treatment. Therefore, determining the cost of the safety edge treatment based on the total cost of resurfacing projects does not appear to be a satisfactory approach.

Table 32. Summary of Combined Georgia, Indiana, and New York Resurfacing Project Costs

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

5.2 Cost of Safety Edge Treatment Based on Amount of Asphalt Used

Another method to determine the cost of the safety edge treatment is to compute the amount of asphalt used to provide the safety edge treatment and multiply this quantity by the bid cost per ton of the HMA for that specific project. The HMA costs associated with the application of the safety edge treatment have been determined with Indiana data, as shown below in Table 33. The average HMA costs for the eight projects were determined to be $594 per km ($955 per mi) of safety edge treatment on both sides of the roadway. This appears to be the best available estimate for the safety edge treatment cost.

Table 33. Estimate Cost of Safety Edge Treatment in Indiana

Location	Project length (mi)	HMA thickness (in)	Wedge area[a] (ft^2)	Total wedge volume (ft^3)	Total HMA needed (tons)	HMA Cost[b]	HMA cost per mi
SR-18	16.43	1.5	0.1875	16,266	406.64	$12,769	$777.15
US -136	8.35	1.5	0.1875	8,267	206.66	$7,880	$943.72
SR-11	5.13	1.5	0.1875	5,079	126.97	$4,545	$886.05
SR-62	14.02	1.5	0.1875	13,880	347.00	$14,574	$1,039.50
US-231	6.31	1.5	0.1875	6,247	156.17	$6,950	$1,101.38
SR-17	6.54	1.5	0.1875	6,475	161.87	$6,151	$940.50
SR-39	15.59	1.5	0.1875	15,434	385.85	$13,891	$891.00
SR-68	14.00	1.5	0.1875	13,860	346.50	$14,900	$1,064.25
Average HMA cost of safety edge treatment (per mi)							$955.44

[a] Based on HMA thickness of 38mm (1.5 inches) for safety edge treatment.
[b] HMA costs per ton based on contract data.

Section 6.
Benefit-Cost Analysis

This section presents the results of a benefit-cost analysis of the safety edge treatment based on the results presented in this report.

6.1 Benefit-Cost Analysis Approach

The benefit-cost ratio for the safety edge treatment has been determined as:

$$\text{B/C} = \frac{(N_{FI} E_{SE} C_{FI} + N_{PDO} E_{SE} C_{PDO})(P/A, i\%, n)}{CC_{SE}} \quad \textbf{(3)}$$

where:

B/C	=	benefit-cost ratio
N_{FI}	=	number of fatal-and-injury crashes per mi per year before application of the safety edge treatment
N_{PDO}	=	number of property-damage-only crashes per mi per year before application of the safety edge treatment
E_{SE}	=	effectiveness (percentage 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 property-damage-only crashes reduced
(P/A, *i*, n)	=	uniform serves 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 ($ per mi)

6.2 Components of the Benefit-Cost Analysis

The following discussion documents 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 mi per year have been estimated for the benefit-cost analysis using the SPFs presented in Section 4.2 of this report. 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 separate SPFs and because using the individual state SPFs constitutes a sensitivity analysis of the results. The SPFs used in the benefit-cost analysis are as follows:

State	Roadway type	Shoulder type	Crash type and security level	Table
Georgia	Two-lane highway	Paved	All crashes	10
Georgia	Two-lane highway	Paved	E&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

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

SPF for total crashes from Table 10:

$$N_{TOT} = \exp(-8.921 + 1.108 \ln(1{,}000)) = 0.282 \text{ crashes per mi per year}$$

SPF for F&I crashes from Table 10:

$$N_{FI} = \exp(-7.818 + 0.853 \ln(1{,}000)) = 0.146 \text{ crashes per mi per year}$$

SPF for PDO crashes from Table 10:

$$N_{PDO} = \exp(-11.414 + 1.349 \ln(1{,}000)) = 0.123 \text{ crashes per mi per year}$$

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 4.3.2, the crash reduction effectiveness of the safety edge treatment is estimated as 5 percent. Continuing the computational example started above for Georgia two-lane highways with paved shoulders with a traffic volume of 1,000 veh/day, the crash reduction from the safety edge treatment would be estimated as:

For F&I crashes:

0.153 (0.05) = 0.007637 crashes reduced per mi per year

For PDO crashes:

0.129 (0.05) = 0.006444 crashes reduced per in per year

6.2.3 Crash Costs

The estimated crash costs used in this analysis are based on those currently used in *SafetyAnalyst* (*11*):

Fatal crash	$5,800,000
A injury crash	402,000
B injury crash	80,000
C injury crash	42,000
Property-damage-only crash	4,000

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:

0.007637 (150,980) + (.006444) (4,000) = $1,179 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* (*11*) and is representative of the real, long-term cost of capital (i.e., not including inflation).

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:

$$(P/A,\ i,\ n) = \frac{(1+i)^n - 1}{i(1+i)^n} \qquad \textbf{(4)}$$

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:

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

6.2.7 Treatment Cost

The cost of the safety edge treatment is estimated as $955 per mi for both sides of the road combined, as explained in Section 5.

6.2.8 Benefit Cost Ratio

The value of the benefit-cost ratio is computed using Equation (3). For the computational example presented above, the benefit-cost ratio is determined as:

$$B/C = \frac{(1{,}179)(6.002)}{955} = 7.410$$

The result indicates that the safety edge treatment provides more than 6 dollars in benefits for each dollar spent on the treatment. This computation example addressed sites with a traffic volume of 1,000 veh/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 Tables 34 through 37 for application of the safety edge treatment to the following types of roadways:

State/Roadway Type	Table
Georgia two-lane highways with paved shoulders	34
Indiana two-lane highways with paved shoulders	35
Georgia two-lane highways with unpaved shoulders	36
Indiana two-lane highways with unpaved shoulders	37

For each state and roadway type, benefit-cost analyses have been performed for traffic volumes ranging from 1,000 to 20,000 veh/day. The overall results of the benefit-cost analysis are illustrated in Figure 6.

For two-lane highways with paved shoulders, application of the safety edge treatment has benefit-cost ratios ranging from 7.4 to 85.8 for Georgia conditions and 7.8 to 60.2 for Indiana conditions. For two-lane highways with unpaved shoulders, the benefit-cost ratios for the safety edge treatment range from 7.3 to 123.8 for Georgia conditions and 5.4 to 25.3 for Indiana conditions.

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, and this is especially so for roadways with higher volume levels where higher crash frequencies are expected.

Table 34. Summary of Benefit-Cost Analysis for Application of Safety Edge Treatment on Georgia Two-Lane Roadways with Paved Shoulders

AADT (veh/day)	1,000	5,000	10,000	15,000	20,000
CRASH FREQUENCIES					
Total crashes per mi per year	0.282	1.675	3.611	5.659	7.784
F&I crashes per mi per year	0.146	0.575	1.039	1.469	1.877
PDO crashes per mi per year	0.123	1.079	2.748	4.748	6.999
F&I crashes per mi per year (adjusted)	0.153	0.583	0.991	1.337	1.646
PDO crashes per mi per year (adjusted)	0.129	1.093	2.620	4.322	6.138
SAFETY BENEFITS − Number of crashes reduced					
F&I crashes reduced per mi per year	0.008	0.029	0.050	0.067	0.082
PDO crashes reduced per mi per year	0.006	0.055	0.131	0.216	0.307
SAFETY BENEFITS − Dollars					
F&I crash reduction benefits ($)	1.179	4.618	8,005	10,957	13,653
PDO crash reduction benefits ($)	1,153	4,399	7,481	10,093	12,426
Total crash reduction benefits ($)	26	219	524	864	1,228
Present value of total benefits ($)	7,075	27,717	48,047	65,765	81,948
TREATMENT COST					
Cost of safety edge treatment (per mi)	955	955	955	955	955
BENEFIT-COST RATIO					
Benefit-cost ratio	7.4	29.0	50.3	68.9	85.8

Table 35. Summary of 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 mi per year	0.664	2.175	3.626	4.888	6.043
F&I crashes per mi per year	0.158	0.444	0.694	0.900	1.082
PDO crashes per mi per year	0.542	1.722	2.832	3.789	4.659
F&I crashes per mi per year (adjusted)	0.150	0.446	0.713	0.938	1.139
PDO crashes per mi per year (adjusted)	0.514	1.729	2.912	3.950	4.904
SAFETY BENEFITS − Number of crashes reduced					
F&I crashes reduced per mi per year	0.008	0.022	0.036	0.047	0.057
PDO crashes reduced per mi per year	0.026	0.086	0.146	0.198	0.245
SAFETY BENEFITS − Dollars					
F&I crash reduction benefits ($)	1,235	3,715	5,966	7,871	9,580
PDO crash reduction benefits ($)	1,133	3,369	5,384	7,081	8,600
Total crash reduction benefits ($)	103	346	582	790	981
Present value of total benefits ($)	7,415	22,297	35,810	47,242	57,502
TREATMENT COST					
Cost of safety edge treatment (per mi)	955	955	955	955	955
BENEFIT-COST RATIO					
Benefit-cost ratio	7.8	23.3	37.5	49.5	60.2

Table 36. Summary of 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 mi per year	0.377	1.822	3.588	5.335	7.068
F&I crashes per mi per year	0.144	0.673	1.307	1.927	2.538
PDO crashes per mi per year	0.226	1.151	2.320	3.496	4.676
F&I crashes per mi per year (adjusted)	0.147	0.672	1.293	1.896	2.487
PDO crashes per mi per year (adjusted)	0.231	1.150	2.296	3.439	4.581
SAFETY BENEFITS -- Number of crashes reduced					
F&I crashes reduced per mi per year	0.007	0.034	0.065	0.095	0.124
PDO crashes reduced per mi per year	0.012	0.057	0.115	0.172	0.229
SAFETY BENEFITS – Dollars					
F&I crash reduction benefits ($)	1,154	5,302	10,219	14.998	19,691
PDO crash reduction benefits ($)	1,108	5,072	9,760	14,311	18,774
Total crash reduction benefits ($)	46	230	459	688	916
Present value of total benefits ($)	6,928	31,822	61,334	90,021	118,185
TREATMENT COST					
Cost of safety edge treatment (per mi)	955	955	955	955	955
BENEFIT-COST RATIO					
Benefit-cost ratio	7.3	33.3	64.2	94.3	123.8

Table 37. Summary of 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 mi per year	0.409	1.263	2.053	2.728	3.338
F&I crashes per mi per year	0.118	0.235	0.317	0.376	0.426
PDO crashes per mi per year	0.336	1.027	1.662	2.202	2.689
F&I crashes per mi per year (adjusted)	0.106	0.236	0.329	0.398	0.456
PDO crashes per mi per year (adjusted)	0.302	1.028	1.725	2.330	2.882
SAFETY BENEFITS − Number of crashes reduced					
F&I crashes reduced per mi per year	0.005	0.012	0.016	0.020	0.023
PDO crashes reduced per mi per year	0.015	0.051	0.086	0.117	0.144
SAFETY BENEFITS − Dollars					
F&I crash reduction benefits ($)	864	1,984	2,825	3,473	4,020
PDO crash reduction benefits ($)	804	1,778	2,480	3,007	3,444
Total crash reduction benefits ($)	60	206	345	466	576
Present value of total benefits ($)	5,187	11,905	16,957	20,844	24,129
TREATMENT COST					
Cost of safety edge treatment (per mi)	955	955	955	955	955
BENEFIT-COST RATIO					
Benefit-cost ratio	5.4	12.5	17.8	21.8	25.3

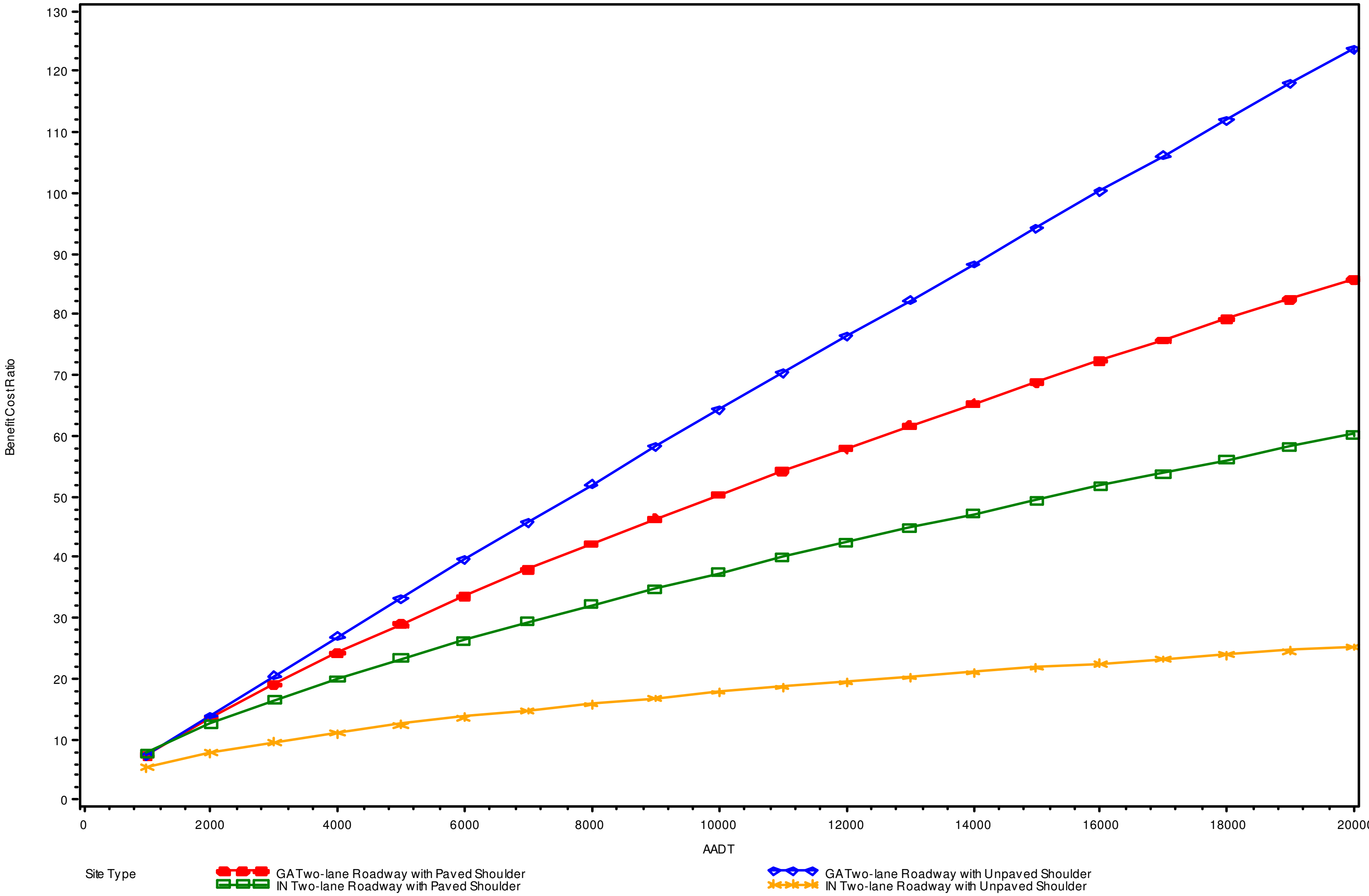

Figure 6. Benefit-cost Ratios by AADT

Section 7. Conclusions

Conclusions from the analysis of drop-off field measurements and crash data, based on three years of data for the period after resurfacing and after installation of the safety edge treatment, are presented below:

1. The EB evaluation results for the safety edge treatment with three years of crash data for the period after resurfacing found that 59 of the 81 comparisons show a positive safety effect for the safety edge treatment. However, only 12 of these comparisons were statistically significant, which may be due in part to the small magnitude of the safety edge effect.
2. The EB evaluation results indicate that for all two-lane highway sites in two states the best estimate of the effectiveness of the safety edge treatment is a reduction of approximately 5 percent in total crashes. While this result was not statistically significant the evaluation results obtained for total crashes were consistently in the positive direction. The effect of the safety edge treatment on total crashes was found to be statistically significant at the 10 percent significance level for two-lane highways with unpaved shoulders. The results of separate evaluations for fatal-and-injury crashes and property-damage-only crashes are too variable to draw conclusions.
3. 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 more variable and inconsistent. More sites and higher crash frequencies would be 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. The safety edge effect was usually statistically significant for Georgia paved sites, but not significant or significant in the negative sense for Indiana sites.
4. 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 and the results of the cross-sectional analysis, while not definitive, suggest that the safety edge treatment is effective on multilane highways.
5. An increase in total crashes for the first 12 to 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 result from this effect. The use of three years of crash data after

resurfacing resulted in more realistic estimates of the safety effectiveness of the safety edge.

6. A test of the proportion of fatal-and-injury crashes after resurfacing indicates that the proportion of fatal-and-injury crashes decreased significantly after resurfacing. However, there is no apparent shift in crash severity distributions between sites that were resurfaced with and without the safety edge treatment.
7. In summary, 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.
8. Field visits to sites resurfaced with the safety edge treatment found, in one state, that shoulder materials were not pulled up to the level of the pavement, leaving the safety edge exposed (see Figure 3). It is not known how this construction practice might affect the effectiveness of the safety edge treatment.
9. Resurfacing with or without the safety edge treatment was found to decrease the proportion of drop-off-heights that exceed 51mm (2 in), at least in the short term. However, there is little evidence that resurfacing with the safety edge treatment is more effective than resurfacing without the safety edge treatment in reducing the proportion of drop-off heights that exceed 51 mm (2 in). 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 present evidence that the safety edge treatment sites have fewer high drop-offs than the comparison sites that did not have the safety edge treatment.
10. The cost of adding the safety edge treatment to a resurfacing project is minimal. Comparisons of overall project costs and overall cost 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 suggest that the cost of the safety edge treatment is approximately $594 per km ($955 per mi) for application to both sides of the roadway combined.
11. Benefit-cost analysis based on the estimated 5 percent crash reduction effectiveness of the safety edge treatment found that this treatment is so inexpensive that it is highly cost-effective for application in a broad range of conditions on two-lane highways. Computed benefit cost ratios ranged from 7 to 86 for two-lane highways with paved shoulders and from 5 to 124 for two-lane highways with unpaved shoulders. The benefit-cost ratios generally increase with increasing traffic volume.

Section 8. Recommendations

1. 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.
2. Although the overall effectiveness of the safety edge treatment found in this study was not statistically significant, this is not surprising given that the magnitude of that safety effect appears to be small (i.e., approximately 5 percent). However, the safety edge treatment is so inexpensive that its application under most conditions appears to highly cost effective. The effect of the safety edge treatment would be cost effective for two-lane highways with traffic volumes over 1,000 veh/day even if its effectiveness were 1 percent, rather than 5 percent.
3. 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.

Section 9. References

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Appendix A
Identification of Drop-Off-Related Crashes

All crashes obtained from the 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 A-1.

Table A-1. 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 3 to 6 km (2 to 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 0.16 to 1.45 km (0.1 to 0.9 mi), increments of 0.16 km (0.1 mi). The location defined by the predefined distance plus the random offset was used as the starting point for data collection. Field data collection personnel were given discretion to move the starting point, if appropriate, 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 the 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 ever 16 m (52 ft) on both sides of the roadway over a 0.16-km (0.1 mi) interval beginning at the starting point. A field data collection form is illustrated in Figure B-1. The data collection intervals are illustrated in Figure B-2. The set of measurements illustrated in the figure was repeated at intervals of 3 to 6 km (2 to 4 mi) along the roadway, as described above.

The roadway characteristics recorded at the starting point of each data collection include:

- 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: ____

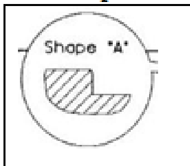
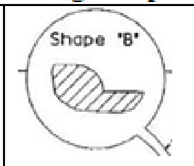
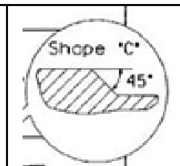
Speed Limit: __________ **Orientation:** N / S E / W

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	Squashed Wedge	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

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)		

Horizontal Curve left right none

Vertical crest sag none

Initial Grade ______ up down

Final Grade ______ up down

Roadside Rating ______

Additional Comments:

Figure B-1. Sample Data Collection Form

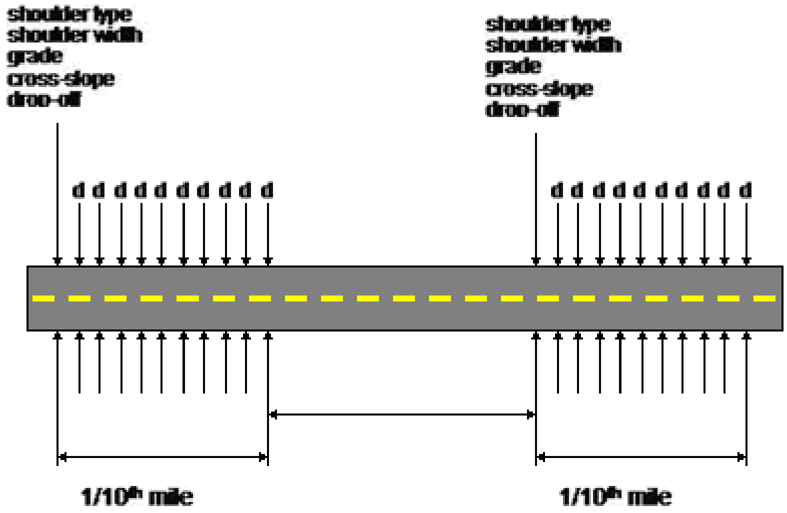


Figure B-2. Data Collection Intervals

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 B-1. Shapes A, B, and C were defined in other literature. Most shapes correspond to A, B, or C. Shape A typically corresponds to concrete pavement edge shape. The likely cause of such drop-offs is settling of the concrete pavement. It 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 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 100 mm (4 in) or less beyond the pavement edge line, it was included in the lane width. Where pavement extended 100 mm (4 in) or more beyond the pavement edge line, it was treated as a paved shoulder.

Drop-Off Height

Drop-off height was measured to the nearest 3.18 mm (0.125 in) since most measuring tools measure in 3.18 mm (0.125 in) increments. Additionally, measurement tools marked with 3.18 mm (0.125 in) increments have been found to be easier to read consistently than those marked with 2.54 mm (0.1 in) increments. It is assumed that a tire could still catch on just a few inches of drop-off, even if shoulder material is at grade beyond that distance. Therefore, drop-off height is measured approximately 100 mm (4 in) from the edge of pavement for Shape A, or 100 mm (4 in) from the base of the pavement for Shapes B and C (see Figure B-3).

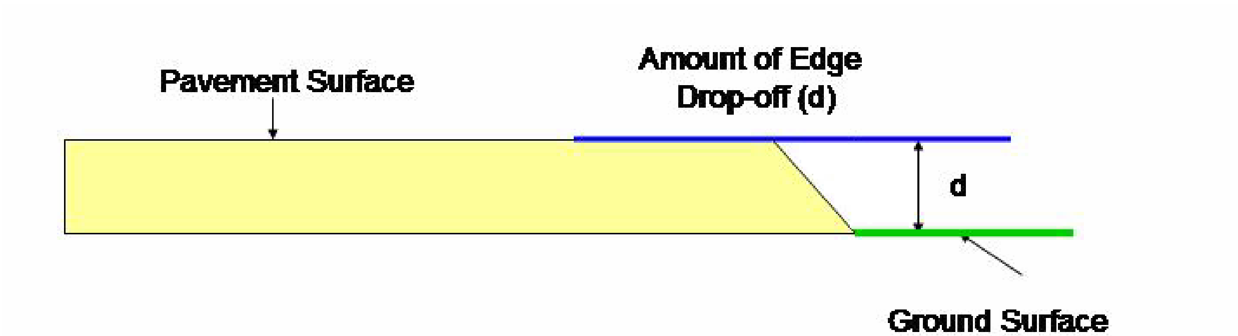


Figure B-3. Measurement of Pavement Edge Drop-Off Perpendicular to Pavement Surface

Drop-off height is measured by placing a level across the top of the pavement surface so that it overhangs the shoulder. A ruler is then used to measure the vertical distance between the shoulder and the level at the appropriate location as discussed above. Drop-off height is measured from the ground to the base of the level as shown in Figure B-4.

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

Figure B-4. Measurement of Pavement Edge Drop-Off Height