Safety Evaluation of the Safety Edge Treatment

Year 1 Interim 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 2008

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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. The work was performed in MRI's Engineering Division, directed by Dr. Robert G. Barton. This interim 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 that will be considered in the Year 2 analysis.

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 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 1 in to 6 in or more, even though maintenance performance standards usually require maintenance when the drop-off exceeds 1.5 to 2 in (*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.

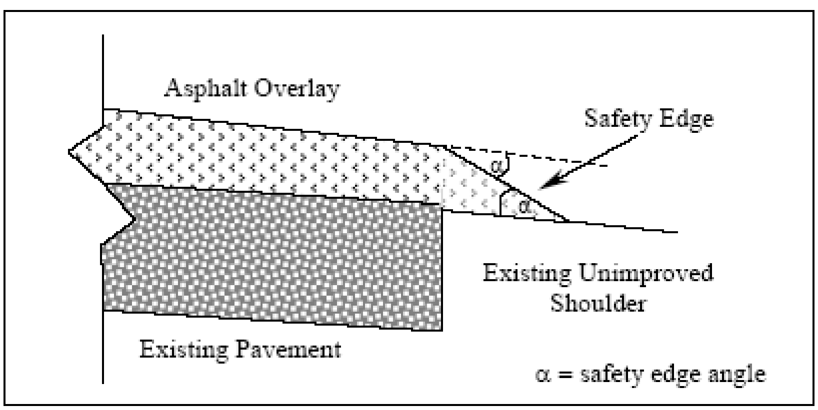

Figure 1. Safety Edge Detail

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 will extend over a three-year period. This interim report presents the evaluation results for the first year after implementation of the treatment. A second interim report will be prepared after a second year of data are available. A final report will be prepared at the end of the 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 (*2*).

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

1.3 Summary of Evaluation Plan-Year 1

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 Year 1 Interim 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 one year after resurfacing. Data collected and analyzed in this report includes field measurements of drop-offs present on the treated sites before and during the first year after resurfacing; crash records for two to five years before the site was resurfaced and one year 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 first year after resurfacing.

The report also presents the safety evaluation results using traffic volume and crash data for the period before resurfacing of the treatment and comparison sites and the first full year 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 Year 1 interim 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.

The results presented in this report are based on only one year of data after resurfacing and, therefore, should be considered as preliminary and subject to change as additional years of after data are collected.

Cost data for the resurfacing projects at the treatment and comparison sites are presented in the report, but no findings are presented concerning the cost-effectiveness of the safety edge treatment. Such findings would be premature until more definitive safety evaluation results are available.

It is planned that two more years of data for the period after resurfacing will be collected for each treatment and comparison site. More definitive results are expected each year, as the size of the project database expands. A second interim report will be prepared when the second year of data for the period after resurfacing is available. A final report will be prepared when all three years of data for the period after resurfacing are available.

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 preliminary results of the analysis results for the field measurements of pavement edge drop-offs. Section 4 presents preliminary results of the safety effectiveness evaluation. Section 5 presents project cost comparisons for sites resurfaced with and without the safety edge. Section 6 presents conclusions drawn from the preliminary analysis results, and Section 7 presents recommendations for the remainder 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 have 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 Year 1 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. For sites 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. For sites 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 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 have not been resurfaced during the study period before resurfacing of the treatment and comparison sites and are not expected to be resurfaced during the entire 3-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 because it is unlikely that an EB evaluation can be conducted for the limited set of treatment sites in New York. The New York data can be included in other planned evaluations without the need for reference sites.

Projects were divided into smaller roadway segments 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 396 sites: 242 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 1,134 km (705 mi) in Georgia, 835 km (519 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. Site Mileage Summary

State	Roadway type	Shoulder type	Site type[a]	Number of sites	Length(mi)
GA	Multilane	Paved	T	10	18.3
			C	8	12.9
			R	12	22.8
	Two-lane	Paved	T	23	75.0
			C	10	27.0
			R	51	202.5
		Unpaved	T	21	43.3
			C	28	93.3
			R	79	210.1
		Combined		242	705.1
IN	Two-lane	Paved	T	14	25.5
			C	8	21.2
			R	29	104.4
		Unpaved	T	15	59.0
			C	18	71.7
			R	64	237.3
		Combined		148	519.0
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 86 sites, with a total length of 372 km (231 mi), at which the safety edge treatment was implemented. This includes 54 treatment sites in Georgia, 29 treatment sites in Indiana, and 3 treatment sites in New York. The project database also includes 75 comparison sites with a total length of 388 km (241 mi) and 235 reference sites with a total length of 1,250 km (777 mi).

2.2 Preliminary 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 to date include data for the period before resurfacing of the treatment and comparison sites and for the first full year 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., 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 are being 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 (*3*) 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 (*3*) 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 is 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	18.3	375	131	77
GA	Multilane	Paved	C	8	1999 to 2004	2006	12.9	304	95	64
GA	Multilane	Paved	R	12	1999 to 2004	2006	22.8	864	163	96
GA	Two-lane	Paved	T	23	1999 to 2004	2006	75.0	598	205	116
GA	Two-lane	Paved	C	10	1999 to 2004	2006	27.0	363	171	118
GA	Two-lane	Paved	R	51	1999 to 2004	2006	202.5	2,334	795	489
GA	Two-lane	Unpaved	T	21	1999 to 2004	2006	43.3	650	267	172
GA	Two-lane	Unpaved	C	28	1999 to 2004	2006	93.3	791	405	275
GA	Two-lane	Unpaved	R	79	1999 to 2004	2006	210.1	1443	698	420
GA			Combined	242	1999 to 2004	2006	705.1	7,722	2,930	1,827
IN	Two-lane	Paved	T	14	2003 to 2004	2006	25.5	120	31	6
IN	Two-lane	Paved	C	8	2003 to 2004	2006	21.2	181	40	14
IN	Two-lane	Paved	R	29	2003 to 2004	2006	104.4	475	134	41
IN	Two-lane	Unpaved	T	15	2003 to 2004	2006	59.0	68	25	8
IN	Two-lane	Unpaved	C	18	2003 to 2004	2006	71.7	239	119	52
IN	Two-lane	Unpaved	R	64	2003 to 2004	2006	237.3	702	238	91
IN			Combined	148	2003 to 2004	2006	519.0	1,785	587	212
NY	Two-lane	Paved	T	3	1999 to 2004	2006	10.0	95	49	0
NY	Two-lane	Paved	C	3	1999 to 2004	2006	15.2	156	57	0
NY			Combined	6	1999 to 2004	2006	25.2	251	106	0
Combined				396			1,249.2	9,758	3,623	2,039

[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		Site length (mi)	Number of fatal-and-injury crashes during before and after study periods combined[b]		
					Before resurfacing	After resurfacing		Total crashes	Run-off road crashes	Drop-off-related crashes
GA	Multilane	Paved	T	10	1999 to 2004	2006	18.3	109	51	37
			C	8	1999 to 2004	2006	12.9	101	42	30
			R	12	1999 to 2004	2006	22.8	325	86	57
	Two-lane	Paved	T	23	1999 to 2004	2006	75.0	210	90	61
			C	10	1999 to 2004	2006	27.0	176	94	72
			R	51	1999 to 2004	2006	202.5	772	365	257
	Two-lane	Unpaved	T	21	1999 to 2004	2006	43.3	201	117	87
			C	28	1999 to 2004	2006	93.3	348	217	160
			R	79	1999 to 2004	2006	210.1	578	355	244
			Combined	242	1999 to 2004	2006	705.1	2,820	1,417	1,005
IN	Two-lane	Paved	T	14	2003 to 2004	2006	25.5	12	7	2
			C	8	2003 to 2004	2006	21.2	48	16	6
			R	29	2003 to 2004	2006	104.4	92	53	21
		Unpaved	T	15	2003 to 2004	2006	59.0	12	9	2
			C	18	2003 to 2004	2006	71.7	69	51	29
			R	64	2003 to 2004	2006	237.3	124	84	32
			Combined	148	2003 to 2004	2006	519.0	357	220	92
NY	Two-lane	Paved	T	3	1999 to 2004	2006	10.0	46	33	0
			C	3	1999 to 2004	2006	15.2	62	31	0
			Combined	6	1999 to 2004	2006	25.2	108	64	0
Combined				396			1,249.2	3,285	1,701	1,097

[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

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 almost entirely non-overlapping, which is undesirable. To a lesser extent, the same is true for two-lane highway sites with paved shoulders in Indiana.

2.2.4 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 again during the first year after resurfacing. However, some of the project sites were resurfaced before field visits would 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

State	Roadway type	Shoulder type	Site type[a]	Number of sites	Site length (mi)	AADT (veh/day) Minimum	AADT (veh/day) Mean before resurfacing	AADT (veh/day) Mean after resurfacing	AADT (veh/day) Maximum
GA	Multilane	Paved	T	10	18.3	8,187	15,413	14,691	21,900
			C	8	12.9	4,659	8,942	8,825	19,690
			R	12	22.8	6,428	9,389	9,219	13,453
			Combined	30	54.0	4,659	11,278	10,938	21,900
	Two-lane	Paved	T	23	75.0	419	4,392	4,344	11,500
			C	10	27.0	1,699	6,365	7,748	10,100
			R	51	202.5	618	6,044	6,300	17,272
			Combined	84	304.5	419	5,630	5,937	17,272
	Two-lane	Unpaved	T	21	43.3	1,285	3,763	3,823	9,308
			C	28	93.3	543	3,810	3,978	12,876
			R	79	210.1	702	3,361	3,318	9,880
			Combined	128	346.6	543	3,525	3,545	12,876
IN	Two-lane	Paved	T	14	25.5	2,185	8,692	8,768	14,804
			C	8	21.2	3,439	5,438	5,510	7,625
			R	29	104.4	1,163	4,582	4,616	9,028
			Combined	51	151.0	1,163	5,845	5,896	14,804
	Two-lane	Unpaved	T	15	59.0	382	1,640	1,620	3,107
			C	18	71.7	1,007	2,304	2,267	6,320
			R	64	237.3	475	3,313	3,298	13,301
			Combined	97	368.0	382	2,867	2,847	13,301
NY	Two-lane	Paved	T	3	10.0	1,058	3,154	3,215	5,710
			C	3	15.2	1,110	4,255	4,533	7,110
			Combined	6	25.2	1,058	3,704	3,874	7,110
Combined				396	1,249.2	382	4,699	4,749	21,900

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

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 the first full 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 GENMOD procedure in SAS software. 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 in) and all observations for the other site type are below 51 mm (2 in), 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. For odds ratio point estimates greater than 1.0, the number of times higher odds that treatment sites contained measurements above 51 mm (2 in) compared to the comparison sites is equal to the odds ratio. If the odds ratio is less than 1.0, then the reciprocal of the odds ratio indicate the number of times higher odds that the comparison sites contained measurements above 51 mm (2 in) compared to the treatment sites.

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 in), the odds ratio point estimate, the odds ratio confidence interval, and statistical significance of the odds ratio point estimate are given in Table 5. The only combinations for which no statistically significant differences between the treatment and comparison sites were found were multilane highway paved shoulder and two-lane highway unpaved shoulder sites in Georgia. 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 in) than treatment sites.

The results in Table 5 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 indicates that these two types of sites are relatively well matched in terms of shoulder conditions in the period before resurfacing.

For Georgia and 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. The opposite is the case for Indiana sites on two-lane highways with unpaved shoulders and on 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. 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 6 presents summary descriptive statistics for these measures. Histograms for a sample of

Table 5. Comparison of the Proportions of Drop-Off Heights That Exceed 2 in Between the Treatment and Comparison Sites for the Period Before Resurfacing

State	Roadway type	Shoulder type	Site type[a]	Drop-off heights that exceed 2 in: Number	Drop-off heights that exceed 2 in: Proportion	Odds ratio point estimate	Lower confidence limit	Upper confidence limit	Statistically significant at 0.05 level?
GA	Multilane	Paved	T	2	0.07	0.909	0.166	4.955	N
			C	5	0.06				
	Two-lane	Paved	T	9	0.04	4.055	1.823	9.019	Y
			C	23	0.14				
		Unpaved	T	14	0.06	1.420	0.708	2.845	N
			C	22	0.08				
IN	Two-lane	Paved	T	5	0.04	2.604	0.858	7.900	Y
			C	10	0.10				
		Unpaved	T	150	0.39	0.487	0.333	0.714	Y
			C	49	0.24				
NY	Two-lane	Paved	T	35	0.47	0.020	0.000	0.117	Y[b]
			C	0	0.00				

[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.

Table 6. Summary of Pavement Edge Drop-Off Height Measurements

				Before resurfacing							After resurfacing						
					Drop-off height (in)							Drop-off height (in) (Year 1)					
State	Road type	Shoulder type	Site type[a]	Number of measurements	Minimum	Mean	Median	Maximum	Standard deviation	Coefficient of variation %	Number of measurements	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	1.046	0.875	2.875	0.504	48
			C	82	0	0.810	0.750	3.000	0.709	88	86	0.250	1.037	1.000	2.375	0.466	45
	Two-lane	Paved	T	228	0	0.539	0.500	3.750	0.629	117	226	0	0.927	0.875	2.375	0.493	53
			C	161	0	0.881	0.750	4.000	0.938	107	150	0	0.887	0.875	1.875	0.470	53
		Unpaved	T	230	0	0.778	0.750	3.750	0.627	81	237	0	1.000	1.000	2.500	0.489	49
			C	261	0	1.015	1.000	4.750	0.717	71	278	0	0.795	0.750	2.875	0.547	69
IN	Two-lane	Paved	T	117	0	0.625	0.500	3.500	0.599	96	115	0	0.769	0.750	1.875	0.388	50
			C	96	0	0.959	0.750	3.250	0.708	74	95	0.250	1.519	1.375	4.250	0.765	50
		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	203	0	1.351	1.250	6.875	0.998	74	198	0.125	1.145	1.000	5.250	0.669	58
NY	Two-lane	Paved	T	75	0	1.930	1.875	5.125	1.263	65	77	0	1.109	0.875	4.000	0.886	80
			C	42	0	0.776	0.750	1.750	0.487	63	43	0	1.116	1.000	2.750	0.506	45

[a] Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

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 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 before and after study periods.

To formally assess whether 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 in) was evaluated to determine if there were differences between the before and after 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 in) were compared between the periods before and after resurfacing for each type of site rather than between treatment and comparison sites.

Ideal results for this analysis would be obtained if the probability that the period after resurfacing had fewer drop-off measurements that exceed 51 mm (2 in) was statistically significant. This is indicated in the results in Table 7 by an odds ratio point estimate greater than 1.0 [i.e., the before period has higher odds of having drop-off height that exceeds 51 mm (2 in) than the period after resurfacing] and the confidence interval for the odds ratio does not contain the value 1.0, which indicates statistical significance. Since the odds ratios were greater than 1.0 in 9 of the 12 cases shown in Table 7, the sites in the period before resurfacing generally had higher odds of having drop-off heights above 51 mm (2 in), than the sites in the period after resurfacing. Thus, it appears that resurfacing tends to reduce the proportion of extreme drop-off heights. However, only about half of these observed odds ratios greater than 1.0 were statistically significant at the 0.05 level.

The odds ratio for the treatment sites was above 1.0 for five 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. However, just as noted above, only about half of the observed odds ratios greater than 1.0 were statistically significant.

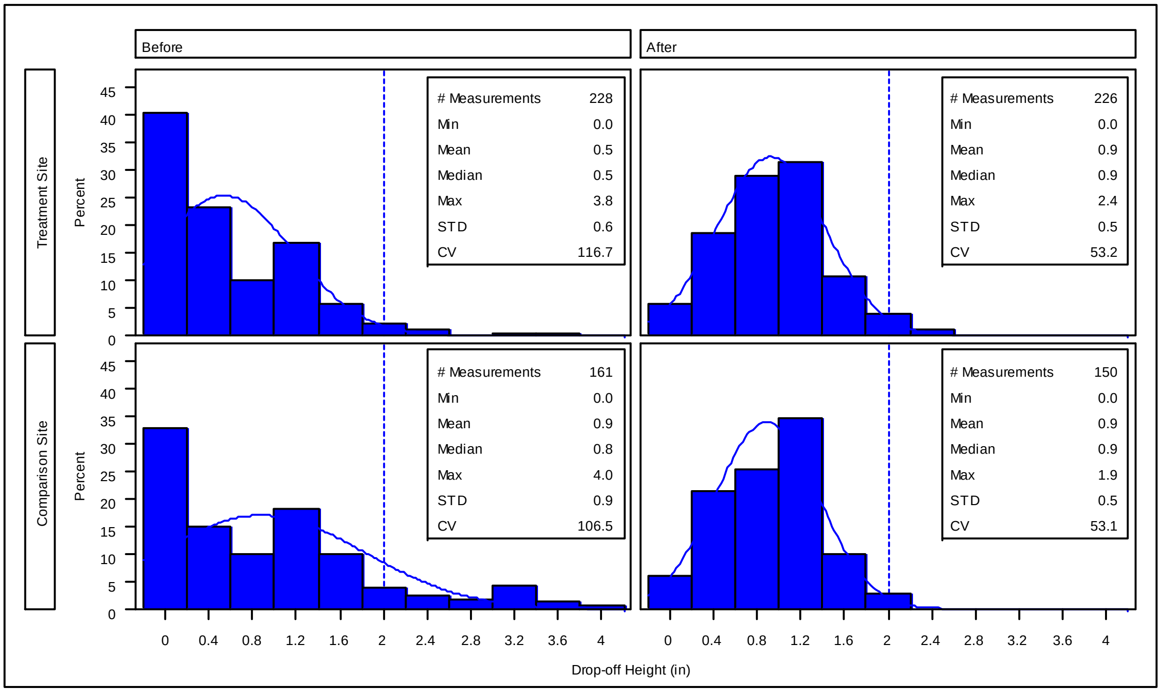

Figure 2. Drop-off Measurement Distributions for Two-Lane Highways with Paved Shoulders in Georgia

Figure 3. Exposed Safety Edge

Table 7. Comparison of the Proportions of Drop-Off Heights That Exceed 2 in for the Treatment and Comparison Sites Between the Periods Before and After Resurfacing

State	Roadway type	Shoulder type	Site type[a]	Period	Drop-off heights that exceed 2 in: Number	Drop-off heights that exceed 2 in: Proportion	Odds ratio point estimate	Lower 95% confidence limit	Upper 95% confidence limit	Statistically significant at the 0.05 level?
GA	Multilane	Paved	T	B	4	0.14	0.982	0.169	5.693	N
				A	8	0.14				
			C	B	10	0.12	1.052	0.029	3.777	N
				A	10	0.12				
	Two-lane	Paved	T	B	18	0.08	1.286	0.470	3.514	N
				A	14	0.06				
			C	B	46	0.28	35.113	6.067	Infinity	Y[c]
				A	0	0.00				
	Two-lane	Unpaved	T	B	28	0.12	1.642	0.696	3.872	N
				A	18	0.08				
			C	B	44	0.16	1.736	0.868	3.470	N
				A	28	0.10				
IN	Two-lane	Paved	T	B	10	0.08	6.813	0.916	Infinity	Y[c]
				A	0	0.00				
			C	B	20	0.20	0.364	0.163	0.815	Y
				A	46	0.48				
	Two-lane	Unpaved	T	B	300	0.78	1.649	1.214	2.240	Y
				A	208	0.56				
			C	B	98	0.48	2.682	1.540	40,671.000	Y
				A	42	0.22				
NY	Two-lane	Paved	T	B	70	0.94	3.937	1.887	8.217	Y
				A	28	0.36				
			C	B	0	0.00	0.417	0.000	5.432	N[c]
				A	4	0.10				

[a] Site types:
T = Treatment-sites resurfaced with safety edge
C = Comparison-sites resurfaced without safety edge

[b] Study period
B = Before resurfacing
A = After resurfacing

[c] Indicates that a median unbiased estimate was used.

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 slightly more effective than resurfacing without the safety edge treatment in reducing the proportion of extreme drop-off heights. However, these results cannot be stated with statistical significance based on the Year 1 data.

This analysis will be repeated with the field measurement data for Years 2 and 3. In particular, these data will be used to investigate whether the drop-offs are less likely to develop in the future on sites resurfaced with the safety edge treatment than on sites resurfaced without the safety edge treatment.

It will also be desirable to investigate whether drop-offs of a given height involve less risk for motorists on sites where the safety edge treatment is present than on sites without the safety edge treatment. However, analysis of this issue will require both field measurement data and several years of crash data for the period after resurfacing.

Section 4. Preliminary Analysis Results for Safety Evaluation

This section presents preliminary 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, particularly in this Year 1 analysis, since only one year of crash data is available 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 (*4*). However, a more recent, larger study in NCHRP Project 17-9(2) (*5*) 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 are being conducted to evaluate this issue. Thus, the results for safety effectiveness of the safety edge treatment in this first-year interim report may be confounded by the safety effect of pavement resurfacing, but it is expected that this confounding effect may be 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 (*6*). The specific version of the EB technique used in this evaluation was that developed for the FHWA SafetyAnalyst software tools (*7*). 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. 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

(*8*), 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 was the only independent variable 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 in the following functional form:

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

where:

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

Statistically significant models were not found at the 10 percent significance level for all cases. In particular, no models were found for multilane highway sites with paved shoulders in Georgia, due to the small number of sites. Also, the reference sites did not provide a sufficient number of target crashes to develop statistical models with acceptable confidence for run-off-road and drop-off-related crashes. Statistically significant models may be found in the future if the sample size is increased or as more years of crash data are obtained. Therefore, where SPFs for run-off-road and drop-off-related crashes were needed, predicted values for SPFs for all crash types combined were multiplied by the applicable proportion of run-off-road or drop-off-related crashes.

For total and fatal and injury crashes, the model coefficients with their standard errors are presented in Tables 8 and 9 for Georgia and Indiana, respectively. All AADT coeffiecients shown are significant at the 10-percent significance level or better. These SPFs are illustrated in Figures 4 and 5.

These SPFs will be updated with additional years of data as the study progresses. Regression relationships in Indiana may be improved more than in Georgia with additional years of data as these initial models were developed with four and eight years of crash data, respectively.

Table 8. SPFs for Georgia Sites

Road type	Shoulder type	Number of sites	Intercept (standard error)	AADT coefficient[a] (standard error)	Overdispersion parameter	R^2_{LR} (%)
Total crashes						
Two-lane	Paved	51	–10.482 (1.101)	1.301 (0.128)	0.525	64.6
Two-lane	Unpaved	79	–7.066 (1.528)	0.898 (0.191)	0.539	20.9
Fatal-and-injury crashes						
Two-lane	Paved	51	–9.050 (0.997)	1.004 (0.116)	0.337	56.7
Two-lane	Unpaved	79	–6.788 (1.533)	0.737 (0.192)	0.332	15.3

[a] These values are significant at the 10% level.

Table 9. SPFs for Indiana Sites

Road type	Shoulder type	Number of sites	Intercept (standard error)	AADT coefficient[a] (standard error)	Overdispersion parameter	R^2_{LR} (%)
Total crashes						
Two-lane	Paved	29	–3.835 (2.481)	0.481 (0.299)	0.547	8.1
Two-lane	Unpaved	64	–4.479 (1.182)	0.540 (0.150)	0.630	15.6
Fatal-and-injury crashes						
Two-lane	Paved	29	–5.099 (3.941)	0.431 (0.476)	0.648	2.8
Two-lane	Unpaved	64	–6.467 (1.386)	0.571 (0.176)	0.329	13.7

[a] These values are significant at the 10% level.

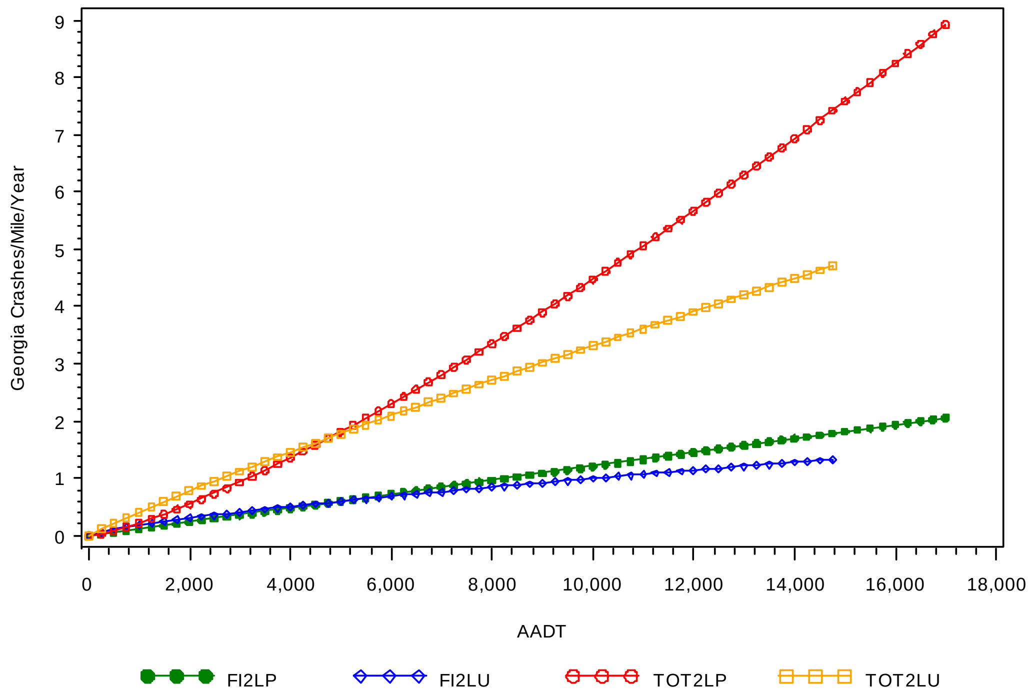

Figure 4. Georgia SPFs by Crash Severity and Roadway and Shoulder Type

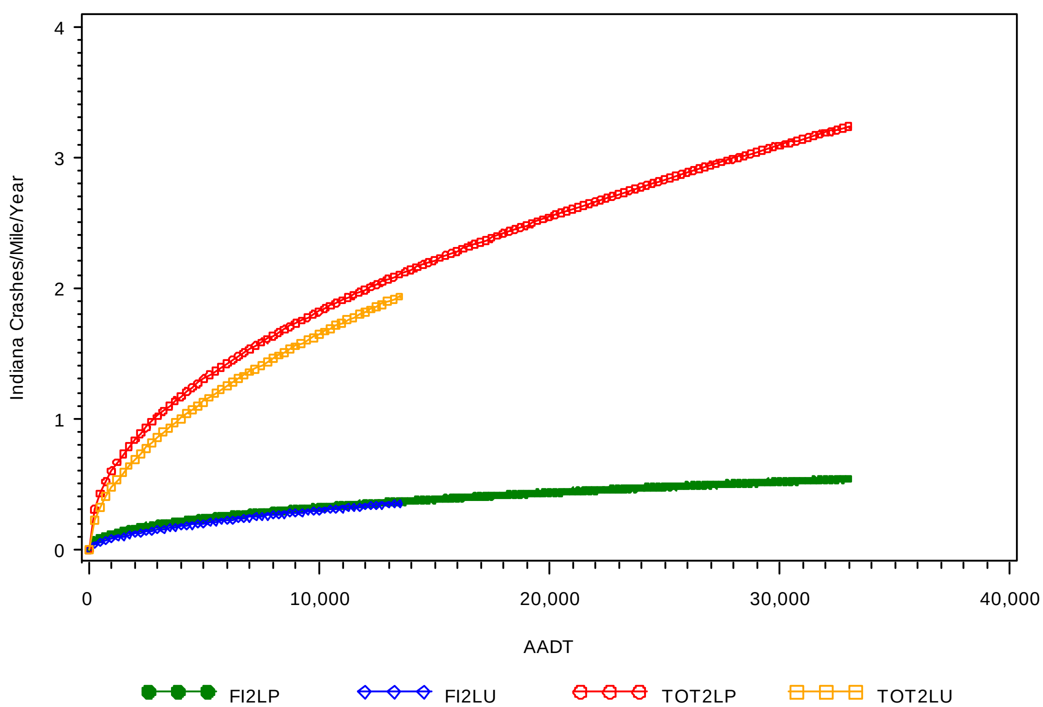

Figure 5. Indiana SPFs by Crash Severity and Roadway and Shoulder Type

As noted above, for safety evaluations to be performed on run-off-road and drop-off-related crashes, the proportion of these crashes, developed from reference sites, were needed. Predicted values for these crash types can then be determined by applying these proportions to the SPFs for all crash types. Table 10 presents these proportions estimated from the reference site data.

Table 10. Proportions of Run-Off-Road and Drop-off Related Crashes to Total Crashes

State	Roadway type	Shoulder type	Crash severity level	Proportion of run-off-road crashes	Proportion of drop-off-related crashes
GA	Two-lane	Paved	TOT	0.341	0.210
			FI	0.473	0.333
		Unpaved	TOT	0.484	0.291
			FI	0.614	0.422
IN	Two-lane	Paved	TOT	0.282	0.086
			FI	0.576	0.228
		Unpaved	TOT	0.339	0.130
			FI	0.677	0.258

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 provided in Tables 11 and 12 for Georgia and Indiana respectively.

Table 11. Georgia SPF Calibration Factors

Roadway type	Shoulder type	Crash severity level	Calibration factors							
			1999	2000	2001	2002	2003	2004	2005	2006
Two-lane	Paved	TOT	0.730	0.924	1.019	1.054	0.863	1.037	0.805	0.812
		FI	0.754	1.015	1.081	1.002	0.972	1.077	0.856	0.773
		PDO	0.718	0.885	0.991	1.078	0.809	1.013	0.776	0.827
	Unpaved	TOT	0.652	0.827	0.819	0.809	0.656	0.743	0.834	0.816
		FI	0.635	0.834	0.922	0.919	0.721	0.817	1.113	0.897
		PDO	0.671	0.834	0.774	0.763	0.631	0.714	0.690	0.784

Table 12. Indiana SPF Calibration Factors

Roadway type	Shoulder type	Crash severity level	Calibration factors			
			2003	2004	2005	2006
Two-lane	Paved	TOT	1.271	1.219	0.884	0.552
		FI	1.473	1.462	0.666	0.488
		PDO	1.227	1.167	0.936	0.569
	Unpaved	TOT	1.446	1.091	0.871	0.555
		FI	1.201	1.357	0.812	0.651
		PDO	1.505	1.039	0.887	0.537

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 the plots generated in these analyses found little or no concern for the majority of the state/roadway type/shoulder type combinations. However, potential concerns were found for two specific situations: rural multilane highway sites with paved shoulders in Georgia and rural two-lanes highway sites with paved shoulders in Indiana. For the Georgia multilane highway sites with paved shoulders, the treatment and comparison groups were almost entirely separated in AADT ranges as illustrated in Figure 6. For the Indiana two-lane highway sites with paved shoulders, the treatment and comparison groups were also somewhat separated in AADT ranges, but had the additional issue of large variation in crash frequencies for some specific AADT values. These data are shown in Figure 7.

Yearly total crash and target crash distributions were also present in box plots to review data consistency from year to year. Ideal plots, as illustrated in Figure 8, 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. However, only one year of after-period data is currently available. 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. This concern can be resolved by the inclusion of more years of data for the period after resurfacing since one would expect a high after-period crash frequency to decrease the next year, returning to the mean, without any additional changes to the 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. Again, extending the duration of the after study period to include additional years may reduce this effect.

Overall, this analysis found one additional potential problem. 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 after period year and, therefore may be excluded from future analyses. A box plot for the sites of this type is shown in Figure 9.

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

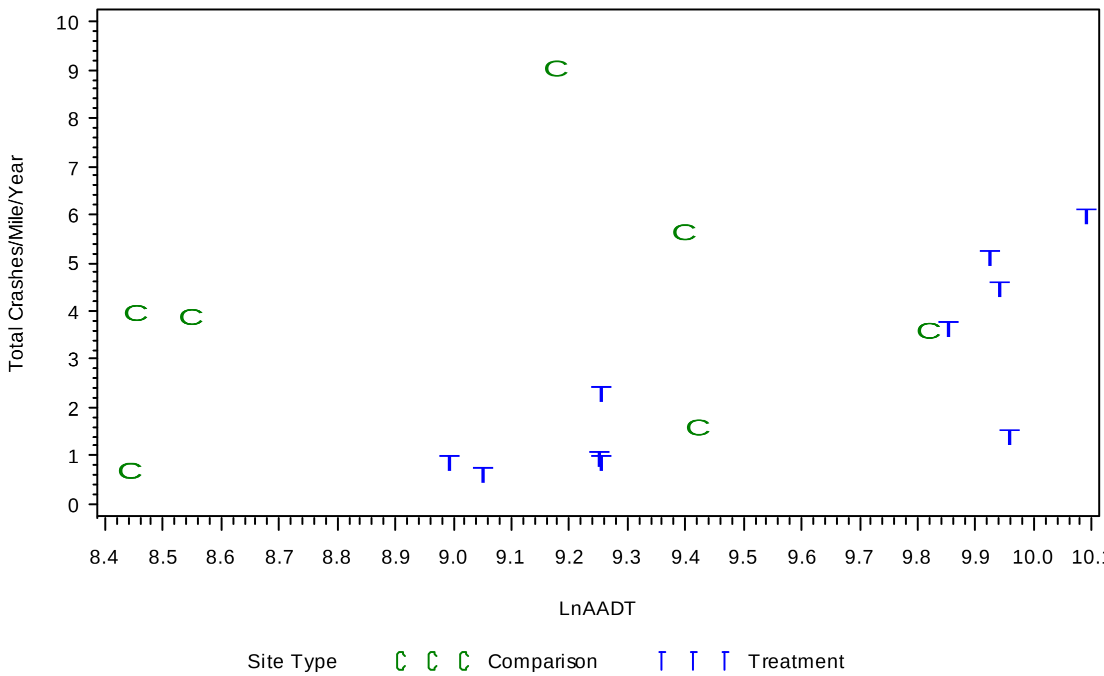

Figure 6. Plot of Crash Frequency Versus Traffic Volume for Multilane Highway Sites with Paved Shoulders in Georgia

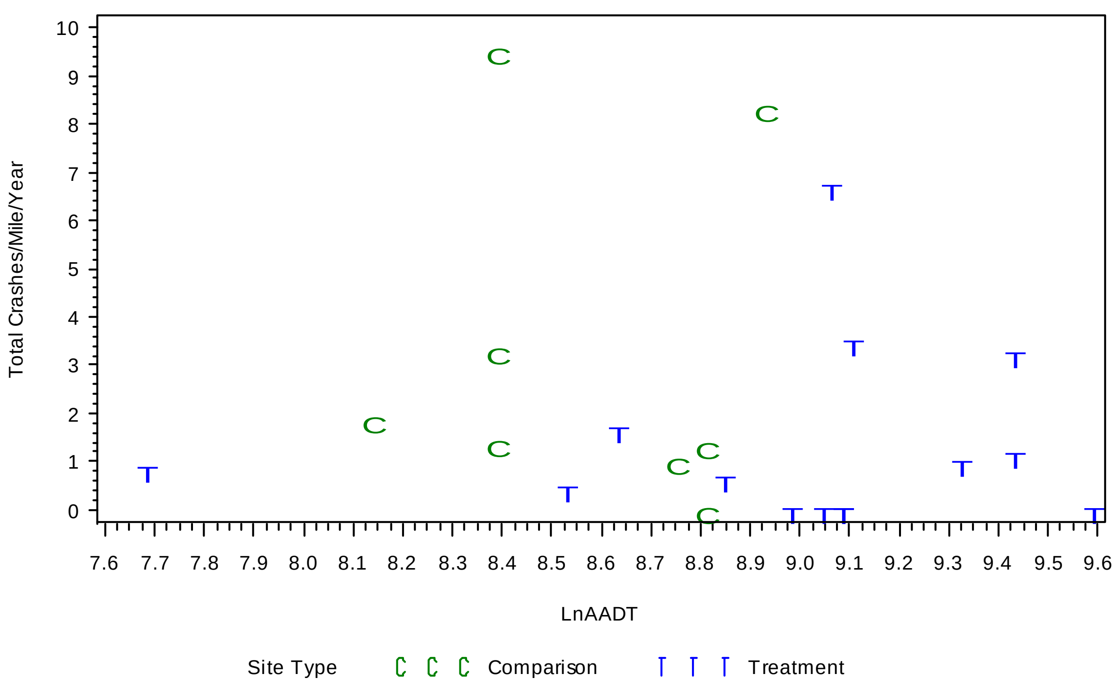

Figure 7. Plot of Crash Frequency Versus Traffic Volume for Two-Lane Highway Sites With Paved Shoulders in Indiana

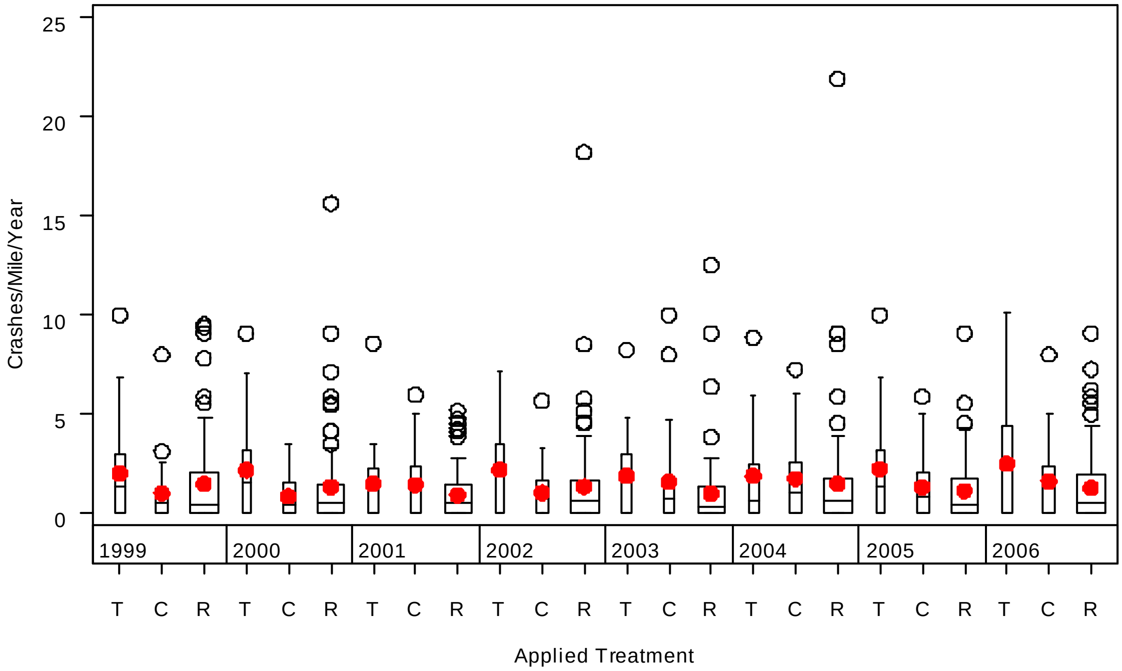

Figure 8. Box Plot of Yearly Crash Frequencies for Two-Lane Highway Sites with Unpaved Shoulders in Georgia

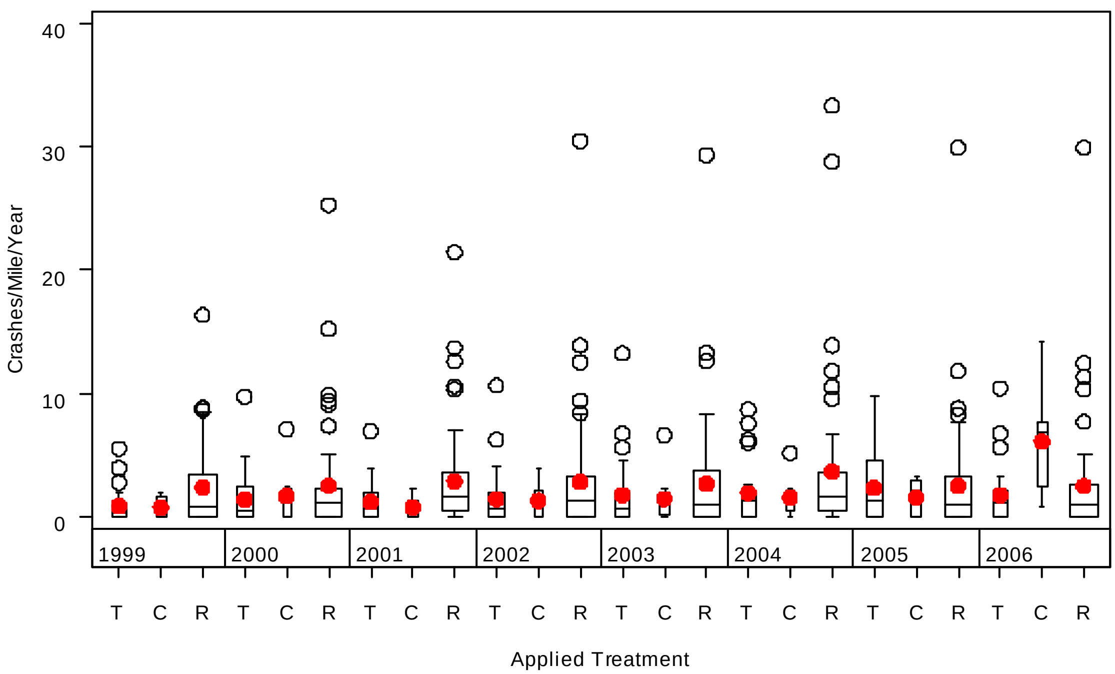

Figure 9. Box Plot of Yearly Crash Frequencies for Two-Lane Highway Sites With Paved Shoulders in Georgia

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, 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 13 and 14. 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 13 show that there tend to be significant differences between treatment and comparison site crash frequencies in Indiana in the period before resurfacing, with treatment sites having lower crash rates than comparison sites. However, this trend was not found for all roadway type/shoulder type combinations due to the low crash frequency in Indiana. Treatment and comparison sites in Georgia tend to be similar in safety performance for the period before resurfacing. The few cases showing a difference were only moderately significant.

Results from the analysis of observed crash frequencies are similar to those for the EB-adjusted crashes, but with smaller goodness-of-fit measures (R^2_{LR}). 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 a larger value of R^2_{LR}.

Some site types that could not be evaluated using the EB-adjusted data, because no SPFs were available, could be evaluated using the observed crash frequencies. For example, an analysis of multilane highway sites in Georgia was conducted using the observed crash frequency data. For these sites, it was found that the difference in crash frequency between treatment and comparison sites was statistically significant for the period before resurfacing, with treatment sites having lower crash frequencies. The remaining additional comparisons that were performed with the observed crash frequency data were not statistically significant and tended to have small R^2 values.

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 supported, or at least not refuted, by crash analysis results. In addition, two-lane highway sites with unpaved shoulders in Georgia had a slightly higher

Table 13. Evaluation of Treatment vs. Comparison Site Effect for the Period Before Resurfacing Using EB-Adjusted Crash Frequencies

State	Road type	Shoulder type	Crash type and severity level[a]	Number of sites	Intercept	AADT effect: Coefficient	AADT effect: Standard error	AADT effect: p-Value	AADT effect: Statistically significant?[b]	Treatment vs. comparison effect: Coefficient	Treatment vs. comparison effect: Standard error	Treatment vs. comparison effect: p-Value	Treatment vs. comparison effect: Statistically significant?[b]	Dispersion parameter	R^2_{LR}%
GA	Two-lane	Paved	TOT	33	–9.247	1.133	0.139	< 0.001	Y	0.194	0.188	0.302	N	0.145	68.6
			FI	33	–8.895	1.017	0.102	< 0.001	Y	–0.164	0.127	0.196	N	0.005	77.9
			PDO	33	–11.045	1.261	0.219	< 0.001	Y	0.400	0.288	0.165	N	0.376	53.6
			rorTOT	33	–7.912	0.881	0.168	< 0.001	Y	–0.106	0.218	0.625	N	0.126	48.5
			rorFI	33	–7.983	0.830	0.149	< 0.001	Y	–0.397	0.184	0.031	Y	0.004	55.1
			rorPDO	33	–9.753	0.992	0.310	0.001	Y	0.129	0.382	0.735	N	0.489	25.3
			doTOT	33	–9.041	0.967	0.171	< 0.001	Y	–0.309	0.218	0.155	N	0.075	52.9
			doFI	33	–8.851	0.895	0.178	< 0.001	Y	–0.518	0.205	0.011	Y	0.000	52.9
			doPDO	33	–11.731	1.157	0.322	< 0.001	Y	–0.148	0.403	0.714	N	0.374	28.7
GA	Two-lane	Unpaved	TOT	49	–8.181	1.021	0.121	< 0.001	Y	0.404	0.150	0.007	Y	0.156	59.3
			FI	49											
			PDO	49	–10.032	1.179	0.187	< 0.001	Y	0.614	0.224	0.006	Y	0.393	47.0
			rorTOT	49	–6.852	0.765	0.130	< 0.001	Y	0.236	0.165	0.153	N	0.133	39.2
			rorFI	49											
			rorPDO	49	–8.601	0.885	0.215	< 0.001	Y	0.452	0.261	0.083	Y	0.394	25.9
			doTOT	49	–7.276	0.765	0.140	< 0.001	Y	0.229	0.183	0.210	N	0.131	34.3
			doFI	49											
			doPDO	49	–9.281	0.908	0.213	< 0.001	Y	0.423	0.272	0.120	N	0.297	24.8
IN	Two-lane	Paved	TOT	22	–1.358	0.294	0.414	0.478	N	–0.867	0.368	0.019	Y	0.324	21.0
			FI	22											
			PDO	22	–1.025	0.232	0.475	0.625	N	–0.889	0.421	0.035	Y	0.429	17.9
			rorTOT	22	–2.936	0.275	0.445	0.536	N	–0.528	0.371	0.155	N	0.000	9.4
			rorFI	22											
			rorPDO	22	–3.527	0.298	0.690	0.666	N	–0.854	0.558	0.126	N	0.114	12.9
			doTOT	22											
			doFI	22											
			doPDO	22											

Table 13. Evaluation of Treatment vs. Comparison Site Effect for the Period Before Resurfacing Using EB-Adjusted Crash Frequencies (Continued)

State	Road type	Shoulder type	Crash type and severity level[a]	Number of sites	Intercept	AADT effect				Treatment vs. comparison effect				Dispersion parameter	R^2_{LR}%
						Coefficient	Standard error	p-Value	Statistically significant?[b]	Coefficient	Standard error	p-Value	Statistically significant?[b]		
IN	Two-lane	Unpaved	TOT	33	–3.051	0.412	0.177	0.020	Y	–0.725	0.209	0.001	Y	0.079	47.3
			FI	33											
			PDO	33	–2.896	0.368	0.213	0.083	Y	–0.892	0.254	< 0.001	Y	0.132	44.4
			rorTOT	33	–3.953	0.424	0.235	0.071	Y	–0.908	0.281	0.001	Y	0.033	39.9
			rorFI	33											
			rorPDO	33	–3.799	0.366	0.324	0.259	N	–1.306	0.405	0.001	Y	0.160	36.9
			doTOT	33											
			doFI	33											
			doPDO	33											

[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 0.10 level

Table 14. Evaluation of Treatment vs. Comparison Site Effect for the Period Before Resurfacing Using Observed Crash Frequencies

State	Road type	Shoulder type	Crash type and severity level[a]	Number of sites	Intercept	AADT effect: Coefficient	AADT effect: Standard error	AADT effect: p-value	AADT 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	18	–9.376	1.187	0.376	0.002	Y	–1.107	0.418	0.008	Y	0.359	38.2
			FI	18	–5.536	0.627	0.410	0.126	N	–0.739	0.426	0.083	Y	0.329	16.1
			PDO	18	–12.337	1.474	0.419	< 0.001	Y	–1.309	0.475	0.006	Y	0.422	42.7
			rorTOT	18	–5.857	0.632	0.330	0.056	Y	–0.317	0.369	0.390	N	0.200	16.1
			rorFI	18											
			rorPDO	18	–7.524	0.753	0.406	0.064	Y	–0.251	0.453	0.579	N	0.277	16.4
			doTOT	18	–8.943	0.905	0.275	0.001	Y	–0.349	0.210	0.097	Y	0.000	35.0
			doFI	18											
			doPDO	18	–9.279	0.876	0.396	0.027	Y	–0.313	0.355	0.377	N	0.056	20.2
GA	Two-lane	Paved	TOT	33	–10.407	1.241	0.246	< 0.001	Y	0.300	0.331	0.364	N	0.608	45.1
			FI	33	–9.686	1.071	0.234	< 0.001	Y	–0.098	0.325	0.764	N	0.465	39.9
			PDO	33	–11.760	1.329	0.277	< 0.001	Y	0.538	0.354	0.128	N	0.623	44.5
			rorTOT	33	–7.965	0.870	0.267	0.001	Y	0.009	0.339	0.979	N	0.481	26.9
			rorFI	33	–7.323	0.723	0.289	0.012	Y	–0.356	0.378	0.346	N	0.472	20.4
			rorPDO	33	–9.569	0.973	0.305	0.001	Y	0.239	0.381	0.530	N	0.492	25.0
			doTOT	33	–8.923	0.939	0.259	< 0.001	Y	–0.256	0.333	0.442	N	0.379	31.9
			doFI	33	–7.814	0.757	0.284	0.008	Y	–0.623	0.370	0.092	Y	0.333	25.5
			doPDO	33	–11.737	1.158	0.323	< 0.001	Y	0.026	0.408	0.950	N	0.421	27.8
GA	Two-lane	Unpaved	TOT	49	–9.003	1.121	0.231	< 0.001	Y	0.480	0.262	0.067	Y	0.676	34.2
			FI	49	–9.743	1.104	0.223	< 0.001	Y	0.039	0.251	0.876	N	0.446	33.4
			PDO	49	–9.521	1.117	0.224	< 0.001	Y	0.769	0.265	0.004	Y	0.624	37.7
			rorTOT	49	–6.794	0.754	0.233	0.001	Y	0.317	0.267	0.235	N	0.588	18.5
			rorFI	49	–7.334	0.741	0.274	0.007	Y	–0.002	0.310	0.995	N	0.662	12.9
			rorPDO	49	–7.997	0.810	0.229	< 0.001	Y	0.624	0.282	0.027	Y	0.516	22.5
			doTOT	49	–7.117	0.743	0.254	0.004	Y	0.312	0.293	0.288	N	0.657	15.5
			doFI	49	–7.440	0.710	0.325	0.029	Y	0.047	0.359	0.897	N	0.892	9.0
			doPDO	49	–8.734	0.838	0.217	< 0.001	Y	0.609	0.285	0.033	Y	0.368	23.4

Table 14. Evaluation of Treatment vs. Comparison Site Effect for the Period Before Resurfacing Using Observed Crash Frequencies (Continued)

State	Road type	Shoulder type	Crash type and severity level[a]	Number of sites	Intercept	AADT effect: Coefficient	AADT effect: Standard error	AADT effect: p-value	AADT 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}%
IN	Two-lane	Paved	TOT	22	–1.744	0.382	0.716	0.594	N	–1.316	0.679	0.053	Y	1.597	14.6
			FI	22	–12.787	1.501	1.061	0.157	N	–2.818	0.862	0.001	Y	0.693	42.1
			PDO	22	–0.319	0.176	0.738	0.812	N	–1.014	0.686	0.139	N	1.511	10.0
			rorTOT	22	–3.920	0.444	0.742	0.549	N	–1.502	0.612	0.014	Y	0.554	26.2
			rorFI	22											
			rorPDO	22	–3.879	0.370	0.768	0.630	N	–0.997	0.644	0.122	N	0.522	11.5
			doTOT	22											
			doFI	22											
			doPDO	22											
IN	Two-lane	Unpaved	TOT	33											
			FI	33											
			PDO	33	–0.006	0.011	0.442	0.979	N	–1.847	0.599	0.002	Y	1.067	33.5
			rorTOT	33											
			rorFI	33											
			rorPDO	33	–3.137	0.297	0.487	0.542	N	–1.670	0.621	0.007	Y	0.957	28.2
			doTOT	33											
			doFI	33											
			doPDO	33	–3.785	0.207	0.691	0.765	N	–1.375	0.924	0.137	N	1.627	10.8
NY	Two-lane	Paved	TOT	6											
			FI	6											
			PDO	6											
			rorTOT	6											
			rorFI	6											
			rorPDO	6											
			doTOT	6											
			doFI	6											
			doPDO	6											

[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 0.10 level.

probability that high proportions of drop-offs would occur on comparison sites and the analysis results indicated a slightly higher crash frequency for comparison sites. Two-lane highway sites with paved shoulders in Georgia had comparison sites with a significantly higher probability of having more high drop-offs, but the crash analysis showed only non-significant differences. However, in this case, there were higher crash frequencies for total and run-off-road crashes for the comparison sites. Drop-off-related crashes for this case tended to be slightly higher for the treatment sites than for the comparison sites.

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 Georgia treatment and comparison sites showed similar crash frequencies in the period before resurfacing. By contrast, there were some statistically significant differences in crash frequencies between treatment and comparison sites in Indiana 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 five-year period from 2000 to 2004. The study period after resurfacing was one year (2006). 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 was no opportunity for seasonal biases.

The EB procedure was programmed and executed in the SAS software package. Effectiveness estimates and their precision estimates, along with their statistical significance, are presented for specific crash types in Tables 15 through 23.

Table 15. 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: 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	23	1.310	30.9	Increase	13.8	Y	Y	39.6	Y
			C	10	1.707	70.6	Increase	19.4	Y	Y		
		Unpaved	T	21	1.220	22.0	Increase	12.3	N	Y	–16.3	N
			C	28	1.057	5.7	Increase	10.0	N	N		
IN	Two-lane	Paved	T	14	2.043	103.7	Increase	30.3	Y	Y	–3.2	Y
			C	8	2.011	100.5	Increase	32.0	Y	Y		
		Unpaved	T	15	1.990	98.4	Increase	35.8	Y	Y	–67.2	N
			C	18	1.315	31.2	Increase	21.0	N	N		

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

Table 16. 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	23	1.148	14.8	Increase	20.1	N	N	96.1	N
			C	10	2.111	110.9	Increase	33.1	Y	Y		
		Unpaved	T	21	1.136	13.5	Increase	21.2	N	N	–6.8	N
			C	28	1.068	6.8	Increase	14.9	N	N		
IN	Two-lane	Paved	T	14	2.417	139.7	Increase	87.6	N	N	199.0	N
			C	8	4.422	338.6	Increase	123.8	Y	Y		
		Unpaved	T	15	1.014	1.1	Increase	50.8	N	N	111.3	N
			C	18	2.128	112.4	Increase	59.6	N	Y		

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

Table 17. 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			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	23	1.422	42.0	Increase	19.1	Y	Y	–0.8	Y
			C	10	1.415	41.2	Increase	23.5	N	Y		
		Unpaved	T	21	1.257	25.6	Increase	15.1	N	N	–20.9	N
			C	28	1.048	4.7	Increase	13.6	N	N		
IN	Two-lane	Paved	T	14	1.987	97.9	Increase	32.4	Y	Y	–37.3	Y
			C	8	1.614	60.7	Increase	30.8	N	Y		
		Unpaved	T	15	2.284	127.1	Increase	44.8	Y	Y	–115.2	N
			C	18	1.122	11.9	Increase	21.6	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 Total Run-off-Road Crashes

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing			Statistically significant?		Safety edge effect	
						Percent change	Direction	Standard error (%)	5% level	10% level	Difference between C and T (%)	Both effects significant?
GA	Two-lane	Paved	T	23	1.626	62.4	Increase	26.4	Y	Y	18.3	Y
			C	10	1.809	80.7	Increase	30.4	Y	Y		
		Unpaved	T	21	1.271	27.0	Increase	19.5	N	N	–35.3	N
			C	28	0.918	–8.3	Decrease	13.1	N	N		
IN	Two-lane	Paved	T	14	1.776	75.5	Increase	56.3	N	N	26.6	N
			C	8	2.048	102.1	Increase	65.2	N	N		
		Unpaved	T	15	1.493	48.0	Increase	51.2	N	N	–28.8	N
			C	18	1.197	19.3	Increase	29.9	N	N		

* 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 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			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	23	1.536	53.4	Increase	35.6	N	N	70.3	N
			C	10	2.241	123.7	Increase	48.5	Y	Y		
		Unpaved	T	21	1.048	4.7	Increase	26.4	N	N	4.5	N
			C	28	1.092	9.2	Increase	19.5	N	N		
IN	Two-lane	Paved	T	14	2.546	150.2	Increase	129.5	N	N	2.1	N
			C	8	2.565	152.3	Increase	130.3	N	N		
		Unpaved	T	15	0.773	–23.2	Decrease	54.7	N	N	161.7	N
			C	18	2.393	138.6	Increase	76.5	N	Y		

* 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 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			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	23	1.697	68.9	Increase	39.5	N	Y	–28.7	N
			C	10	1.411	40.2	Increase	37.9	N	N		
		Unpaved	T	21	1.444	44.0	Increase	28.3	N	N	–73.5	N
			C	28	0.707	–29.5	Decrease	17.0	N	Y		
IN	Two-lane	Paved	T	14	1.514	47.9	Increase	60.4	N	N	30.5	N
			C	8	1.837	78.4	Increase	74.0	N	N		
		Unpaved	T	15	2.009	95.2	Increase	81.0	N	N	–125.9	N
			C	18	0.698	–30.8	Decrease	27.0	N	N		

* 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 Total Drop-Off-Related Crashes

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing			Statistically significant?		Safety edge effect	
						Percent change	Direction	Standard error (%)	5% level	10% level	Difference between C and T (%)	Both effects significant?
GA	Two-lane	Paved	T	23	1.740	73.7	Increase	36.1	Y	Y	–1.8	Y
			C	10	1.723	71.9	Increase	36.7	N	Y		
		Unpaved	T	21	1.459	45.7	Increase	26.2	N	Y	–53.1	N
			C	28	0.927	–7.4	Decrease	16.3	N	N		
IN	Two-lane	Paved	T	14	0.741	–29.9	Decrease	72.1	N	N	328.7	N
			C	8	4.183	298.9	Increase	185.1	N	N		
		Unpaved	T	15	2.359	129.1	Increase	121.1	N	N	–27.8	N
			C	18	2.034	101.3	Increase	64.1	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 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			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	23	1.691	68.8	Increase	45.6	N	N	39.67	N
			C	10	2.089	108.4	Increase	54.7	N	Y		
		Unpaved	T	21	1.285	28.3	Increase	34.6	N	N	–14.1	N
			C	28	1.143	14.2	Increase	24.0	N	N		
IN	Two-lane	Paved	T	14	2.141	97.3	Increase	205.5	N	N	134.0	N
			C	8	3.511	231.3	Increase	247.9	N	N		
		Unpaved	T	15	0.000	–100.0	Decrease	0.0	N	N	356.8	N
			C	18	3.597	256.8	Increase	149.1	N	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 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	23	1.776	75.4	Increase	58.8	N	N	–47.5	N
			C	10	1.295	27.9	Increase	47.4	N	N		
		Unpaved	T	21	1.623	61.3	Increase	40.0	N	N	–98.1	N
			C	28	0.635	–36.8	Decrease	20.5	N	Y		
IN	Two-lane	Paved	T	14	0.000	–100.0	Decrease	0.0	N	N	398.0	N
			C	8	4.613	298.0	Increase	254.5	N	N		
		Unpaved	T	15	5.057	332.6	Increase	280.0	N	N	–302.2	N
			C	18	1.335	30.5	Increase	61.7	N	N		

* Site types:
T = Test-sites resurfaced with safety edge.
C = Control-sites resurfaced without safety edge.

The results of the EB analysis indicate that crash frequencies generally increased from before to after resurfacing for both the treatment and comparison sites. This can generally be attributed to the short-term effect of resurfacing, discussed in Section 4.1 of this report. The safety edge effect shown in the results tables is the difference between the before-after effect for the comparison sites and the before-after effect 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. The estimate of the safety edge effectiveness is considered reliable only if the before-after effects for both the treatment and comparison sites are statistically significant.

Statistically significant effects were found for two state/roadway type/shoulder type combinations for total crashes. However, only a few statistically significant effects were found for other crash types, as the data for those crash types are more sparse. For two-lane highway sites with paved shoulders in Georgia, the results indicate that the safety edge treatment decreases total nonintersection crash frequency by 39.6 percent, which is statistically significant. However, for the comparable sites in Indiana, the safety edge treatment was associated with an increase in crash frequency of 3.2 percent.

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

- only one year of crash data are available for the period after resurfacing.
- 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 which increased the variability in the data and made the statistical test less powerful.
- multilane highway sites in Georgia could not be included in the EB analysis because there were not enough reference sites to develop useful SPFs for multilane highways.
- crash data for run-off-road and drop-off-related accidents were too sparse to develop SPFs for these crash types, so the SPFs for total crashes has to be used together with proportions of run-off-road and drop-off-related crashes.

More meaningful and reliable results are expected when another year or two of crash data are available for the period after resurfacing. This should reduce the variability of crash frequencies for the period after resurfacing and provide more crash data for the sites with unpaved shoulders. Additional data acquisition to improve the SPFs will be considered in future years.

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 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 differences 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. Traffic volume and site type (treatment vs. comparison) were the main factors of interest in the analysis. For overdispersed data, the analysis was conducted with negative binomial modeling. However, when no overdispersion could be detected in the data (i.e., the dispersion parameter was not statistically different from zero), Poisson regression was used.

The safety edge treatment effect and its standard error were calculated for each target crash type, adjusted for any covariates, and presented in Table 24. The significance and p-value for the treatment vs. comparison site effect are also provided.

Table 24. 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 sites	Intercept	AADT effect: Coefficient	AADT effect: Standard error	AADT effect: p-Value	AADT effect: Statistically significant?[c]	Treatment effect: Coefficient	Treatment effect: Standard error	Treatment effect: p-Value	Treatment effect: Statistically significant?[c]	Dispersion parameter	R^2_{LR}%	Safety edge effect[b] (%)
GA	Multilane	Paved	TOT	18	–9.812	1.187	0.352	0.001	Y	–0.832	0.356	0.019	Y	0.134	44.9	56.5
			FI	18												
			PDO	18	–12.297	1.429	0.464	0.002	Y	–1.204	0.486	0.013	Y	0.230	44.4	70.0
			rorTOT	18												
			rorFI	18												
			rorPDO	18												
			doTOT	18												
			doFI	18												
			doPDO	18												
GA	Two-lane	Paved	TOT	33	–9.369	1.228	0.279	< 0.001	Y	–0.323	0.365	0.376	N	0.450	47.6	27.6
			FI	33	–10.475	1.255	0.395	0.002	Y	–0.541	0.473	0.253	N	0.746	31.2	41.8
			PDO	33	–10.172	1.253	0.332	< 0.001	Y	–0.133	0.444	0.764	N	0.544	38.5	12.5
			rorTOT	33	–6.941	0.869	0.356	0.015	Y	–0.627	0.491	0.202	N	0.630	29.3	46.6
			rorFI	33	–6.848	0.749	0.586	0.201	Y	–0.561	0.726	0.439	N	1.693	9.6	43.0
			rorPDO	33	–8.164	0.951	0.464	0.040	Y	–0.658	0.670	0.326	N	0.985	23.4	48.2
			doTOT	33	–10.740	1.251	0.507	0.014	Y	–0.594	0.658	0.367	N	0.970	30.0	44.8
			doFI	33	–8.841	0.937	0.773	0.225	N	–0.435	0.903	0.630	N	1.921	9.5	35.3
			doPDO	33	–15.813	1.722	0.619	0.005	Y	–0.443	0.731	0.545	N	0.636	31.2	35.8
GA	Two-lane	Unpaved	TOT	49	–8.970	1.129	0.216	< 0.001	Y	0.603	0.251	0.016	Y	0.314	34.1	–82.8
			FI	49	–7.760	0.887	0.165	< 0.001	Y	0.112	0.225	0.618	N	0.000	25.1	–11.9
			PDO	49	–11.257	1.329	0.238	< 0.001	Y	0.847	0.262	0.001	Y	0.226	37.7	–133.3
			rorTOT	49												
			rorFI	49	–6.991	0.732	0.200	< 0.001	Y	0.036	0.293	0.903	N	0.000	19.0	–3.6
			rorPDO	49												
			doTOT	49												
			doFI	49												
			doPDO	49												

Table 24. 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 sites	Intercept	AADT effect Coefficient	AADT effect Standard error	AADT effect p-Value	AADT effect Statistically significant?[c]	Treatment effect Coefficient	Treatment effect Standard error	Treatment effect p-Value	Treatment effect Statistically significant?[c]	Dispersion parameter	R^2_{LR}%	Safety edge effect[b] (%)
IN	Two-lane	Paved	TOT	22	0.696	0.035	0.629	0.955	N	–0.312	0.557	0.576	N	0.692	1.8	26.8
			FI	22	–6.559	0.752	0.979	0.442	N	–1.402	0.781	0.073	Y	0.537	15.0	75.4
			PDO	22												
			rorTOT	22												
			rorFI	22												
			rorPDO	22												
			doTOT	22												
			doFI	22												
			doPDO	22												
IN	Two-lane	Unpaved	TOT	33	–3.555	0.401	0.291	0.167	N	–0.105	0.366	0.774	N	0.361	7.2	10.0
			FI	33	–1.685	0.001	0.612	0.998	N	–1.291	0.729	0.077	Y	0.349	11.3	72.5
			PDO	33	–4.835	0.519	0.309	0.093	Y	0.199	0.391	0.610	N	0.368	7.8	–22.0
			rorTOT	33												
			rorFI	33												
			rorPDO	33												
			doTOT	33												
			doFI	33												
			doPDO	33												
NY	Two-lane	Paved	TOT	6												
			FI	6												
			PDO	6												
			rorTOT	6												
			rorFI	6												
			rorPDO	6												
			doTOT	6												
			doFI	6												
			doPDO	6												

[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 24 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 only six of the models shown in the table. In four of these cases, the safety performance of the treatment sites was better than at the comparison sites, with differences ranging from 56 to 75 percent, indicating that the safety edge was effective. However, in two cases, both for two-lane highways with unpaved shoulders in Georgia, the safety performance of the comparison site was better than the treatment site by 83 to 133 percent, indicating that the safety edge adversely affected safety. It should be kept in mind that these differences may be attributable to factors other than the safety edge.

In summary, the cross-sectional analysis results suggest that the safety edge treatment may be effective in reducing crashes, but the available data are too limited to obtain statistically significant results in most cases.

The potential biases and limitations of this analysis are:

- only one year of crash data are available for the period after resurfacing
- 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

More reliable results may be obtained with another year or two of data, but some of the concerns discussed above for this analysis will remain.

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 25. 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 (*7*). The primary measures of interest presented in Table 25 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, which occurred in almost all cases. 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 24 out of 33 cases shown in Table 25; 12 of the 24 positive results were for sites resurfaced with the safety edge treatment and 12 were for sites resurfaced without the safety edge treatment. Only 4 of the 33 comparisons of severity proportions were statistically significant, 3 cases for comparison sites and 1 case for a treatment site. 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 between resurfacing with and without the safety edge treatment in the shift in severity distributions.

Table 25. Comparison of Proportions of Fatal and Injury Crashes Before and After Resurfacing

Crash type	State	Roadway type	Shoulder type	Site type[a]	Average before proportion	Average after proportion	Estimated average difference	Number of sites	Estimated median difference	Lower 90% confidence limit	Upper 90% confidence limit	Significant at the 0.10 level?
TOT	GA	Multilane	Paved	T	0.358	0.381	0.023	9	0.039	–0.219	0.302	No
				C	0.331	0.109	–0.222	7	–0.244	–0.381	–0.117	Yes
		Two-lane	Paved	T	0.248	0.209	–0.039	15	–0.062	–0.229	0.106	No
				C	0.418	0.395	–0.023	9	–0.048	–0.279	0.237	No
			Unpaved	T	0.192	0.239	0.047	16	–0.025	–0.155	0.250	No
				C	0.360	0.314	–0.047	23	–0.040	–0.161	0.071	No
	IN	Two-lane	Paved	T	0.074	0.119	0.045	5	0.079	–0.111	0.389	No
				C	0.211	0.264	0.053	7	0.102	–0.117	0.201	No
			Unpaved	T	0.128	0.111	–0.017	7	–0.021	–0.500	0.406	No
				C	0.231	0.248	0.018	13	0.018	–0.167	0.217	No
	NY	Two-lane	Paved	T	0.507	0.222	–0.285	3	–0.338			No Test
				C	0.407	0.179	–0.228	3	–0.257			No Test
ROR	GA	Multilane	Paved	T	0.337	0.450	0.113	9	0.096	–0.341	0.510	No
				C	0.331	0.087	–0.244	5	–0.400	–0.548	–0.228	Yes
		Two-lane	Paved	T	0.294	0.170	–0.124	15	–0.181	–0.400	0.016	No
				C	0.423	0.321	–0.101	7	–0.125	–0.500	0.251	No
			Unpaved	T	0.292	0.248	–0.044	15	–0.125	–0.363	0.250	No
				C	0.363	0.369	0.006	17	0.021	–0.183	0.212	No
	IN	Two-lane	Paved	T	0.016	0.155	0.139	4	0.500	–0.056	1.000	?
				C	0.398	0.208	–0.190	6	–0.250	–0.393	–0.117	Yes
			Unpaved	T	0.114	0.089	–0.025	5	–0.021	–0.688	0.667	No
				C	0.334	0.338	0.003	10	0.000	–0.417	0.300	No
	NY	Two-lane	Paved	T	0.685	0.333	–0.352	3	–0.420			No Test
				C	0.628	0.278	–0.350	3	–0.413			No Test
DO	GA	Multilane	Paved	T	0.400	0.367	–0.034	9	–0.036	–0.515	0.381	No
				C	0.351	0.104	–0.247	6	–0.333	–0.667	–0.024	Yes
		Two-lane	Paved	T	0.387	0.196	–0.192	13	–0.375	–0.722	–0.047	Yes
				C	0.462	0.232	–0.230	7	–0.500	–0.639	–0.026	Yes
			Unpaved	T	0.283	0.272	–0.011	13	–0.077	–0.361	0.336	No
				C	0.306	0.334	0.027	13	0.063	–0.167	0.314	No
	IN	Two-lane	Paved	T	0.000	0.071	0.071	1	1.000			No Test
				C	0.271	0.167	–0.104	3	–0.292			No Test
			Unpaved	T	0.083	0.000	–0.083	2	–0.625			No Test
				C	0.435	0.241	–0.194	9	–0.375	–0.875	0.000	No
	NY	Two-lane	Paved	T	0.000	0.000	0.000					No Test
				C	0.000	0.000	0.000					No Test

[a] Site types:
T = Treatment sites resurfaced with safety edge.
C = Comparison sites resurfaced without safety edge.

Section 5. Preliminary Analysis Results for Project Cost Data

This section presents the preliminary analysis results for project cost data. The project plan involves the conduct of a benefit-cost analysis of the safety edge treatment. This benefit-cost analysis cannot be completed until final safety effectiveness estimates for the safety edge treatment are obtained. However, an effort to assemble cost data for the safety edge treatment that will be needed for the benefit-cost analysis has begun.

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 26. Costs per mile of safety edge resurfacing vs. non-safety-edge resurfacing were found to be $110,000 vs. $140,000.

Table 26. Georgia Resurfacing Project Costs

	Weighted average cost		Nonweighted average cost	
Cost item	Safety edge	Comparison	Safety edge	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 27. Costs per mile of safety edge resurfacing vs. non-safety edge resurfacing were found to be $140,000 vs. $150,000.

Table 27. Indiana Resurfacing Project Costs

	Weighted average cost		Nonweighted average cost	
Cost item	Safety edge	Comparison	Safety edge	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 28. 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 28. New York Resurfacing Project Cost

	Weighted average cost		Nonweighted average cost	
Cost item	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 costs for all states costs is shown in Table 29. Collectively, the cost of resurfacing with the safety edge treatment was found to be less than without the safety edge treatment. This seems unlikely, but it may be possible to conclude that the provision of the safety edge treatment did not substantially increase the cost of the resurfacing in these three states.

Table 29. Summary of Georgia, Indiana, and New York Resurfacing Costs

	Weighted average cost		Nonweighted average cost	
Cost item	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

Another method to compute 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 being used in Table 30 below. 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.

Table 30. 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 per mile of safety edge treatment							$955.44

[a] Based on HMA thickness of 1.5 in for safety edge treatment.
[b] HMA costs per ton based on contract data.

Section 6. Conclusions

Conclusions from the Year 1 analysis of drop-off field measurements and crash data are presented below. These conclusions should be considered preliminary until additional data from subsequent years for the period after resurfacing are available.

1. The results of Empirical Bayes (EB) and cross-sectional analyses with the Year 1 data suggest that the safety edge treatment is effective in reducing crashes. However, one year of data for the period after resurfacing is not sufficient to obtain statistically significant results for the effectiveness of the safety edge treatment.
2. The total crash frequency increased for projects both with and without safety edge treatment in the first year after resurfacing compared to the total crash frequency in the period before resurfacing. This indicates that resurfacing increases total crash frequency in the first year after resurfacing.
3. 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 after resurfacing may result from this effect. Including additional years of crash data for the period after resurfacing will increase sample sizes and may allow more in-depth analysis of drop-off-related crashes which should provide better estimates of the effectiveness of the safety edge.
4. 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. There is no apparent shift in crash severity distributions between resurfacing with and without the safety edge treatment.
5. 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.
6. There is some evidence that overall resurfacing with the safety edge treatment is slightly more effective than resurfacing without the safety edge treatment in reducing the proportion of drop-off heights that exceed 51 mm (2 in). However, there is not sufficient evidence to show statistical significance based on the Year 1 data.
7. The cost of adding the safety edge 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 its cost is approximately $594 per km ($955 per mi) for treatment on both sides of the roadway.

Section 7. Recommendations

1. The safety effectiveness of the safety edge treatment is difficult to determine due to the small number of drop-off related crashes in the first year after resurfacing. The evaluation should continue as planned to include crash data for the second and third years after resurfacing. The availability of two additional years of crash data should lead to less variable and more reliable analysis results.
2. Crash data from reference sites was not sufficient to develop SPFs for multilane sites in Georgia or for run-off-road and drop-off related crashes. Additional reference sites may be needed in Year 2 to allow development of SPFs for multilane highways and for run-off-road and drop-off related crashes.
3. Additional analysis approaches may be considered in Year 2 to overcome small sample sizes and lack of SPFs. Specifically, two additional analyses that could be considered are prediction modeling considering year-to-year variability in the after period and modeling using study period as an independent variable.
4. Field measurements of pavement edge drop-off heights should continue in Years 2 and 3 to investigate whether extreme drop-offs are less likely to develop on sites resurfaced with the safety edge treatment than on sites resurfaced without the safety edge treatment.

Section 8.
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: ____

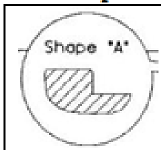
Speed Limit: __________ **Orientation:** N / S E / W

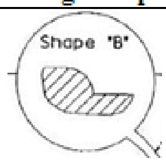
Pavement Type: Asphalt Concrete

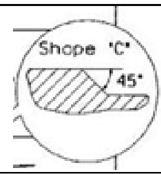
Shoulder Type:

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:







Shape "A"	Shape "B"	Shape "C"		
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

Horizontal Curve left right none

Vertical crest sag none

Initial Grade ______ up down

Final Grade ______ up down

Roadside Rating ______

Additional Comments:

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

Figure B-1. Sample Data Collection Form

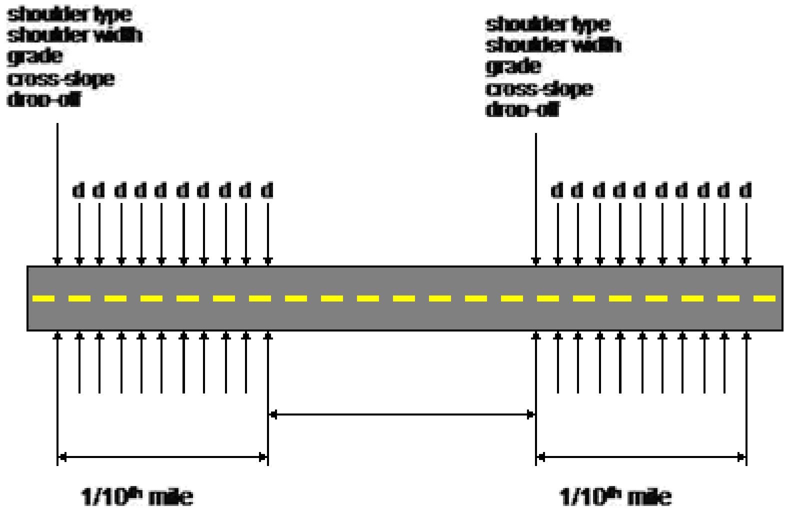


Figure B-2. Data Collection Intervals

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 width (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).

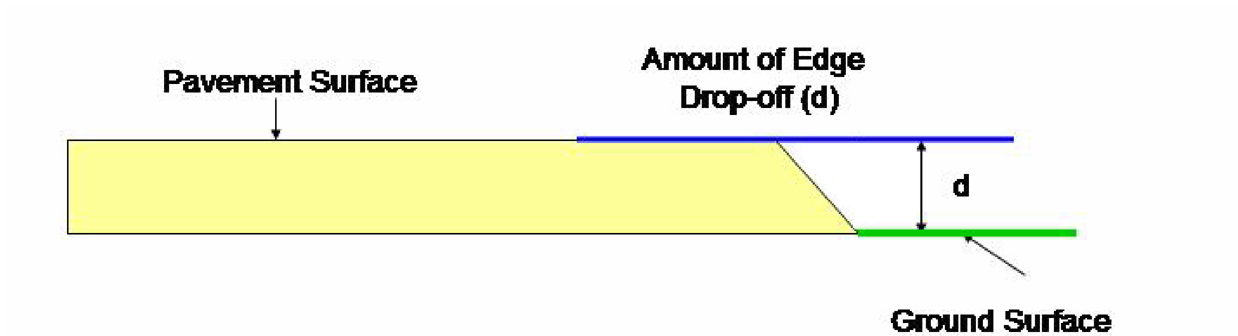


Figure B-3. Measurement of Pavement Edge Drop-Off Perpendicular to Pavement Surface

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