Safety Effects of the SafetyEdge[SM]

Technical Summary of Crash Modification Factors

FHWA Safety Program

U.S. Department of Transportation
Federal Highway Administration

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INTRODUCTION

The objective of this study was to evaluate the safety effectiveness and to develop benefit-cost (B/C) ratios for the application of the SafetyEdge℠ treatment using scientifically rigorous crash-based analysis methods. More than half of all fatal crashes that occur annually in the United States involve a roadway departure, defined by FHWA as a crash which occurs after a vehicle crosses an edge line, a center line, or otherwise leaves the traveled way. Pavement edge drop-offs are known to contribute to some of the most severe roadway departure crashes. The typical scenario begins with one or more of the vehicle tires leaving the paved roadway. If the driver attempts to return to the paved surface without slowing, and a significant vertical edge drop-off is present, the sidewall of one or more tires will scrub against this edge and the driver may oversteer in an effort to return to the paved roadway. This may result in a driver losing control of the vehicle, contributing to a head-on collision in the opposing travel lane, a rollover, or a run-off-road (ROR) event on either side of the road. To mitigate roadway departure crashes, it is important to reduce the number of vehicles that encroach onto the roadside, and to minimize the consequences of a roadway departure event. One strategy to achieve the latter objective is to eliminate vertical pavement edges that may become drop-offs over the life of the pavement.

The SafetyEdge℠ is constructed with a low-cost paver attachment that enables the pavement edge to be paved and compacted to a finished 30-degree angle to eliminate vertical edges and promote a smooth return to the travel lane after one or more wheels leave the pavement. Figure 1 illustrates typical cross-sections immediately after completing an asphalt pavement resurfacing project with and without the SafetyEdge℠. The illustration on the left in Figure 1 shows the SafetyEdge℠ with compacted backfill material that is graded flush with the paved road surface, while the illustration on the right in Figure 1 shows the backfill material graded flush with the paved roadway surface, but without the SafetyEdge℠ treatment beneath the graded backfill material. Over time, the material adjacent to the edge of pavement settles or erodes, exposing the edge, which is shown in Figure 2. The left panel in Figure 2 illustrates how the angled SafetyEdge℠ can easily be traversed by vehicles attempting to re-enter the roadway, while the panel on the right side of Figure 2 shows how the vertical or near-vertical pavement edge drop-off with traditional paving techniques can cause tire-scrubbing, which may lead to loss of control.

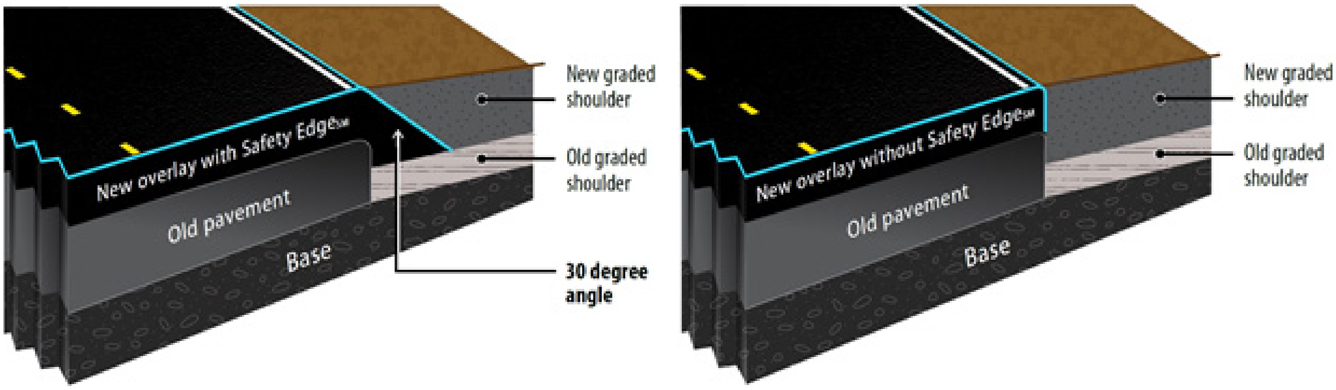

Figure 1. Graphic. SafetyEdge℠ versus conventional paved edge immediately after repaving.

(Left panel: SafetyEdge℠ immediately after paving with backfill material graded flush with paved surface. Right panel: Conventional pavement overlay without the SafetyEdge℠ with backfill material graded flush with the paved surface)

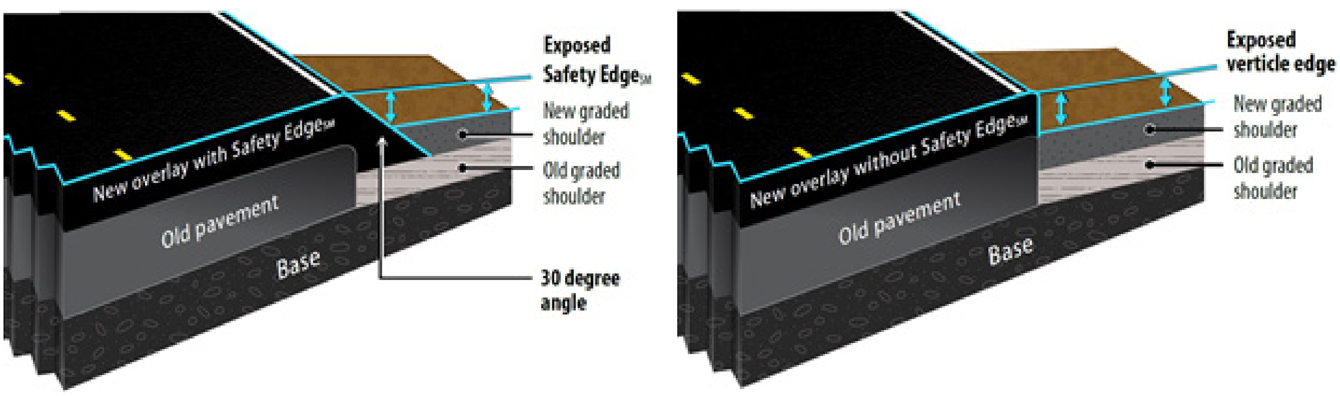

Figure 2. Graphic. SafetyEdge℠ versus conventional paved edge after backfill material settles or erodes.

(Left panel: SafetyEdge℠ is exposed to traffic after backfill material settles or erodes. Right panel: Conventional pavement overlay without the SafetyEdge℠ after backfill material settles or erodes)

This study builds on past SafetyEdge℠ research by using a multi-State database and state-of-the-art analysis methodology. The large sample of repaving projects with and without the SafetyEdge℠ afforded the opportunity to develop crash modification factors (CMFs) for several crash types and to disaggregate the CMFs based on traffic volume and other roadway features. The CMFs were used to develop benefit-cost ratios for the SafetyEdge℠ treatment on two-lane rural highways.

METHODOLOGY

This research team compared the safety performance of two-lane rural highways with and without the SafetyEdge[SM] treatment using an EB observational before-after study design (Hauer, 1997, Gross et al., 2010). The EB evaluation method accounts for regression-to-the-mean (if it exists), and for differences in traffic volume and for crash trends between the periods before and after the treatment was applied. The approach is comprised of the following three steps:

- **Step 1:** Predict what the safety performance of rural two-lane highways would have been in the after period had the SafetyEdge[SM] not been implemented.
- **Step 2:** Estimate what the actual safety performance was in the after period with the SafetyEdge[SM].
- **Step 3:** Compare the results of Step 1 and Step 2.

The study developed aggregate CMFs for several crash types, including one for drop-off-related crashes, the target crash type addressed by the SafetyEdge[SM]. In addition, CMFs were developed for single-vehicle ROR and opposite direction crashes, two common crash outcomes when a vehicle encounters a vertical edge and the driver loses control. Finally, CMFs were developed for fatal and injury (FI) crashes and total crashes. Intersection-related and animal crashes were not included in the sample of any crash type used in the safety evaluation. The evaluation also considered average annual daily traffic, paved roadway width, presence of a horizontal curve, and the posted speed limit when investigating the disaggregate SafetyEdge[SM] treatment effects.

The economic evaluation of the SafetyEdge[SM] treatment integrated the results of the safety evaluation. The expected annual benefit of the SafetyEdge[SM] was estimated separately for ROR and FI crashes using the CMFs developed as part of this study.

Additionally, this effort included manual field data collection for a sample of two-lane highways repaved with and without the SafetyEdge[SM] in Iowa, North Carolina, and Ohio in order to provide information on the characteristics of the treatment and reference sites. The data included measurements of the pavement edge shape and depth.

SAFETY EVALUATION DATA SUMMARY

Sites that were re-paved with or without the SafetyEdge[SM] in 2012 or earlier were included in the treatment and reference group samples. The analysis period ranged from 2005 through 2015, depending on the treatment installation dates and availability of data from the participating transportation agencies. At least three years of before and after period data were sought for each treatment and reference group site. Only re-paving projects that were completed during a single calendar year were included in the analysis, and the year of construction was excluded from the safety evaluation. Data from the States of Iowa, North Carolina, Ohio, and Pennsylvania, along with data from Marion County, Florida, were included in the evaluation.

Tables 1 through 5 provide a summary of the number of treatment and reference group sites, mile-years of data, average daily traffic volumes, and total crashes for the before and after periods. Detailed information regarding the roadway inventory and other crash types considered in the evaluation can be found in the final report.

Total, FI, ROR, and opposite direction crashes could be identified in all of the crash data files supplied by the five agencies included in the evaluation, although in some cases ROR data were limited to ROR to the right crashes. Drop-off-related crashes could be identified only in the Iowa, North Carolina, Ohio, and Pennsylvania data files. In Pennsylvania, the sample of drop-off-related crashes was too small to develop a CMF for this crash type. In Iowa, drop-off-related crashes represented 2.5 to 13.5 percent of the total crashes during the before or after periods at the treatment or reference group sites. In North Carolina and Ohio, drop-off-related crashes ranged from 7.2 to 13.9 percent and 3.5 to 6.6 percent, respectively, of the total crashes.

Table 1. Safety evaluation data summary – Iowa.

Site Type	Number of Sites	Miles	Before period mile years	After period mile years	Before period mean AADT	After period mean AADT	Before period total crashes	After period total crashes
Treatment	279	316.1	1,008	1,205	933	1,756	393	308
Reference	108	74.2	211	284	1,321	2,002	96	102

Table 2. Safety evaluation data summary – Marion County, Florida.

Site Type	Number of Sites	Miles	Before period mile years	After period mile years	Before period mean AADT	After period mean AADT	Before period total crashes	After period total crashes
Treatment	40	36.4	165	127	6,250	5,675	130	162
Reference	51	21.3	99	71	3,616	3,546	101	104

Table 3. Safety evaluation data summary – North Carolina.

Site Type	Number of Sites	Miles	Before period mile years	After period mile years	Before period mean AADT	After period mean AADT	Before period total crashes	After period total crashes
Treatment	727	369.1	2,375	948	3,285	3,065	2,496	1,139
Reference	573	196.8	1,263	502	2,059	2,275	847	397

Table 4. Safety evaluation data summary – Ohio.

Site Type	Number of Sites	Miles	Before period mile years	After period mile years	Before period mean AADT	After period mean AADT	Before period total crashes	After period total crashes
Treatment	447	576.0	3,847	606	3,535	2,998	3,899	718
Reference	163	203.0	1,296	286	3,185	2,442	1,168	272

Table 5. Safety evaluation data summary – Pennsylvania.

Site Type	Number of Sites	Miles	Before period mile years	After period mile years	Before period mean AADT	After period mean AADT	Before period total crashes	After period total crashes
Treatment	170	24.0	72	72	1,493	1,560	53	38
Reference	1,411	159.0	318	637	1,382	1,370	277	503

SAFETY EVALUATION RESULTS

The safety evaluation consisted of approximately 1,321 mi of rural two-lane highways repaved with the SafetyEdge^{SM}. The reference group included nearly 654 mi of two-lane rural highways repaved without the SafetyEdge^{SM}. The reference group sites were used to estimate safety performance functions (SPFs) for use in the EB methodology for total, FI, ROR, opposite direction, and drop-off-related crashes when the sample of crashes was adequate. SPFs were estimated separately using data from each transportation agency, producing agency-specific CMFs. CMFs are used to estimate the expected number of crashes after a safety countermeasure has been implemented—values exceeding 1.0 indicate that crashes are expected to increase after implementing the countermeasure, while values less than 1.0 indicate a reduction in the expected number of crashes. The agency-specific CMFs developed in the safety evaluation were aggregated into an overall CMF for each crash type.

CMF for Drop-off Related Crashes

Since drop-off related crashes are the specific subset of all crashes that the SafetyEdge^{SM} treatment is intended to mitigate, it is no surprise that the greatest potential crash reduction is for this crash type. Figure 3 shows the CMF point estimates for drop-off-related crashes and the associated 95th percentile confidence intervals. Data from the Iowa, North Carolina, and Ohio departments of transportation were used to develop the drop-off-related CMF. When combining these data across all States, the resulting "All" CMF for drop-off-related crashes is 0.655, which indicates that the SafetyEdge^{SM} is associated with a 34.5 percent reduction in drop-off-related crashes on two-lane rural highways. Only the combined "All" CMF and the North Carolina CMF were statistically significant at the 95th-percentile confidence level. The Ohio drop-off-related CMF for SafetyEdge^{SM} projects was statistically significant at the 90-percent confidence level.

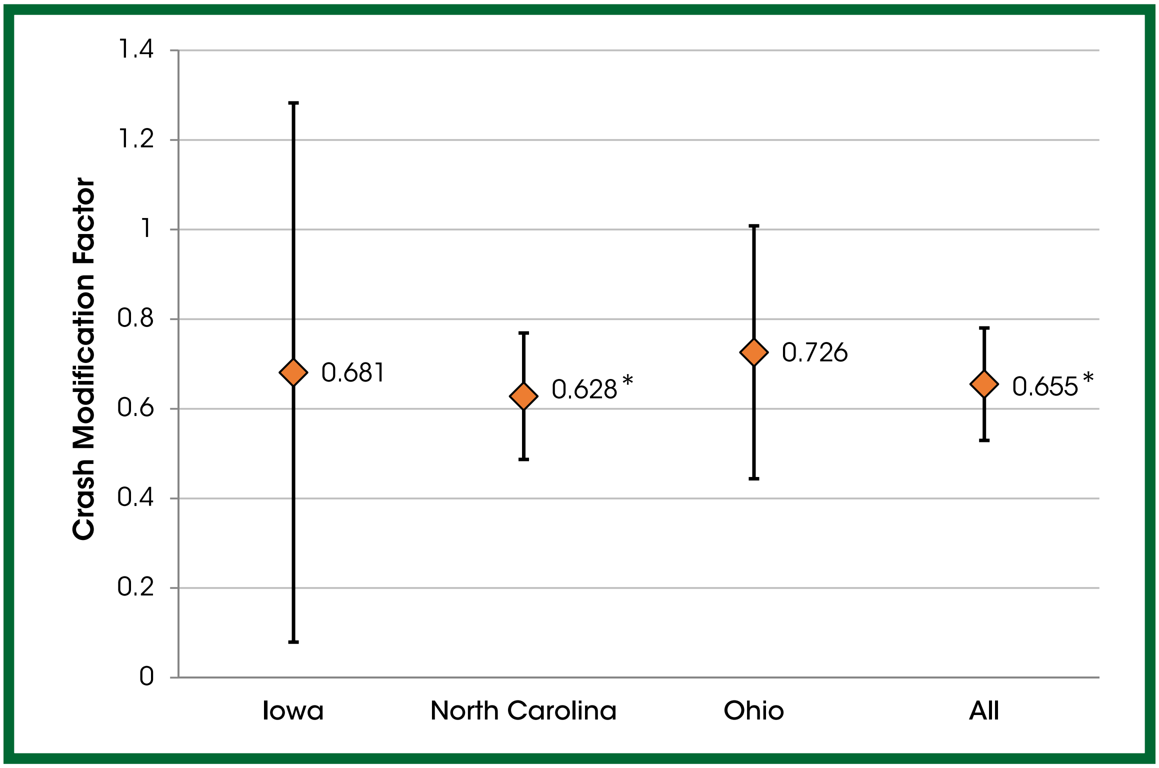

Figure 3. Chart. CMFs for drop-off related crashes.

(*indicates CMF is statistically significant at 95-percent confidence level)

CMFs for ROR and Opposite Direction Crashes

ROR (including rollover) and head-on plus opposite direction sideswipes (referred to as opposite direction) crashes are two common outcomes when a driver loses control of the vehicle after encountering a vertical pavement edge. Figures 4 and 5 show the ROR and opposite direction CMFs, respectively, developed from data from all five transportation agencies included in the safety evaluation, as well as an aggregate CMF by combining the results from all five transportation agencies.

The aggregated CMF for ROR crashes was 0.790. This result was statistically significant, with the 95-percent confidence interval ranging from 0.708 to 0.872. The individual ROR CMFs for Ohio and Pennsylvania were also statistically significant; however, the combined CMF is the most robust, representing a crash reduction of 21 percent after application of the SafetyEdge[SM] treatment to the sample of two-lane rural highways included in the present study.

For the opposite direction crash type, the aggregate CMF developed using data from all five transportation agencies included in the safety evaluation was 0.813, which was statistically significant at the 95th percentile confidence level. This indicates that, after implementing the SafetyEdge(SM) treatment on the sample of two-lane rural highways included in the present safety evaluation, opposite direction crashes were expected to be 18.7 percent lower than along similar two-lane rural highways that were not repaved with the SafetyEdge(SM). The opposite direction CMFs for Marion County, Florida, North Carolina and Pennsylvania were also statistically significant based on the sample of data used in the safety evaluation.

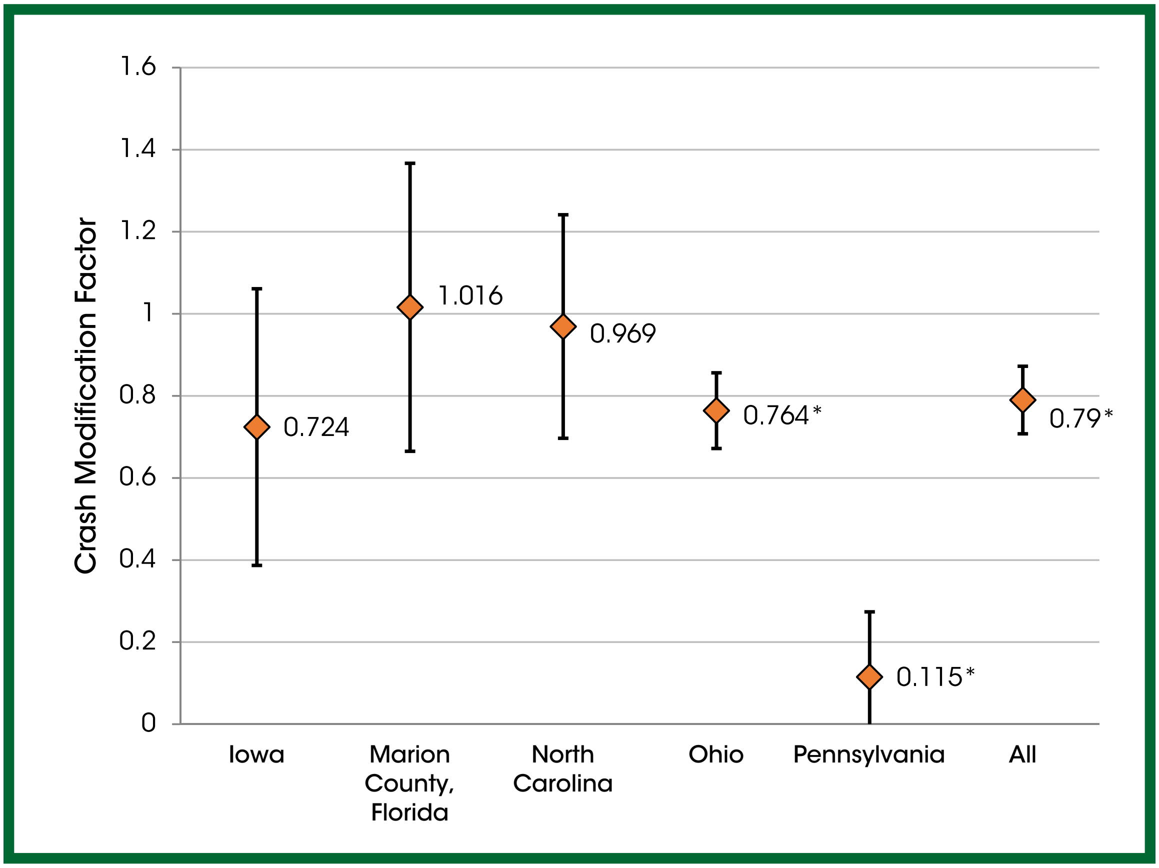

Figure 4. Chart. CMFs for ROR crashes.

(*indicates CMF is statistically significant at 95-percent confidence level)

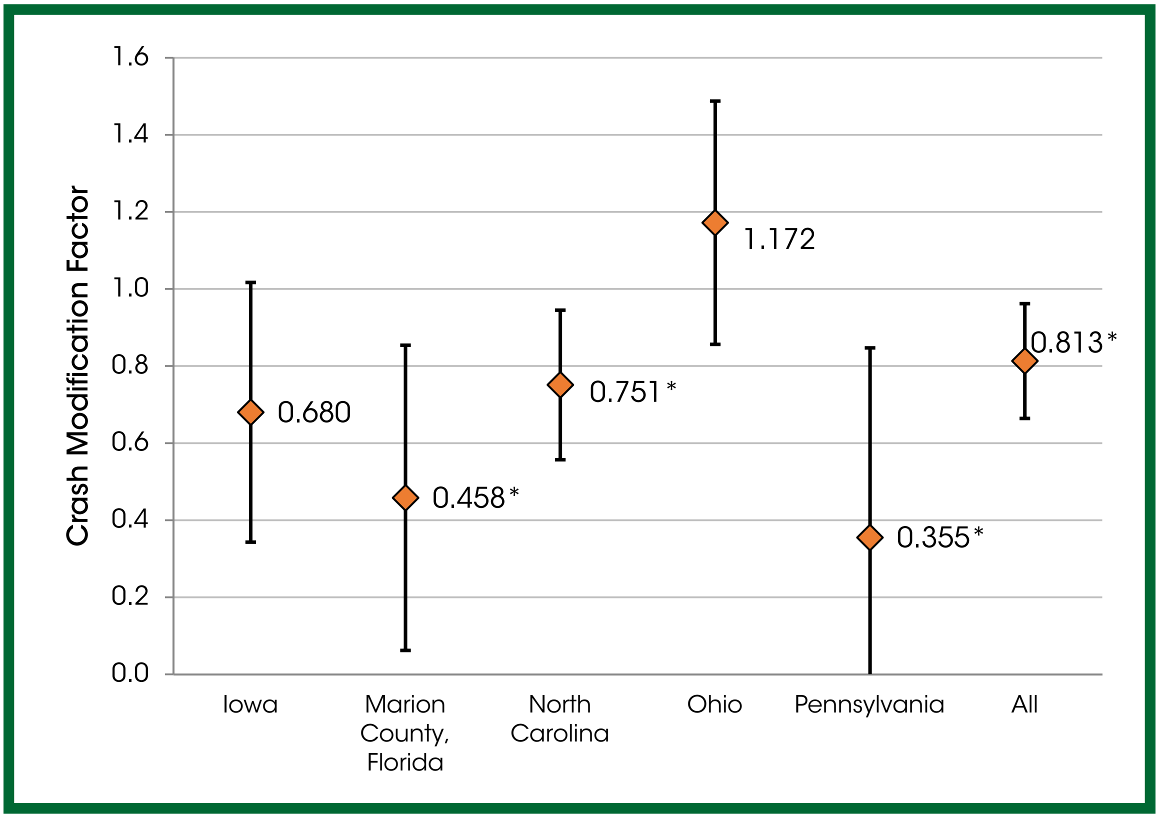

Figure 5. Chart. CMFs for opposite direction crashes.

(*indicates CMF is statistically significant at 95-percent confidence level)

CMF for Fatal and Injury Crashes

The FI CMF, shown for all five transportation agencies in Figure 6, was also statistically significant when aggregating the data in the study sample. The CMF was 0.892, which indicates that the SafetyEdge[SM] is associated with a 10.8-percent reduction in FI crashes along two-lane rural highway segments included in the evaluation. The 95th percentile confidence interval produces a CMF that ranges from 0.825 to 0.959. The FI CMFs developed for Marion County, Florida, and for Pennsylvania, were also statistically significant at the 95th percentile confidence level.

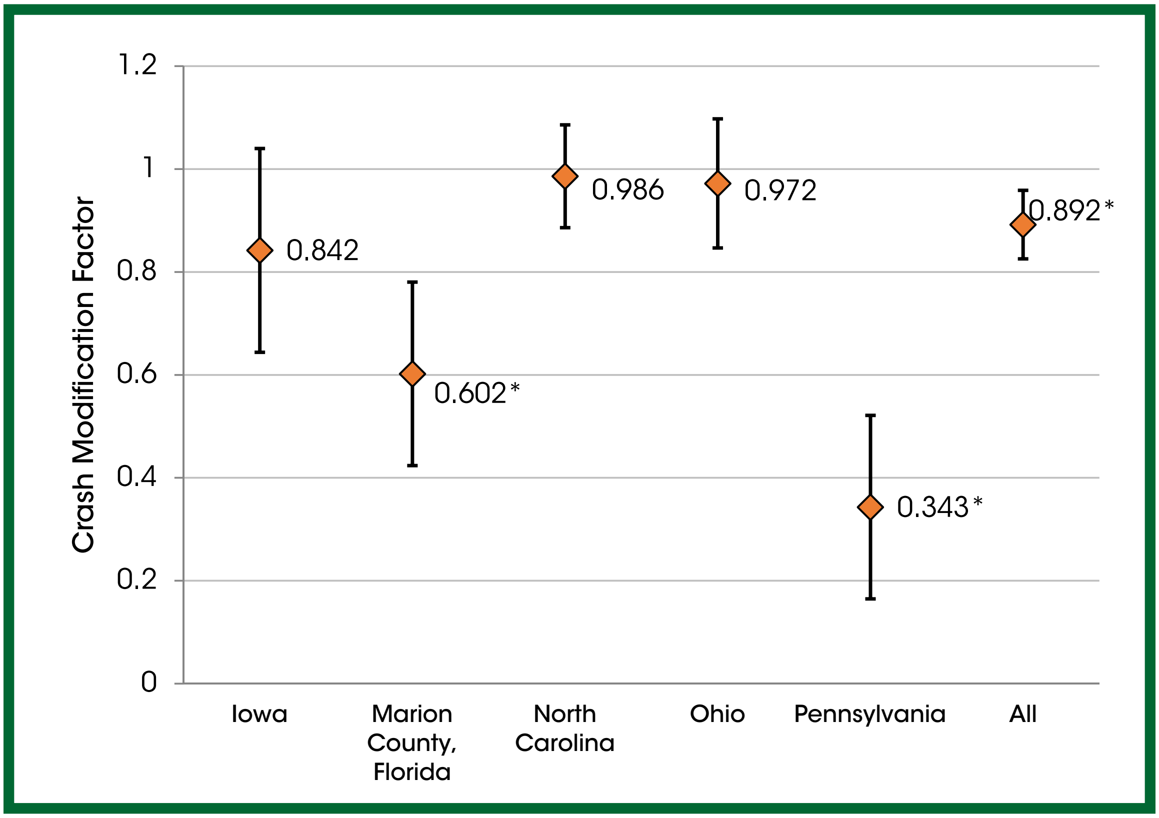

Figure 6. Chart. CMFs for FI crashes.

(*indicates CMF is statistically significant at 95-percent confidence level)

CMF for Total Crashes

When aggregating the data across all five transportation agencies, the CMF for total crashes was 0.989, which was not statistically significant. This result was expected because the SafetyEdge^{SM} treatment is most likely associated with only a portion of roadway departure crashes on two-lane rural highways, which represents a low proportion of total crashes.

CMFunction for ROR Crashes

In addition to the analysis results presented above, the CMFs were disaggregated by the expected number of ROR crashes per mile-year before the SafetyEdge[SM] was applied. A CMFunction was developed using a single independent variable, the expected crash frequency per mile-year before treatment, which logically captures the effects of the other variables investigated in the univariate categorical analysis. The CMFunction, which was estimated using linear regression, is:

$$\mathbf{CMF_{ROR} = 0.975 - (0.432 \times \text{Expected ROR crash frequency per mile-year})}$$

Figure 7. Equation. CMFunction for ROR crashes.

ECONOMIC ANALYSIS

This economic analysis derived the safety benefits based on the CMFs from the ROR and FI crash types. The estimated CMFs were 0.790 for ROR and 0.892 for FI crashes (see Figures 4 and 6, respectively). The most recent FHWA mean comprehensive crash costs (developed in 2001) were used as a base (Council et al., 2005) and updated to 2016 dollars considering changes to the U.S. Department of Transportation (USDOT) value of a statistical life (VSL) from 2001 to 2016. The resulting aggregate 2016 unit costs for a ROR crash and an FI crash were calculated as $313,667 and $400,188, respectively. Using the annual crash reductions based on the aggregate CMFs from the present study, the analysis estimated annual benefits of $16,612,854 for ROR crashes and $20,538,582 for FI crashes.

The material considered in the construction cost was hot-mix asphalt with an average cost of $75.00 per ton for a hot-mix asphalt surface or wearing course from the five transportation agencies included in the evaluation. For an assumed 10-year service life, a discount rate of 7 percent based on the Office of Management and Budget Circular A-4 (OMB, 2016), and information on typical SafetyEdge℠ cross-sections, the estimated annualized SafetyEdge℠ treatment cost ranged from $10.65 per mile-year to $21.30 per mile-year for two-inch and four-inch hot-mix asphalt depths, respectively. For the approximately 1,320 mi of two-lane rural highways repaved with the SafetyEdge℠ included in the sample for the present study, the total annual costs were $14,075 and $28,151, respectively, for the two-inch and four-inch paving depths.

The resulting B/C ratios for ROR crashes, calculated as the ratio of the annual benefit to the annual cost, were 1,180 and 590 for the two-inch and four-inch depths, respectively. The analysis for FI crashes yielded B/C ratios of 1,460 and 730 for the two-inch and four-inch depths, respectively. These B/C values demonstrate that the SafetyEdge℠ is an effective countermeasure to reduce both ROR and FI crashes on two-lane rural highways. Additionally, applying the USDOT sensitivity analysis recommendations of 0.56 and 1.40 times the value of a statistical life (USDOT, 2016) directly to these B/C ratios yields values that, even with conservative assumptions, the SafetyEdge℠ can be applied cost effectively.

FIELD MEASUREMENT OF SAFETYEDGE℠ TREATMENT AND REFERENCE GROUP SITES

Pavement edge measurements were collected along approximately 50 mi of SafetyEdge℠ treatment sites in Iowa, 60 mi in North Carolina, and 55 mi in Ohio. Among these sites, 375 measurements of the SafetyEdge℠ shape were recorded. Pavement edge measurements were collected along approximately 25 mi of reference group sites in each of the three States. There were 210 reference group site measurements in the sample. Examples of the field measurements at treatment and reference group sites are shown in Figures 8 and 9, respectively.

At the reference group and treatment sites in Ohio, the backfill material was nearly flush with the paved roadway surface and appeared be very stable under both weather and traffic conditions, so traffic along the majority of these sections had not yet been exposed to pavement edge drop-offs. The edges were dug out periodically at both treatment and reference sites to verify that the edge type was correctly identified in the data set. At the treatment sites (where the SafetyEdge℠ was used), the angle ranged from 9.8 to 39.8 degrees, with an average angle of 31.8 degrees and a standard deviation of 5.8 degrees.

At the measured sites in North Carolina, the backfill material (often turf) covered much of the pavement edges. At several of the reference group sites in North Carolina, the edge of the pavement was raveling. Raveling was observed at only a few of the SafetyEdge℠ sites, providing preliminary evidence that sites treated with the SafetyEdge℠ may be more durable at the pavement edge than sites that are not paved with a SafetyEdge℠. At the treatment sites in North Carolina, the SafetyEdge℠ had an angle that ranged from 9.1 to 63.4 degrees, with an average angle of 29.7 degrees and a standard deviation of 11.3 degrees.

At the Iowa SafetyEdge℠ treatment and reference group sites, the backfill material at the pavement edge was no longer flush with the roadway surface at the time of the field review. At the Iowa treatment sites, the pavement edge angle ranged from 21.8 to 42.3 degrees, with an average angle of 30.2 degrees. At the treatment sites in Iowa, the vertical dimension of the SafetyEdge℠ ranged from 1.1 to 3 inches.

Figure 8. Photo. Example of Ohio SafetyEdge[SM] Treatment Site (Coshocton County, State Route 83, Curve to the Right).

Figure 9. Photo. Example of Iowa Reference Group Site (Clinton County, State Route 136, Tangent Section).

SUMMARY

This study estimated CMFs for the SafetyEdge^{SM} treatment on two-lane rural highways using data from five transportation agencies. An EB observational before-after evaluation found statistically significant CMFs aggregated across the three States for which drop-off-related crash data were available. The drop-off-related CMF for the three States combined was 0.655. The analysis also found statistically significant CMFs aggregated across all five States for ROR crashes, opposite direction crashes, and FI crashes. The resulting CMFs for five States combined for ROR and opposite direction crashes were 0.790 and 0.813, respectively. These CMFs were consistent with past studies, indicating that the SafetyEdge^{SM} addresses these specific crash types. The resulting FI CMF of 0.892 is also reasonable based on past research, which indicates that drop-off-related crashes are often quite severe, although they are still only a relatively small proportion of crashes. The total crash CMF was not statistically significant at the 95-percent confidence level, which was somewhat expected because the effect of the SafetyEdge^{SM} is not likely to be seen amongst the large number of "property damage only" crashes in the total crash data sample.

An economic evaluation found that the SafetyEdge^{SM} treatment can be applied cost-effectively. Even with conservative estimates of the pavement service life, VSL, and the depth of the pavement surface (i.e., construction costs), the B/C ratios ranged from 590 to 1,180 for ROR crashes, and from 730 to 1,460 for FI crashes. This large B/C ratio is the result of the nominal added cost to repave a roadway with the SafetyEdge^{SM}.

The pavement edge field data collection effort found the angle of the SafetyEdge^{SM} averaged 32 degrees in Ohio, 30 degrees in North Carolina, and 30 degrees in Iowa, which is consistent with the FHWA design and construction guidance.

In summary, this research indicates that the SafetyEdge^{SM} is a highly-effective safety countermeasure based on the aggregate CMFs developed in this multi-State study. The B/C ratios derived for these crash types underscore the cost-effectiveness of the SafetyEdge^{SM} on two-lane rural highways.

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For More Information:

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