

Safety Edge Crash Modification Factors

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Problem Statement

The Safety Edge is a relatively low-cost countermeasure that can be applied in both asphalt and concrete paving operations. The Safety Edge has been promoted as a low-cost countermeasure to reduce the frequency and severity of rural roadway departure crashes. However, there is little information about the actual effectiveness of the Safety Edge in reducing the number and severity of crashes.

Project Objective and Scope

This study evaluated the safety impact of the Safety Edge for construction projects in 2010 and 2011 in Iowa to assess the effectiveness of the treatment in reducing crashes.

Background

About 56% of traffic fatalities in the US are roadway departures. In 2013, this represented 18,257 fatalities (FHWA 2014).

One contributor to roadway departure crashes is the presence of pavement edge drop-off, which is a vertical elevation difference between two adjacent roadway surfaces. Edge drop-offs are potential safety hazards because significant vertical differences between surfaces can reduce vehicle stability and impede the driver's ability to handle their vehicle (Ivey et al. 1984). A typical pavement edge drop-off-related crash occurs when the driver attempts an immediate return to the roadway and tire scrubbing occurs.

Scrubbing is a condition in which the tire sidewall is forced into the pavement edge, resulting in friction between the tire and pavement. Some drivers compensate for scrubbing by increasing the steering angle. When the right front tire finally remounts the pavement, a sudden loss in friction between the tire and the surface of the pavement edge occurs (Ivey et al. 1988).

Drop-off between a paved travel lane and unpaved shoulder can result when the shoulder is not maintained on a



Placement of Safety Edge by asphalt paving operation

timely basis. Shoulder material may migrate away from the paved roadway with excessive shoulder loading or erosion, increasing the vertical elevation difference. Drop-off also occurs when roadways are resurfaced without providing a proper transition to the shoulder (AASHTO 1987).

The Federal Highway Administration (FHWA 2010) estimates that about 11,000 people are injured and about 160 people lose their lives each year in crashes related to unsafe pavement edges in the US. It is difficult, however, to assess the actual contribution of pavement edge drop-off because its presence is not routinely reported in crash reports.

Dixon (2004) evaluated fatal crashes for Georgia for 1997. The authors randomly selected 150 rural two-lane fatal crashes on state and non-state system roads. Dixon estimated that in 38 of the 69 non-state system fatal crashes (55%), edge rutting or edge drop-off was present. Dixon also determined that, of the 38 sites where drop-off was present, edge drop-off appeared to be one of the crash causal factors for 21 of the sites (55%).

Hallmark et al. (2006) evaluated crash form narratives and diagrams in Missouri and Iowa to assess the frequency and severity of edge drop-off crashes on rural roadways. The summary of crashes from 2002 through 2004 showed that 17.7% of crashes on rural two-lane roadways in Iowa and 24.5% in Missouri were potentially related to pavement edge drop-off.

The researchers compared the severity of potential edge drop-off-related crashes to the severity of run-off-road (ROR) crashes for similar roadways in Iowa and Missouri. The researchers found edge drop-off-related crashes were nearly twice as likely to result in a fatal crash than other ROR crashes in Iowa (5.8 versus 3.0%). In Missouri, pavement edge drop-off-related crashes were also twice as likely to result in a fatality (4.0 versus 1.9%). Differences were statistically significant at the 95% confidence level in Iowa, but not in Missouri.



Pavement edge shape resulting from application of the Safety Edge

Effectiveness of the Safety Edge

The FHWA has promoted use of the Safety Edge when a roadway surface is being constructed, reconstructed, or resurfaced. Instead of a vertical pavement edge face, the treatment slopes the pavement edge, providing a transitional surface for drivers who drift off roadways to return to the paved roadway.

Research in the early 1980s found that a 30 to 45 degree sloped edge on pavements was effective in alleviating the severity of crashes (Graham et al. 2011, Neuman et al. 2003, Moler 2007). Early studies on the effectiveness of applying a sloped transition to the pavement edge face were controlled field or simulator tests (Klein et al 1977, Stoughton et al. 1979, Zimmer and Ivey 1983, Graham and Glennon 1984, Ivey and Sicking 1986, Olson et al. 1986, Delaigue 2005).

While this previous research found that a 30 to 45 degree sloped edge on pavements was effective in alleviating the severity of crashes, some of the research also found that a 30 degree angle was easier to construct. The results of these studies were the basis for the FHWA recommending a 30 degree Safety Edge.

For this study, our team found only one study that assessed the effectiveness of the use of the Safety Edge in reducing crashes on-road. Graham et al. (2011) conducted an observational before and after evaluation of sites treated with pavement safety edges using an empirical Bayes (EB) method. The project scope included two road types: rural two-lane highways with paved shoulders no wider than four feet and multilane highways with paved shoulders no wider than four feet.

The study divided the sites into treatments and control sites. Crash records for 2 to 5 years before and 3 years after the installation of safety edges were analyzed for Colorado, Georgia, Indiana, and New York.

The results indicated that the Safety Edge treatment had a small positive crash reduction effect. Overall, a 5.7% reduction in total crashes was found for rural two-lane roadways. However, the result was not statistically significant.

Graham et al. (2011) also examined the costs and benefits of the treatment for two-lane as well as multilane rural highways. The economic analysis reinforced that the treatment was inexpensive and that its application can be highly cost-effective. The computed minimum values for benefit-cost ratios ranged from 4 to 44 for two-lane highways with paved shoulders and from 4 to 63 for two-lane highways with unpaved shoulders.

The FHWA (2010) estimates that use of the Safety Edge on hot-mix asphalt (HMA) projects adds less than 1% of additional material. Wagner and Kim (2005) also reported that addition of the Safety Edge adds less than 1% in additional material costs. Hallmark et al. (2010) calculated the additional material needed and found that, depending on pavement

width, addition of the Safety Edge for HMA projects added about 0.5% for 1 inch lifts and 2.8% for 5 inch lifts. For portland concrete cement (PCC) projects, the additional costs varied from 5 to 9%.

Other benefits of the Safety Edge include the following:

- Provides temporary safety during construction while pavement edge face is exposed
- Increases production for contractors in states that don't require shoulder pull-up immediately after construction (since shoulder work can be done after overlay is completed)
- Can reduce tort liability by showing "due care"
- Although in-place density verification test data are not available for a statistically significant conclusion, placement equipment may also provide some consolidation of the sloped pavement edge, which may be beneficial in pavement edge maintenance over the long term

Application

The Safety Edge is most frequently used on rural two-lane roadways without paved shoulders, but is also appropriate on all primary highways unless the paved shoulder width is 4 feet or greater or the roadway or shoulder is curbed.

Iowa Department of Transportation (DOT) design guidance requires the Safety Edge unless the roadway is an interchange ramp or loop, the roadway or shoulder has curbs, or paved shoulder width is 4 or more feet (Iowa DOT 2012). The Iowa Safety Edge design guidance does not explicitly address traffic volume thresholds or crash history values as indicators for placement; however, the guidelines suggest that locations with high crash history should also be considered as potential candidate locations.



Hot-mix asphalt application of the Safety Edge on rural roadway

Data Collection

The Iowa DOT adopted the Safety Edge as a standard practice for construction and rehabilitation projects in 2010. Marketing and outreach efforts were also undertaken by the Center for Transportation Research and Education (CTRE) at Iowa State University to promote the use of the Safety Edge to the state and local agencies in Iowa. During this process, the extents of known projects where the Safety Edge had been utilized were noted and utilized to determine Safety Edge treatment sites (Hallmark et al. 2010, Hallmark et al. 2012).

Site Selection

The researchers used locations that were tracked over the 2010 and 2011 construction seasons as treatment sites. The team selected a set of potential control sections by identifying similar roadways near each treatment site.

When possible, the researchers identified sections along the same roadway upstream or downstream of the treatment segment, which ensured similar roadway geometry and traffic characteristics. When this was not feasible, the researchers identified a segment along a roadway with similar lane width, traffic volume, and shoulder width/type along a roadway within 20 miles of each treatment site. In most cases, the control site was adjacent to the treatment site.

The Safety Edge had been applied on PCC projects as well. However, the pavement edge on PCC projects is vertical in the absence of the Safety Edge while the pavement edge for asphalt is a more rounded surface. As a result, the impact of the Safety Edge is expected to be different. Because only a few PCC projects had been installed, the data were not sufficient to create a model for PCC projects.

Both two- and four-lane roadways were included in the data, but applications on four-lane roadways were not common. All of the construction projects that were tracked were rural; however, some paving projects transected a small rural community. The researchers excluded sections that fell within the boundaries of a rural community. As a result, only data for rural two-lane asphalt roadways with speed limits of 45 or more miles per hour (mph) were included.

The location of each of the treatment or control section was mapped against links within the geographic information management system (GIMS) that the Iowa DOT maintains for their roadway inventory. In many cases, treatment or control segments were made up of smaller GIMS segments. The corresponding GIMS segments were identified for each treatment and control section.

Most of the control segments were adjacent segments, but those that were not adjacent were road segments similar to the treatment but within the same county (within 10 miles) or in an adjacent county (within 20 miles). One treatment segment control segment was 68 miles away, but that was the farthest one. On average, the distance between the control and treatment segment was roughly 20 miles.

Roadway information, including roadway geometry (surface width, lane width, number of lanes, shoulder width, shoulder type) and traffic volume data were extracted from the GIMS data. Given some inaccuracies in the GIMS database, the researchers also checked characteristics against information from site visits, aerial imagery, and Google forward roadway views. Contiguous GIMS segments with homogenous roadway characteristics were combined. As a result, the segments that the researchers modeled were not of the same length. This resulted in 659 treatment sites (418 miles) and 1,031 control sites (662 miles).

Crash Data

Treatment and control segments were geographically referenced using a geographic information system (ArcMap). The Iowa DOT collects spatial location of all reported crashes within the data.

The researchers obtained data for crashes occurring along each segment for 10 years, 2004 through 2014. The researchers excluded crashes at intersections along the study sections, because those crashes are not likely to be a result of pavement

edge-drop-off given that the pavement edge is not exposed within intersections. The category of crashes used for the analysis was designated all non-intersection crashes.

In addition to all non-intersection crashes, target crashes were identified and included in a separate model. The Safety Edge is expected to only have an impact on crashes where one or more vehicles in the crash leaves the paved surface, so the researchers identified target crashes as any crash where one of the following events was listed in the sequence of events for ROR crashes: ROR right, ROR straight, ROR left.

Note that, in about 22% of crashes, the officer did not report the sequence of events, which reduced the sample size for the target crashes model.

Methodology and Results

The researchers conducted an observational before-and-after study using an EB methodology. Models were developed for total all non-intersection crashes and ROR/target crashes. Different severity types were also evaluated including all severities (fatal, major, injury, minor, property damage only, and unknown) and injury crashes (fatal, major, injury, minor). There were not sufficient fatal crashes to create a separate model for those.

The EB method was used to develop crash modification factors (CMFs). Expected crash rates are represented by safety performance functions (SPFs) that relate the expected crash rate to traffic and road characteristics.

In the literature, SPF estimation in the context of before-and-after analysis has been conducted via the EB approach in conjunction with a negative binomial model structure (Hauer et al. 2002, Persaud et al. 2001, Persaud and Lyon 2007). The estimated SPF is used to predict treatment site crash rates that would have occurred without the treatment (Hauer 1997). The predicted crash rates are then compared with the observed crash counts during the after period to develop CMFs.

SPFs were developed for each model for before-period crashes on control segments using negative binomial generalized linear models. Length of an individual section was included in the models as an offset variable to account for differing lengths.

Traffic volume was also included in the models. A number of roadway variables were also included in the models as noted in Table 1.

Table 2 provides the details for the SPFs used.

SPFs were used to calculate annual predicted crashes for the after period and annual predicted crashes for the before period per unit length for each of the treatment sites. Using this information, CMFs were developed as shown in Table 3.



Advant-Edger, an adjustable, reversible attachment that can be mounted on either side of the paver, designed to create a well defined and durable 30° Safety Edge

Table 1. Variables included in models

Variable	Description	Treatment segments data	Before control segments data only
ID	Unique section ID	Count: 659	Count: 1,031
AADT	Average annual daily traffic (vehicles per day)	Minimum: 25 Maximum: 5,700 Mean: 1,406	Minimum: 10 Maximum: 6,600 Mean: 1,755
Curve	Horizontal curve falls within section	NA	NA
LaneWDH<12	Lanes less than 12 feet	NA	NA
Rumble	Rumble strips present	NA	NA
Length	Length of section (miles)	Minimum: 0.2 Maximum: 1.8 Mean: 0.6	Minimum: 0.3 Maximum: 1.8 Mean: 0.7
SwdWDH>4	Total width of the shoulder is greater than 4 feet	NA	NA
Year	Year (e.g., 2009)	NA	NA

NA: Not applicable for categorical variables

Table 2. Final models developed for SPFs

Crash Type	Crash Severity	Statistically significant variables and parameter estimates	α^{\wedge}
all non-intersection crashes	total crashes	$N = \text{Length} \times \text{EXP} \{-7.871 + (1.038 \times \text{LN}(\text{AADT})) + (0.476 \times \text{Curve}) + (-0.291 \times \text{Rumble}) + (-0.518 \times \text{ShdWDH} > 4)\}$	0.61
	injury crashes	$N = \text{Length} \times \text{EXP} \{-8.723 + (0.890 \times \text{LN}(\text{AADT})) + (0.480 \times \text{Curve}) + (-0.439 \times \text{ShdWDH} > 4)\}$	0.94
	unknown and PDO crashes	$N = \text{Length} \times \text{EXP} \{-8.133 + (1.051 \times \text{LN}(\text{AADT})) + (0.460 \times \text{Curve}) + (-0.297 \times \text{Rumble}) + (-0.530 \times \text{ShdWDH} > 4)\}$	0.63
target crashes	total crashes	$N = \text{Length} \times \text{EXP} \{-6.771 + (0.718 \times \text{LN}(\text{AADT})) + (0.761 \times \text{Curve}) + (-0.274 \times \text{Rumble}) + (-0.372 \times \text{ShdWDH} > 4) + (0.254 \times \text{LaneWDH} < 12)\}$	1.27
	injury crashes	$N = \text{Length} \times \text{EXP} \{-8.199 + (0.755 \times \text{LN}(\text{AADT})) + (0.647 \times \text{Curve}) + (-0.529 \times \text{ShdWDH} > 4)\}$	6.01
	unknown and PDO crashes	$N = \text{Length} \times \text{EXP} \{-6.862 + (0.681 \times \text{LN}(\text{AADT})) + (0.779 \times \text{Curve}) + (-0.313 \times \text{Rumble}) + (-0.326 \times \text{ShdWDH} > 4) + (0.279 \times \text{LaneWDH} < 12)\}$	0.96

 \wedge Dispersion parameter for the negative binomial model

PDO: Property damage only

Table 3. CMF statistics

Crash Type	Crash Severity	Crashes in the after period		CMF	S.E.	90% confidence interval
		Observed	Estimated			
all non-intersection crashes	total crashes	524	603	0.87	0.038	(0.81, 0.93)*
	injury crashes	85	101	0.84	0.092	(0.69, 0.99)*
	unknown and PDO crashes	466	518	0.90	0.042	(0.83, 0.97)*
target crashes	total crashes	209	238	0.88	0.061	(0.78, 0.98)*
	injury crashes	58	63	0.92	0.121	(0.72, 1.12)
	unknown and PDO crashes	151	172	0.86	0.071	(0.76, 0.99)*

S.E.: standard error

* Statistically significant at 90% confidence level

PDO: Property damage only

Discussion

Results indicate a reduction of 8 to 16% depending on the type of crash. Not all of the results were statistically significant. This is likely due to sample size.

It was expected that ROR crashes would have a higher reduction than total non-intersection crashes given that ROR crashes are those that are prevented by the Safety Edge. This higher reduction may also be due to sample size, but may also be due to how officers code crashes.

Officers are not always aware of the actual series of events that precipitate a crash. As indicated in a previous section, sequence of events was not reported for roughly 22% of crashes. Consequently, the results could be due to a bias in the manner in which officers chose to code or not code sequence of events for a given crash.

Only one other study was found that assessed the effectiveness of the use of the Safety Edge in reducing crashes on-road. Graham et al. (2011) found a 5.7% reduction with the Safety Edge, but the study included both two-lane highway and multilane highways. In addition, the results of that study were not statistically significant. In comparison, a 13% reduction in total crashes was found in this research for rural two-lane roadways. Graham et al (2011) found a 1.7% reduction in non-intersection fatal and major injury crashes, which was not statistically significant, whereas, this study found a 16% reduction.

Graham et al. (2011) found a 6.3% reduction in all ROR crashes and a small increase in ROR injury crashes, but the results were not statistically significant. Our study found an 11% decrease in total ROR crashes, which was statistically significant, and an 11% reduction in ROR injury crashes, but these results were not statistically significant.

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