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Safety Evaluation of Centerline Plus Shoulder Rumble Strips

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This document is a technical summary of the Federal Highway Administration report *Safety Evaluation of Centerline Plus Shoulder Rumble Strips* (FHWA-HRT-15-048).

Objective

The Federal Highway Administration (FHWA) organized 37 States to participate in the FHWA Evaluation of Low-Cost Safety Improvements Pooled Fund Study as part of its strategic highway safety plan support effort. The purpose of the study was to evaluate the safety effectiveness of several low-cost safety improvement strategies through scientifically rigorous crash-based studies. One of the strategies evaluated for this study is the combination of centerline and shoulder rumble strips. This strategy is intended to reduce the frequency of crashes by alerting drivers that they are about to leave the travelled lane.

While research into the performance of shoulder and centerline rumble strips applied separately has been conducted, the combination of shoulder and centerline rumble strips is still relatively rare and has not been studied to the same degree. This study sought to fill this knowledge gap.

Introduction

The dual application of centerline rumble strips in combination with shoulder rumble strips is a recommended strategy in volumes 4 and 6 of the National Cooperative Highway Research Program (NCHRP) 500 Series Guidebooks.[1,2] These guidebooks describe shoulder rumble strips as 0.5-inch-deep, crosswise grooves in the road shoulder that are spaced about 7 inches apart and cut in groups of four or five. States have developed various designs and methods of installation, including rolling the rumble strips into hot asphalt or concrete as they are laid or milled in later. The rumble strips produce a vibrotactile—or auditory—warning in the form of a sudden rumbling sound or vibration to inattentive, drowsy, or sleeping drivers that encroach on the shoulder. Shoulder rumble strips are used extensively in the United States on all types of roadways.

Centerline rumble strips are similar to shoulder rumble strips but are placed on the center line, typically extending into the travel lane by 5 to 18 inches. They may be placed continuously or with periodic gaps. Shoulder and centerline rumble strips are compatible with other measures taken to reduce crashes (e.g., curve flattening) and may be included in existing construction plans with minimal extra cost.

A literature review revealed that while research into the safety performance of shoulder and centerline rumble strips that have been applied separately has been conducted, most notably for NCHRP Report 641, the combined application of shoulder and centerline rumble strips has been relatively rare, and evaluations to date have, as a result, been limited in scope.[3] The one U.S. study of relevance evaluated the safety impacts of applying centerline and shoulder rumble strips in combination using data for 80 mi of rural two-lane roads in Mississippi and applied the empirical Bayes (EB) before-after approach.[4] *Target collisions* were defined as the sum of head-on, sideswipe-opposite-direction, and single-vehicle run-off-road collisions. The results showed a 35-percent reduction in target collisions of all severities and a 39.6-percent reduction in fatal+injury target collisions. A Canadian study evaluated the safety impacts of applying centerline and shoulder rumble strips alone and in combination on two-lane rural and four-lane divided rural highways in British Columbia, Canada.[5] The results of this EB before-after study indicated that the combined application on two-lane roads indicated a reduction of 21.4 percent in off-road right, off-road left, and head-on collisions combined.

This study builds on these limited efforts using a multi-State database.

Methodology

This research examined the safety impacts of the combined application of centerline and shoulder rumble strips on two-lane rural roads in Kentucky, Missouri, and Pennsylvania. In Missouri and Pennsylvania, the rumble strips were installed where none existed before. In Kentucky, all roadways previously had shoulder rumble strips installed; therefore, the results for this State could be considered conservative in that even greater crash reductions would be expected for run-off-road crashes if shoulder rumble strips had not previously existed. It should be noted, however, that it is possible that the rumble strips had exceeded their service life, although this factor could not be determined.

The objective was to estimate the safety effectiveness of this strategy as measured by changes in the frequency of crashes (excluding intersection-related and animal-vehicle crashes). Target crash types included the following:

- Total crashes (all types and severities combined).
- Injury crashes (K (fatal), A (incapacitating), B (non-incapacitating), and C (possible) injuries on KABCO scale).
- Run-off-road crashes (all severities combined).
- Head-on crashes (all severities combined).
- Sideswipe-opposite-direction crashes (all severities combined).

A further objective was to conduct a disaggregate analysis to investigate whether the safety effects varied by factors such the level of traffic volume, the frequency of crashes before treatment, vehicle speed, lane width, and shoulder width. It was also of interest to examine the differences between the combined effects of centerline and shoulder rumble strips and the effects of either in isolation.

The evaluation of overall effectiveness included the consideration of the installation costs and crash savings in terms of the benefit-cost (B/C) ratio.

The EB methodology for observational before-after studies was used for the evaluation.[6] This methodology is considered rigorous in that it accounts for regression-to-the-mean using a reference group of similar but untreated sites. In the process, safety performance functions (SPFs) were not applied. SPFs are equations used to estimate the expected crash frequency of a site based on its characteristics that influence crashes (e.g., traffic volumes). The use of SPFs in the EB methodology addresses the following:

- It overcomes the difficulties of using crash rates in normalizing for volume differences between the before and after periods.
- It accounts for time trends.
- It reduces the level of uncertainty in the estimates of safety effect.
- It properly accounts for differences in crash experience and reporting practice in amalgamating data and results from diverse jurisdictions.
- The methodology provides a foundation for developing guidelines for estimating the likely safety consequences of a contemplated strategy.

The SPFs used in the EB methodology were estimated through generalized linear modeling assuming a negative binomial error distribution, which is consistent with the state of research in developing these models. In specifying a negative binomial error structure, an overdispersion parameter, which is used in the EB calculations, was estimated iteratively from the model and the data. For a given dataset, smaller values of this parameter indicate relatively better models.

The full report includes a detailed explanation of the methodology, including a description of how the estimate of safety effects for target crashes was calculated.

Results

Based on the data for all three States combined, results are presented in two parts. The first part contains aggregate results, and the second part is based on a disaggregate analysis that attempted to discern factors that may be most favorable to the installation of centerline plus shoulder rumble strips.

Aggregate Analysis

The aggregate results for all three States are shown in table 1, which provides the estimates of expected crashes in the after period without treatment, the observed crashes in the after period, and the estimated crash modification factor (CMF) and its standard error for all crash types considered. The percent change in crashes is 100(1 – estimate of the CMF); thus, a CMF of 0.80 with a standard deviation of 0.025 indicates a 20-percent reduction in crashes with a standard deviation of 2.5 percent.

The combined results in table 1 indicate reductions for all crash types analyzed that are statistically significant at the 95-percent confidence level. The crash type with the smallest CMF (which translates to the greatest reduction) is head-on, with a CMF of 0.632. Run-off-road and sideswipe-opposite-direction crashes have estimated CMFs of 0.742 and 0.767, respectively. For all crash types combined, CMFs of 0.800 for all severities and 0.771 for fatal+injury were estimated. It is important to remember that all crash types considered exclude intersection- and animal-related crashes.

The most comprehensive and reliable multi-State study to date of both shoulder and centerline rumble strips is published in NCHRP Report 641.[3] This report does not include findings for the combination of shoulder and centerline rumble strips but does recommend CMFs for these treatments separately. A comparison of the results for the combined treatment in table 1 with the recommended CMFs for the individual treatments is encouraging in that it appears that the effect of combining centerline and shoulder rumble strips further

Table 1. Results for combined States.

	Total	Injury	ROR	HO	S-OD	HO+ S-OD	ROR+HO+ S-OD
EB estimate of crashes expected in the after period without strategy	2409.00	986.63	712.11	102.64	101.41	204.05	916.15
Count of crashes observed in the after period	1,927	761	529	65	78	143	672
Estimate of CMF	0.800	0.771	0.742	0.632	0.767	0.700	0.733
Standard error of estimate of CMF	0.025	0.034	0.041	0.085	0.097	0.064	0.035

HO = Head-on.
ROR = Run-off-road.
S-OD = Sideswipe-opposite-direction.

reduces run-off-road crashes compared to shoulder rumble strips alone and total and fatal+injury crashes compared to centerline rumble strips alone. However, it appears that shoulder rumble strips did not reduce head-on+sideswipe-opposite-direction crashes further than applying centerline rumble strips in isolation, which is intuitive.

Disaggregate Analysis

The disaggregate analysis sought to identify those conditions under which the treatment is most effective. Run-off-road, head-on, and sideswipe-opposite-direction crashes were the focus of this analysis because they were the focus of this treatment. The analysis found no clear trend between the CMFs and values for posted speed, lane width, or shoulder width. Table 2 presents the results with respect to the other two variables.

For AADT, as shown in table 2, larger percentage crash reductions were found for run-off-road crashes for higher AADTs with some stability reached at approximately an AADT of 3,200. At AADTs above 3,200, the estimated CMF did not change significantly. At AADTs lower than 3,200, a run-off-road crash CMF of 0.851 was estimated versus 0.702 for AADTs at 3,200 or greater. For head-on+sideswipe-opposite-direction crashes, the stability in the CMF was reached at an AADT of approximately 9,200, and the trend was reversed with a CMF of 0.679 at AADTs lower than 9,200 and 0.817 for AADTs greater than 9,200. A possible explanation for a larger CMF value for head-on+sideswipe-opposite-direction crashes is that at higher AADTs, there were fewer passing opportunities, and not all head-on or sideswipe-opposite-direction crashes were due to vehicles drifting out of their lane.

For the expected crash frequency per mi-year without treatment, as shown in table 2, larger percentage crash reductions were found for run-off-road crashes for higher crash frequencies with some stability reached at a crash rate of approximately 0.500/mi-year. At rates lower than 0.500, a run-off-road crash CMF of 0.840 was estimated versus 0.621 for rates at 0.500 or greater. For head-on+sideswipe-opposite-direction crashes, the stability in the CMF was reached at a rate of approximately 0.065, and the trend was reversed with a CMF of 0.608 at rates less than 0.065 and 0.715 for rates greater than 0.065. Because expected crashes increased with volume

Table 2. Results disaggregated by ranges of average annual daily traffic (AADT) and expected crash frequency.

Crash Type	AADT		Expected Crashes/mi-year Without Treatment	
	Range	CMF (Standard Error)	Range	CMF (Standard Error)
Run-off-road	< 3,200	0.851 (0.089)	< 0.500	0.840 (0.058)
	≥ 3,200	0.702 (0.045)	≥ 0.500	0.621 (0.055)
Head-on+sideswipe-opposite-direction	< 9,200	0.679 (0.069)	< 0.065	0.608 (0.147)
	> 9,200	0.817 (0.172)	≥ 0.065	0.715 (0.071)

as seen in the SPFs developed, the trend of a larger CMF at a higher crash rate for head-on+sideswipe-opposite-direction crashes would be expected, given the results for AADT.

Caution should be used in interpreting and applying these disaggregate results because they are not robust enough to develop CMFunctions. A *CMFunction* is an equation that would allow the estimation of CMFs for different levels of AADT and expected crash frequency. However, they may be used in prioritizing treatment sites. For example, sites with a high proportion of run-off-road crashes and high AADTs will have higher priority than sites with high AADTs and a high proportion of head-on+sideswipe-opposite-direction crashes.

Economic Analysis

For the purposes of the economic analysis, the assumed treatment is, conservatively, the dual application of centerline and shoulder rumble strips for which the combined CMF of 0.800 for total crashes (table 1) is recommended. Treatment costs ranged from $3,000/mi for Missouri to $12,000/mi in Kentucky. Service lives are 7 to 10 years and 12 to 15 years, respectively. Results are presented for these two extremities.

Based on information from the Office of Management and Budget's *Circular A-4*, a real discount rate of 7 percent was applied to calculate the annual cost of the treatment for 7- and 12-year service lives, respectively.[7] Applying the lower ends of the service life ranges conservatively gives annual costs of $557/mi and $1,551/mi for the two cost/service life extremes.

The most recent FHWA mean comprehensive crash costs disaggregated by crash severity, location type, and speed limit are based on 2001 dollar values.[8] The 2001 unit costs for property damage only (PDO) and fatal+injury crashes from the FHWA report ($7,428 and $158,177) were multiplied by the ratio of the 2014 value of a statistical life of $9.2 million to the 2001 value of $3.8 million.[9,8] By applying this ratio of 2.42 to the unit costs for PDO and fatal+injury crashes and then weighting by the frequencies of these two crash types in the after period, an aggregate 2014 unit cost for total crashes of $162,045 was obtained. Fatal crashes were not considered on their own because of the very low numbers of such crashes in the data, which would skew the results.

The total crash reduction was calculated by subtracting the actual crashes in the after period from the expected crashes in the after period had the treatment not been implemented. The number of crashes saved per mi-year was 0.1881, which was obtained by dividing the total crash reduction (482.0) by the number of after period mi-years per site (2,562).

The annual benefit (i.e., crash savings) of $30,481 is the product of the crash reduction per mi-year (0.1881) and the aggregate cost of a crash (all severities combined) ($162,045). The B/C ratio was calculated as the ratio of the annual benefit per mi to the annual cost per mi. The B/C ratios were estimated to be 20.2 for the higher cost/higher service life assumption and 54.7 for the lower cost/lower service life assumption. These results suggest that the treatment, even in its most expensive variation, can be highly cost effective.

Summary and Conclusions

The objective of this study was to perform a rigorous before-after evaluation of the safety effectiveness, as measured by crash frequency, of shoulder and centerline rumble strips applied in combination on two-lane rural roads. The CMFs shown in table 3 are recommended for various crash types.

To date, the most comprehensive and reliable study of both shoulder and centerline rumble strips individually applied is published in NCHRP Report 641 — *Guidance for the Design and Application of Shoulder and Centerline Rumble Strips*.[3] Compared to the recommended CMFs from that study, the results suggest that the effect of combining centerline and shoulder rumble strips further reduces run-off-road crashes compared to shoulder rumble strips alone and both total and fatal+injury crashes compared to centerline rumble strips alone. However, it appears that shoulder rumble strips do not further reduce head-on+sideswipe-opposite-direction crashes than applying centerline rumble strips in isolation.

A disaggregate analysis of the results indicated that larger percentage crash reductions were found for run-off-road crashes for sites with higher AADTs. For head-on+sideswipe-opposite-direction crashes, smaller percentage crash reductions were found for higher AADTs. For the expected crash frequency per mi-year without treatment, larger percentage crash reductions were found for run-off-road crashes for higher crash frequencies. For head-on+sideswipe-opposite-direction crashes, smaller percentage crash reductions were seen at higher crash frequencies. Caution should be used in interpreting and applying these disaggregate results because they are not robust enough to develop CMFunctions that would allow the estimation of CMFs for different levels of AADT and expected crash frequency. However, they may be used in prioritizing treatment sites.

B/C ratios were estimated to range from 20.2 for a higher cost/higher service life assumption to 54.7 for a lower cost/lower service life assumption. These results, which are based on conservative service life assumptions, suggest that the treatment, even in its most expensive variations, can be highly cost effective.

Table 3. Recommended CMFs.

Crash Type	CMF	Standard Error of CMF
Total	0.800	0.025
Injury	0.771	0.034
Run-Off-Road	0.742	0.041
Head-On	0.632	0.085
Sideswipe-Opposite-Direction	0.767	0.097
Head-On+Sideswipe-Opposite-Direction	0.700	0.064
Run-Off-Road+Head-On+Sideswipe-Opposite-Direction	0.733	0.035

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