TECH**BRIEF**

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Safety Evaluation of Profiled Thermoplastic Pavement Markings

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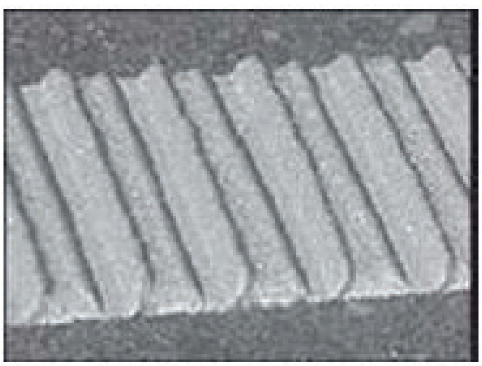
This document is a technical summary of the Federal Highway Administration report *Safety Evaluation of Profiled Thermoplastic Pavement Markings* (FHWA-HRT-17-076).

Objective

The Federal Highway Administration (FHWA) established the Development of Crash Modification Factors (DCMF) program in 2012 to address highway safety research needs for evaluating new and innovative safety strategies (improvements) by developing reliable quantitative estimates of their effectiveness in reducing crashes. The goal of the DCMF program is to save lives by identifying new safety strategies that effectively reduce crashes and promote those strategies for nationwide implementation by providing measures of their safety effectiveness and benefit-to-cost (B/C) ratios through research. State transportation departments and other transportation agencies need to have objective measures for safety effectiveness and B/C ratios before investing in broad applications of new strategies for safety improvements. Forty State transportation departments provide technical feedback on safety improvements to the DCMF program and implement new safety improvements to facilitate evaluations. These States are members of the Evaluation of Low-Cost Safety Improvements Pooled Fund Study, which functions under the DCMF program. This study evaluated the application of profiled thermoplastic pavement markings. This strategy involves upgrading existing markings from flat-line thermoplastic or other standard markings to the profiled product. These markings are designed to provide an improved level of vision to drivers, particularly during wet-road surface conditions. The profiled nature also provides a rumble effect for errant vehicles. There are two types of profiled markings—raised and inverted profile patterns—as shown in figure 1 and figure 2.

Figure 1. Photo. Raised profiled thermoplastic marking.[1]

Figure 2. Photo. Inverted profiled thermoplastic marking.[1]



Introduction

This research examined the safety impacts of profiled thermoplastic pavement markings in Florida and South Carolina. The States applied the markings only on edge lines and mostly on rural, two-lane undivided roads, with some use on rural, multilane divided roadways.

A literature review found no published research evaluating the effect of profiled thermoplastic pavement markings on crashes after the application. According to FHWA, several agencies have used the treatment with good results, but none have conducted a safety effectiveness evaluation.[1]

Methodology

The objective of this study was to estimate the safety effectiveness of this strategy as measured by crash frequency. This study excluded intersection-related, snow/slush/ice, and animal crashes. The study considered the following target crash types:

- Total crashes (all types and severities combined).
- Fatal and injury crashes (K, A, B, and C injuries on the KABCO scale) (K is fatal injury, A is incapacitating injury, B is non-incapacitating injury, C is possible injury, and O is property damage only).
- Run-off-road crashes (all severities combined).
- Head-on crashes (all severities combined).
- Sideswipe-opposite-direction crashes (all severities combined).
- Sideswipe-same-direction crashes (all severities combined).
- Wet-road crashes (all types and severities combined).
- Nighttime crashes (all types and severities combined).
- Nighttime wet-road crashes (all types and severities combined).

A further objective was to conduct a disaggregate analysis to investigate whether the safety effects vary by factors such as the level of traffic volume, the frequency of crashes before treatment, roadway type, posted speed limit, lane width, and shoulder width.

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

The project team used the empirical Bayesian (EB) methodology for observational before–after studies for this evaluation.[(2)] 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, the project team applied safety performance functions (SPFs). SPFs are equations that serve to estimate the expected crash frequency of a site based on characteristics that influence crashes (e.g., traffic volumes). The use of SPFs in the EB methodology was found to have the following advantages:

- Overcomes the difficulties of using crash rates in normalizing for volume differences between the before and after periods.
- Accounts for time trends.
- Reduces the level of uncertainty in the estimates of safety effect.
- Properly accounts for differences in crash experience and reporting practice in amalgamating data and results from diverse jurisdictions.

The methodology also provides a foundation for developing guidelines for estimating the likely safety consequences of a contemplated strategy.

The project team estimated the SPFs used in the EB methodology 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, the project team iteratively estimated an overdispersion parameter, which is used in the EB calculations, from the model and the data. For a given dataset, smaller values of this parameter indicate relatively better models.

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

Results

The results are presented in two parts. The first part contains aggregate results, and the second part discusses a disaggregate analysis that attempted to discern factors that may be most favorable to the installation of profiled thermoplastic pavement markings.

Aggregate Analysis

Table 1 and table 2 detail the results for each State. This includes the estimates of predicted 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 results were consistent between the two States in that no CMF results were statistically significantly different from 1.0. Results for both States also indicated a modest reduction in total crashes and a reduction in nighttime wet-road crashes of approximately 10 percent, although these were not statistically significant at the 95-percent confidence level.

Table 3 provides the results for the combined South Carolina and Florida data for the crash types analyzed in both States. Even with the combined data, none of the estimated CMFs were statistically significant at the 95-percent confidence level.

Table 1. Results for South Carolina.

Crash Type	EB Estimate of Crashes Predicted in After Period Without Strategy	Count of Crashes Observed in After Period	Estimate of CMF	Standard Error of Estimate of CMF
Total	789.81	779	0.986	0.041
Fatal and injury	312.59	281	0.898	0.060
Run-off-road	254.45	292	1.146	0.078
Head-on and sideswipe-opposite-direction	49.09	44	0.894	0.143
Sideswipe-same-direction	35.57	36	1.009	0.177
Wet-road	152.73	157	1.027	0.089
Nighttime	281.57	261	0.926	0.064
Nighttime wet-road	60.76	55	0.903	0.131

Table 2. Results for Florida.

Crash Type	EB Estimate of Crashes Predicted in After Period Without Strategy	Count of Crashes Observed in After Period	Estimate of CMF	Standard Error of Estimate of CMF
Total	1,136.28	1,085	0.954	0.035
Fatal and injury	582.48	590	1.012	0.049
Run-off-road	182.59	172	0.941	0.080
Head-on	19.47	24	1.229	0.259
Wet-road	204.13	201	0.983	0.078
Nighttime	348.31	352	1.010	0.062
Nighttime wet-road	63.52	58	0.910	0.129

Table 3. Combined results for South Carolina and Florida.

Crash Type	EB Estimate of Crashes Predicted in After Period Without Strategy	Count of Crashes Observed in After Period	Estimate of CMF	Standard Error of Estimate of CMF
Total	1,926.09	1,864	0.968	0.027
Fatal and injury	895.07	871	0.973	0.038
Run-off-road	437.04	464	1.061	0.056
Wet-road	356.86	358	1.003	0.059
Nighttime	629.87	613	0.973	0.045
Nighttime wet-road	124.28	113	0.908	0.092

Disaggregate Analysis

The project team attempted to further analyze the combined dataset for nighttime wet-road crashes to identify site characteristics under which the safety benefits may be greatest. The project team considered only nighttime wet-road crashes because this is a key target crash type and the only one that showed some consistency and sizable effect for both States; however, the CMF estimates were still not statistically significant at the 95-percent confidence level.

The project team investigated the following variables: number of lanes, surface width, average shoulder width, median width, annual average daily traffic, and expected nighttime wet-road crash frequency per mile prior to treatment. The project team saw no differences or clear trends in the estimated CMF for any of these variables. Therefore, for this dataset, the expected effect of this strategy on nighttime wet-road crashes was the same, regardless of differences in these aspects of the roadway environment.

There are some indications that the CMF for nighttime wet-road crashes might be smaller (the benefit larger) for sites with higher expected nighttime wet-road crash frequency per mile prior to treatment. However, the sample was too small for a robust conclusion in this regard.

Economic Analysis

The project team conducted an economic analysis to determine the estimated B/C ratio for this strategy. They considered nighttime wet-road crashes, which experienced a reduction, for this analysis. The observed benefit—a CMF of 0.908—was not unexpected, because this was the principal target crash type. Although the team based the estimated CMF on a small sample of crashes and it was not statistically significant at the 95-percent confidence level, it was consistent between the two States, which suggests that its use is justified for this purpose.

For cost, the project team used specific costs and information provided by the

South Carolina Department of Transportation (DOT), which were reasonably consistent with the range of costs provided by the Florida DOT for various contracts. The project team conservatively assumed the base condition that characterized the reference group of untreated sites consisted of flat-line thermoplastic pavement markings with an average cost of $0.40 per linear foot. The cost provided for profiled thermoplastic pavement markings was $0.50 per linear foot, so the project team used the relative cost of $0.10 per linear foot as the unit treatment cost for the analysis. With these assumptions, the estimated treatment cost for the two States combined was $524,691.

Although the two DOTs provided service lives of between 3 and 5 years, the analysis assumed, conservatively, a useful service life for safety benefits of 2.5 years, which corresponds to the average after-period length at the treatment sites.

Based on information from the Office of Management and Budget *Circular A-4*, the project team used a real discount rate of 7 percent to calculate the annual cost of the treatment based on the 2.5-year service life.(3) With this information, the installation costs convert to annual costs of $125,926.

For the benefit calculations, the project team used the most recent FHWA mean comprehensive crash costs as a base.(4) They based these costs on 2001 data and indicated that the unit costs (in 2001 dollars) for property-damage-only (PDO) and fatal and injury crashes for all speed limits combined were $7,428 and $158,177, respectively.(4) The project team updated these to 2015 dollars by applying the ratio of the U.S. Department of Transportation (USDOT) 2015 value of a statistical life of $9.4 million to the 2001 value of $3.8 million.(5) By applying this factor of 2.47 to the unit costs for PDO and fatal and injury crashes and then weighting by the frequencies of these two crash types in the after period, the project team obtained the aggregate 2015 unit cost for total crashes as $192,337. The analysis did not consider fatal crashes alone because of the very low numbers of such crashes in the data, which would have skewed the results.

The project team calculated the crash reduction by subtracting the actual crashes in the after period from the expected crashes in the after period had the treatment not been implemented (based on table 3). The number of nighttime wet-road crashes saved per year was 4.48, which was obtained by dividing the crash reduction of 11.28 by the average number of after-period years per site (2.52).

The annual benefit (i.e., crash savings) of $862,033 is the product of the crash reduction per year (4.48) and the aggregate costs of a crash, with all severities combined ($192,337). The B/C ratio of 3.65:1 is calculated as the ratio of the annual benefit to the annual cost. The USDOT recommends that sensitivity analysis be conducted by assuming values of a statistical life 0.55 and 1.38 times the recommended 2015 value.(5) These factors can be applied directly to the estimated B/C ratio to get a range of 2.01:1 to 5.04:1. These results suggest that the treatment, even with conservative assumptions on cost, service life, and the value of a statistical life, can be applied cost effectively despite the relatively low crash effects.

Summary and Conclusions

The objective of this study was to undertake a rigorous before–after evaluation of the safety effectiveness of profiled thermoplastic pavement markings applied to edge lines as measured by crash frequency. The study used data from two-lane and multilane roads in two States—Florida and South Carolina—to examine the effects for specific crash types, including total, fatal and injury, run-off-road, head-on, sideswipe-opposite-direction, sideswipe-same-direction, wet-road, nighttime, and nighttime wet-road crashes. Only nighttime wet-road crashes, the principal target crash type, experienced a material change in yielding a CMF of 0.908, which was not unexpected, because this was the primary target crash type. Although the project team based the estimated CMF on a small sample of crashes and it was not statistically significant at the 95-percent confidence level, it was consistent between the two States, which suggests its use may be justifiable.

Based on the consistent reduction in nighttime wet-road crashes, and estimated with conservative cost and service life assumptions, the B/C ratio relative to flat-line thermoplastic markings was 3.65:1. Applying the sensitivity analysis recommended by the USDOT, this value could range from 2.01:1 to 5.04:1. These results suggest that the treatment—even with conservative assumptions on cost, service life, and the value of a statistical life—can be applied cost effectively despite the relatively low crash effects.

With additional data, future research may provide statistically significant results for those crash types for which a CMF could not be recommended or was statistically insignificant and provide more informative analyses to develop disaggregate CMFs that reflect different application circumstances.

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