TECHBRIEF

Safety Evaluation of Wet-Reflective Pavement Markings

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This document is a technical summary of the Federal Highway Administration report, *Safety Evaluation of Wet-Reflective Pavement Markings* (FHWA-HRT-15-065).

Objective

The Federal Highway Administration (FHWA) organized 38 States for 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 is to evaluate the safety effectiveness of several low-cost safety improvement strategies through scientifically rigorous crash-based studies.

One of the strategies selected for evaluation for this study was the application of wet-reflective pavement markings. This strategy involves upgrading existing markings from standard marking materials to wet-reflective markings, which may be applied as a paint, tape, or thermoplastic material. These markings are designed to provide an improved level of retroreflectivity during wet road surface conditions.

Introduction

This research examined the safety impacts of wet-reflective markings in Minnesota, North Carolina, and Wisconsin. In Minnesota, data were provided where the markings were applied on two-lane roadways and freeways on the center line, edge line, or lane lines. In North Carolina, the markings were applied on the edge line and/or lane lines on freeways. In Wisconsin, the markings have been

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applied for the lane lines on freeways and multilane divided roadways.

A literature review found that although there was some cross-sectional research relating retroreflectivity levels to crashes, there has been no published research evaluating the effect on crashes after applying wet-reflective markings.

Methodology

The objective of this study was to estimate the safety effectiveness of this strategy as measured by crash frequency. Crashes occurring at or related to an intersection and snow/slush/ice- and animal-related crashes were not included.

Target crash types considered 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).
- Sideswipe-same-direction crashes (all severities combined).
- Wet-weather crashes (all types and severities combined).
- Nighttime crashes (all types and severities combined).
- Nighttime wet-weather crashes (all types and severities combined).

The effects for dry-road crashes, which were not specifically evaluated as a target crash type, were inferred from the effects for total and wet-road crashes.

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 benefit/cost (B/C) ratio.

The empirical Bayes (EB) methodology for observational before-after studies was used for the evaluation.[(1)] 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) are applied. SPFs are equations used 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 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 also 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 discusses a disaggregate analysis that attempted to discern factors that may be most favorable to the installation of wet-reflective pavement markings.

Aggregate Analysis

Estimates are provided in table 1 through table 3 for 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 error of 0.025 indicates a 20-percent reduction in crashes with a standard error of 2.5 percent.

Sideswipe-opposite-direction crashes were not analyzed because of very low numbers. The effects for dry-road crashes, which were not specifically evaluated as a target crash type, were inferred from the effects for total and wet-road crashes and are also shown in these tables for information purposes.

The aggregate results for freeways for all three States combined, which are shown in table 1, indicate reductions for total, injury, run-off-road, wet-road, nighttime, and nighttime wet-road, but only the injury and wet-road effects are statistically significant at the 95-percent confidence level. The results for sideswipe-same-direction and dry-road crashes show negligible and statistically insignificant increases in these crash types.

The results for Minnesota two-lane roads in table 2 indicate reductions for total, wet-road, dry-road, nighttime, and nighttime wet-road crashes, none of which are statistically significant at the 95-percent confidence level. The results for wet-road crashes, however, are statistically significant at the 90-percent confidence level. Sideswipe-same-direction, run-off-road, and injury crashes experienced statistically insignificant increases. For the results in table 2, the total number of crashes are low, so lack of statistical significance in the analysis results is not unexpected. The indications of reductions in wet, nighttime, and nighttime wet-road crashes do still support the hypothesis that wet-reflective markings reduce these types of crashes. The results for Wisconsin

Table 1. Results for combined State freeways.

	Total	Injury	Run-Off-Road	Sideswipe-Same-Direction	Wet-Road	Dry-Road	Nighttime	Nighttime Wet-Road
EB estimate of crashes expected in the after period without strategy	4,111.97	1,219.76	466.37	618.28	887.49	3,224.48	1,103.63	248.69
Count of crashes observed in the after period	4,019	1,075	450	625	765	3,254	1,067	244
Estimate of CMF	0.977	**0.881**	0.964	1.010	**0.861**	1.009	0.966	0.979
Standard error of estimate of CMF	0.020	**0.033**	0.054	0.054	**0.040**	0.024	0.038	0.080

Bold = Results that are statistically significant at the 95-percent confidence level.

Table 2. Results for Minnesota two-lane roads.

	Total	Injury	Run-Off-Road	Sideswipe-Same-Direction	Wet-Road	Dry-Road	Nighttime	Nighttime Wet-Road
EB estimate of crashes expected in the after period without strategy	186.26	84.43	79.19	10.61	24.76	161.50	52.04	8.48
Count of crashes observed in the after period	176	89	81	14	17	159	51	7
Estimate of CMF	0.944	1.053	1.022	1.310	0.685	0.984	0.979	0.823
Standard error of estimate of CMF	0.075	0.116	0.118	0.365	0.169	0.083	0.141	0.313

multilane roads in table 3 indicate reductions for total, injury, run-off-road, wet-road, dry-road, and nighttime crashes that are all statistically significant at the 95-percent confidence level. Sideswipe-same-direction results indicate a statistically insignificant decrease, and nighttime wet-road results indicate a negligible and statistically insignificant increase in crashes.

Disaggregate Analysis

An attempt was made to further analyze the combined freeway dataset for wet-road crashes to identify site characteristics under which the safety benefits are greater. Only wet-road crashes were considered because they are the principal target crash type and the only one with a consistent and statistically significant effect across all three States individually. Only freeways were considered because the datasets for multilane and two-way roadways had too few crashes for such an analysis.

A number of variables were investigated, including surface width, shoulder width, area type (urban versus rural), number of lanes, presence of shoulder rumble strips, average annual daily traffic, and expected wet-road crash frequency per mile prior to treatment.

No differences or clear trends were seen for any of these variables and the estimated CMFs. Therefore, for this dataset, the expected effect of this strategy on wet-road crashes on freeways is the same, regardless of differences in these aspects of the roadway environment.

Table 3. Results for Wisconsin multilane roads.

	Total	Injury	Run-Off-Road	Sideswipe-Same-Direction	Wet-Road	Dry-Road	Nighttime	Nighttime Wet-Road
EB estimate of crashes expected in the after period without strategy	556.77	256.08	110.93	93.17	92.62	465.15	133.13	16.71
Count of crashes observed in the after period	460	153	60	88	70	390	93	17
Estimate of CMF	**0.825**	**0.595**	**0.538**	0.941	**0.751**	**0.838**	**0.696**	1.001
Standard error of estimate of CMF	**0.051**	**0.059**	**0.078**	0.115	**0.108**	**0.058**	**0.082**	0.270

Bold = Results that are statistically significant at the 95-percent confidence level.

Economic Analysis

An economic analysis was conducted to determine the estimated B/C ratio for this strategy for multilane roads and freeways. (For two-lane roads, an economic analysis could not be performed because the crash reductions were too small and statistically insignificant.) The statistically significant reduction in total crashes for Wisconsin was used as the benefit in the analysis of multilane roads. For freeways, the statistically significant reduction in targeted wet-road crashes for the three States combined was used as the benefit.

On the cost side, for the installations on multilane roads in Wisconsin, the analysis conservatively assumed, in the absence of details of each installation, that the grooved contrast 4-inch tape, costing $9,200 per mi for a single-lane line treatment, was used for all installations. In total, 259.76 lane mi were installed at an estimated cost of $2,389,792. For freeways, the same per-mile treatment cost was assumed for Wisconsin. For the North Carolina installations, the North Carolina Department of Transportation (NCDOT) indicated that the polyurea treatment costing $1.10 per linear ft was applied. For Minnesota, the analysis conservatively assumed that the ground in markings cost $17,000 per mi. With these assumptions, the total estimated cost for freeway installations in the three States was $6,765,373.

The analysis assumed the useful service life for safety benefits was 2 years. This conclusion is based on information from the Minnesota Department of Transportation, which found that the retroreflectivity lasted 2 years under wet conditions and 4 years under dry conditions. Service lives reported by NCDOT and the Wisconsin Department of Transportation indicated longer periods, so a 2-year life was assumed as the conservative option.

Based on information from the Office of Management and Budget Circular A-4, a real discount rate of 7 percent was used to calculate the annual cost of the treatment based on the 2-year service life.[2] With this information, the installation costs convert to annual costs of $3,741,928 for freeways in the three States and $1,321,794 for multilane roads in Wisconsin.

For the benefit calculations, the most recent FHWA mean comprehensive crash costs disaggregated by crash severity, location type, and speed limit were used as a base to derive comprehensive 2014 unit crash costs of $147,181 for freeways and $139,316 for multilane roads.[3]

The 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 year was 36.87 wet-road crashes for freeways and 51.59 total crashes for multilane roads, which was obtained by dividing the crash reductions (122.49 and 96.77) by the average number of after period years per site (3.32 and 1.88).

The annual benefits (i.e., crash savings) of $5,426,563 and $7,187,312 for freeways and multilane roads, respectively, are the product of the crash reductions per year (36.87 and 51.59) and the aggregate costs of a crash, all severities combined ($147,181 and $139,316). The B/C ratio is calculated as the ratio of the annual benefit to the annual cost. The B/C ratios are estimated to be 1.45 for freeways and 5.44 for multilane roads. The U.S. Department of Transportation (USDOT) recommends that a sensitivity analysis be conducted by assuming values of a statistical life 0.57 and 1.41 times the recommended 2014 value.[(4)] These factors can be applied directly to the estimated B/C ratios to get a range of 0.83 to 2.04 for freeways and 3.10 to 7.67 for multilane roads. These results, which are summarized in table 4, suggest that the treatment, even with conservative assumptions on cost, service life, and the value of a statistical life, can be cost effective, especially for multilane roads.

Summary and Conclusions

The objective of this study was to undertake a rigorous before-after evaluation of the safety effectiveness of wet-reflective pavement markings as measured by crash frequency. The study used data from three States, Minnesota, North Carolina, and Wisconsin, to examine the effects for specific crash types, including total, injury, run-off-road, sideswipe-same-direction, wet-road, dry-road, nighttime, and nighttime wet-road crashes. Table 5 shows the various crash types for which a statistically significant CMF (at the 95-percent confidence level) could be estimated. Crashes occurring at or related to an intersection and snow/slush/ice- and animal-related crashes were not included and should not be included for applying the recommended CMFs.

B/C ratios estimated with conservative cost and service life assumptions are 1.45 for freeways and 5.44 for multilane roads. With the USDOT-recommended sensitivity analysis, these values could range from 0.83 to 2.04 for freeways and 3.10 to 7.67 for multilane roads. These results suggest that the treatment—even with conservative assumptions on cost, service life, and the value of a statistical life—can be cost effective, especially for multilane roads.

With additional data, future research may provide statistically significant results for those crash types for which a CMF could not be recommended as well as more informative analyses to develop disaggregate CMFs.

Table 4. Economic analysis results.

	B/C Ratio		
	Point Estimate	Lower Bound	Upper Bound
Freeways	1.45	0.83	2.04
Multilane Roads	5.44	3.1	7.67

Table 5. Recommended CMFs and standard errors.

	Total	Injury	Run-Off-Road	Wet-Road	Nighttime
Freeways		0.881 (0.033)		0.861 (0.040)	
Multilane Roads	0.825 (0.051)	0.595 (0.059)	0.538 (0.078)	0.751 (0.108)	0.696 (0.082)

Blank cell = No CMF is recommended.

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