TECHBRIEF

Safety Evaluation of Multiple Strategies at Signalized Intersections

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This document is a technical summary of the Federal Highway Administration report *Safety Evaluation of Multiple Strategies at Signalized Intersections* (FHWA-HRT-17-062).

Objective

The Federal Highway Administration 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 ultimate 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-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 have provided technical feedback on safety improvements to the DCMF program and implemented 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 multiple low-cost treatments at signalized intersections. Improvements included basic signing, pavement marking, and signal enhancements. This strategy is intended to reduce the frequency and

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severity of crashes at signalized intersections by alerting drivers to the presence, type, and configuration of the approaching intersection.

Many studies have explored the safety effectiveness of some of the individual countermeasures. However, no study has conducted a rigorous evaluation of the effectiveness of installing packages of these strategies in combination across many intersections. This study sought to fill this knowledge gap.

Introduction

In recent years, there has been an increased interest in the widespread installation of low-cost safety treatments throughout an entire jurisdiction. The South Carolina Department of Transportation (SCDOT) embraced this approach in its intersection safety improvement plan and identified a number of low-cost strategies for implementation at signalized intersections statewide. Typical low-cost treatments at signalized intersections in South Carolina included improvements to basic signing, pavement markings, and traffic signals.

South Carolina selected a unique package of intersection improvements for each intersection. No treatment packages were installed at all intersections, and each treatment was only considered for installation where appropriate. The following is a list of the individual improvements installed as part of the packages at the signalized intersections in South Carolina:

- Replace all signal heads.
- Replace pedestrian signal heads, pushbuttons, and signs.
- Install backplates with retroreflective borders on all signal heads.
- Re-stripe stop lines.
- Re-stripe crosswalks.
- Install warning signs.
- Install overhead signs (e.g., R10-12, R3-5L, and R3-5R).
- Install curb ramps.

A literature search focused on the safety effects of the specific strategies at signalized intersections. The project team identified very few studies that investigated the combined effects of multiple strategies. One study determined the installation of advance warning signs at signalized intersections resulted in a 35-percent reduction in right-angle crashes.[1] Multiple studies confirmed the conspicuity of fluorescent sign sheeting.[2,3] A Virginia Department of Transportation study used a video survey to link retroreflective sign posts with improved nighttime visibility in comparison to signs without retroreflective material on the posts.[4] Several studies evaluated the installation of retroreflective backplates. One resulted in crash reductions of 20 percent in total crashes, 44 percent in angle crashes, and 10 percent in rear-end crashes.[5] Another yielded a 29-percent reduction in total crashes, 37-percent reduction in injury crashes, and 50-percent reduction in late-night/early-morning crashes.[6] The combination of adding retroreflective backplates with upgraded signal lenses reduced total crashes by 9 percent, severe crashes by 10 percent, and nighttime crashes by 14 percent.[7] A number of studies evaluated the safety effects of using 12-inch or larger signal lenses, and resulted in reductions in total, injury, angle, and nighttime crashes.[8–10]

Most of these studies employed study designs that lacked statistical rigor, had limited sample sizes, or had sites in limited geographic areas, which made it difficult to put much credence in the results. Furthermore, no prior studies involved a combination of as many countermeasures used in this research. Thus, additional research is warranted that is based on a more rigorous analysis of these treatments, especially research that considers the effects of multiple low-cost strategies implemented in combination.

Methodology

This study examined the safety impacts of multiple low-cost signing, pavement marking, and traffic signal treatments at signalized intersections in South Carolina on total, fatal and injury, rear-end, right-angle, and nighttime crash frequencies.

The data set included 84 treatment sites and 368 reference sites of all intersection types. The project team categorized intersections for evaluation using the following configuration types:

- 3x22: Three-legged intersections with two lanes on the mainline and two lanes on the cross street.
- 4x22: Four-legged intersections with two lanes on the mainline and two lanes on the cross street.
- 3x42: Three-legged intersections with four lanes on the mainline and two lanes on the cross street.
- 4x42: Four-legged intersections with four lanes on the mainline and two lanes on the cross street.

The evaluation made use of the empirical Bayes (EB) methodology for observational before-after studies.[11] 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 use of safety performance functions (SPFs) addressed the following:

- Overcoming the difficulties of using crash rates in normalizing for volume differences between the before and after periods.
- Accounting for time trends (in the form of before-after adjustment factors, not yearly indicator variables).
- Reducing the level of uncertainty in the estimates of safety effects.
- Properly accounting for differences in crash experience and reporting practice in amalgamating data and results from diverse jurisdictions.
- Providing 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 was consistent with the state of research in developing these models. In specifying a negative binomial error structure, the project team estimated a constant overdispersion parameter 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 and the development of SPFs, including a description of how the estimates of safety effects for target crashes were calculated.

Results

This brief presents the research results in two parts. The first part contains aggregate results. The second part is based on a disaggregate analysis that sought to identify the optimal conditions for installation of the treatment.

Aggregate Analysis

Table 1 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 each crash type considered in this study. The results in table 1 indicate reductions for all crash types analyzed in this study. The CMFs for fatal and injury and right-angle crashes are 0.893 and 0.883, respectively, which are statistically significant at the 95-percent confidence level. The CMFs for total, rear-end, and nighttime crashes are 0.955, 0.974, and 0.969, respectively. The CMFs for total, rear-end, and nighttime crashes are not statistically significant at the 95-percent confidence level, but the CMF for total crashes is statistically significant at the 90-percent confidence level.

Disaggregate Analysis

The disaggregate analysis identified specific CMFs by crash types and different conditions and those conditions under which the multiple low-cost treatments were more effective. The research team identified several variables of interest, including area type, number of legs, lane configuration of the mainline and the cross street, and traffic volumes.

The disaggregate analysis indicated larger crash reductions of all types for urban areas and intersections with two-lane major roads. For total entering volume, the disaggregate analysis indicated the strategy is slightly more effective on average for intersections with lower traffic volumes. The disaggregate analysis also showed the multi-treatment strategy can yield similar crash reductions across the range of expected crashes without the treatments.

Table 1. Aggregate results for EB before-after study.

Statistic	Total	Fatal and Injury	Rear-End	Right-Angle	Nighttime
EB estimate of crashes expected in the after period without the systemic improvement	2,801	617	1,385	1,042	599
Count of crashes observed in the after period	2,675	551	1,349	921	581
Estimated CMF	0.955	0.893*	0.974	0.883*	0.969
Standard error of the estimated CMF	0.023	0.045	0.034	0.035	0.048

*Indicates statistically significant results at the 95-percent confidence level.

Economic Analysis

An economic analysis was conducted to estimate the B/C ratio for implementing various pavement marking, signing, signal, and pedestrian improvements at signalized intersections. The statistically significant aggregate reduction in total crashes was used to calculate the conservative value of benefits for an average intersection.

Based on work order cost data for signalized intersections provided by SCDOT, the economic analysis assumed an average pavement marking and signing construction cost of approximately $7,000. Typical cost estimates for replacing signal heads, installing pedestrian signal assemblies, and installing curb ramps were available and were roughly $13,300, $18,300, and $10,000 per intersection, respectively. Preliminary engineering, project management, and other general costs were not provided; however, analysts with this information can split these costs between all intersections. SCDOT used contractors to select and construct treatments at each intersection, and State forces planned and managed the project. Annual maintenance and operations costs were not available except for pedestrian signal head maintenance and are otherwise assumed to be zero (i.e., these costs will not be incurred within the service life).

The analysis assumed the useful service life for safety benefits was 7 years. Pavement markings were assumed to last roughly 4 years and all other treatments roughly 7 to 10 years with minimal maintenance. A conservative average of 7 years was used for the overall project.

This study used comprehensive crash cost estimates for fatal and injury crashes and property-damage-only crashes from the recent report by Persaud (updated from an earlier report by Council et al.) to estimate the annual economic benefits.[9,10] Using these numbers and the severity distribution at treatment sites, the research team estimated the cost for an average crash at a signalized intersection as $95,186 in 2015 dollars.

Persaud refers to a June 2013 U.S. Department of Transportation (USDOT) memo that prescribes sensitivity analysis based on low and high values of crash costs.[9,11] Specifically, the USDOT memo suggests that analysts should apply sensitivity analysis by estimating B/C ratios for 0.57 and 1.41 times the 2015 crash costs.[11]

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 intersection treatments not been implemented. The total crash reduction was then divided by the average number of after period years per site to compute the total crashes saved per year. The treatments saved 50.6 crashes per year for the study sites, or an average reduction of 0.6 crashes per site per year across the 84 treatment sites. Similarly, the treatments resulted in a reduction of 26.5 fatal and injury crashes, or approximately 0.3 fatal and injury crashes reduced per site per year across all 84 sites.

The annual economic benefits were calculated by multiplying the crash reduction per site per year by the cost of a crash. Table 2 presents the resulting B/C ratios, with lower and upper bounds resulting from the sensitivity analysis for two scenarios: 1) assuming signing, marking, and signal improvements, and 2) assuming scenario one plus pedestrian-related improvements.

Table 2. B/C ratios.

Treatments	Lower Bound	Average B/C	Upper Bound
Signing, marking, and signal head replacements	6.6	11.7	16.4
Signing, marking, signal head replacements, and pedestrian signal installation with curb ramps	2.3	4.1	5.8

These results suggest that the various intersection treatments, even with conservative assumptions of service life and the value of a statistical life, can be cost effective in reducing crashes at signalized intersections.

Summary and Conclusions

The objective of this study was to undertake a rigorous before-after evaluation of the safety effectiveness, as measured by crash frequency, of multi-strategy, low-cost improvements at signalized intersections. The study used data from South Carolina to examine the effects for the specific crash types total, fatal and injury, rear-end, right-angle, and nighttime crashes. Based on the aggregate results, table 3 presents the recommended CMFs for the various crash types.

The disaggregate analysis sought to identify those conditions under which the multiple low-cost treatments are most effective. Variables of interest included area type (urban or rural), number of legs (three or four), lane configuration of the mainline and the cross street, traffic volumes, and expected crashes without treatment. The disaggregate analysis results indicate larger crash reductions of all types for urban areas and intersections with two-lane major roads. For total entering volume, the disaggregate analysis results indicate the strategy is slightly more effective on average for intersections with lower traffic volumes. The strategy is approximately equally effective across the range of expected crashes before treatment.

The B/C ratio, estimated with conservative cost and service life assumptions and considering the benefits for total crashes, is 11.7 to 1 excluding pedestrian improvements. With the USDOT recommended sensitivity analysis, these values could range from 6.6 to 1 up to 16.4 to 1. These results suggest that the multiple low-cost treatments, even with conservative assumptions on cost, service life, and the value of a statistical life, can be cost effective in reducing crashes at signalized intersections.

Table 3. Recommended CMFs.

Variable	Total	Fatal and Injury	Rear-End	Right-Angle	Nighttime
CMF	0.955	0.893*	0.974	0.883*	0.969
Standard error	0.023	0.045	0.034	0.035	0.048

*Indicates statistically significant results at the 95-percent confidence level.

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