TECH**BRIEF**

Safety Evaluation of Multiple Strategies at Stop-Controlled Intersections

FHWA Publication No.: FHWA-HRT-17-087

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This document is a technical summary of the Federal Highway Administration report *Safety Evaluation of Multiple Strategies at Stop-Controlled Intersections* (FHWA-HRT-17-086).

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 to 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 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.

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This study evaluated a combined application of multiple low-cost treatments at stop-controlled intersections. Improvements included basic signing and pavement markings. The intent of this strategy is to reduce the frequency and severity of crashes at stop-controlled intersections by alerting drivers to the presence and type of approaching intersection.

Many studies have explored the safety effectiveness of basic signing or pavement marking improvements. 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, agencies have shown increased interest in the widespread installations 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 stop-controlled and signalized intersections statewide. Typical low-cost treatments at stop-controlled intersections in South Carolina included signing and pavement marking improvements. Each intersection received all treatments appropriate for the site.

The following is an overview of the types of basic signing and pavement marking improvements. Each treatment was installed when appropriate. Each intersection received a unique package of improvements suited for implementation at that site. The possible improvements included the following:

- Signing improvements:
    - Double up 36-inch x 36-inch intersection warning signs on fluorescent yellow sheeting on the left and right sides of the street.
    - Add an advance street name plaque (W16-8) on fluorescent yellow sheeting accompanying each right-side intersection warning sign.
    - Double up 48-inch x 48-inch STOP and YIELD signs on the left and right sides.
    - Use retroreflective sign posts for the above signs.
- Pavement marking improvements:
    - Place stop lines within 4 to 10 ft of the nearest through lane along the major road.
    - Install yield lines at all lanes having yield conditions.
    - Add a dashed white edge line through the intersection along the major road.
    - Re-mark all existing stop lines, crosswalks, arrows, and word messages unless:
        - The roadway has been resurfaced within 1 calendar year and new thermoplastic markings have been applied.
        - Existing markings are uniformly reflective and aboveground thickness is 90 mil or greater.

- Otherwise directed by a district representative.

- o Mark all turn lanes to include the pattern of lane arrows and accompanying word message "ONLY" based on the turn lane length, in accordance with Standard Drawing 625-410-00.

A literature search focused on the safety effects of the specific strategies at stop-controlled intersections. Very few studies investigated the effects of multiple strategies. An evaluation by the Institute of Transportation Engineers, which examined the safety effects of doubling up stop signs, found that these strategies yielded an 11-percent reduction in total crashes.[1] An FHWA study found that doubling up and oversizing stop signs resulted in a 48-percent reduction in total crashes; however, there were potential biases with study design, sample size, and selection bias.[2] Multiple studies confirm the conspicuity of fluorescent sign sheeting.[3,4] 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.[5] Several studies evaluated the installation of minor-road stop line pavement markings, resulting in a total crash reduction of 19 percent in two studies and a 47-percent reduction in right-angle crashes in one of the studies.[1,6] The combination of adding a center line, adding a stop line, and replacing a 24-inch stop sign with a 30-inch stop sign yielded a 67-percent reduction in right-angle crashes.[7] The combination of stop lines and short intervals of double yellow center lines through the intersection resulted in a 53-percent decrease in total crashes.[2]

Most of these studies employed study designs that lacked statistical rigor and frequently neglected to estimate standard errors for the crash reductions, which makes it difficult to put much credence in the results. Furthermore, none of the previous studies conducted a comprehensive evaluation with regard to crash type and severity. The previous studies generally reported the effect on total crashes or angle crashes, and virtually none estimated the effect on injury crashes. Thus, there is a need for additional research of the stop-controlled strategies of interest that employs rigorous study designs and analyzes a full range of crash types and severities.

Methodology

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

The data sample included 434 treatment sites and 568 reference sites of all intersection types. The research team categorized intersections for evaluation using the following configuration types:

- 3 x 22: Three-legged intersections with two lanes on the main line and two lanes on the cross street.
- 4 x 22: Four-legged intersections with two lanes on the main line and two lanes on the cross street.

- 3 x 42: Three-legged intersections with four lanes on the main line and two lanes on the cross street.
- 4 x 42: Four-legged intersections with four lanes on the main line and two lanes on the cross street.

The evaluation made use of the empirical Bayesian (EB) methodology for observational before–after studies.[8] 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) 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.
- Provides a foundation for developing guidelines for estimating the likely safety consequences of a contemplated strategy.

The researchers 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 researchers 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 estimate of safety effects for target crashes was 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 shows the aggregate results. For all crash types, the table provides the estimates of expected crashes in the after period without treatment, the observed crashes in the after period, the estimated crash modification factor (CMF), and the standard error of the CMF.

The reductions were statistically significant at the 95-percent confidence level for all crash types. For all crash types combined, the CMFs were 0.917 for all severities and 0.899 for fatal and injury crashes. The crash type with the smallest CMF, which indicates the greatest crash reduction, was nighttime crashes with a CMF of 0.853. The CMFs for rear-end and right-angle crashes were 0.933 and 0.941, respectively.

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

Crash Type	After-Period Crashes—Expected (Without Systemic Improvement)	After-Period Crashes—Observed	Estimated CMF	Standard Error of Estimated CMF
Total	4,614	4,231	0.917*	0.017
Fatal and injury	1,434	1,290	0.899*	0.028
Rear-end	1,577	1,472	0.933*	0.030
Right-angle	1,955	1,840	0.941*	0.026
Nighttime	1,072	953	0.853*	0.031

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

Disaggregate Analysis

The disaggregate analysis identified those conditions under which the multiple low-cost treatments are more effective. The research team identified several variables of interest, including area type, number of legs, lane configuration of the main line and cross street, traffic volumes, and expected crashes without treatment. All of these variables are likely correlated, and caution should be exercised in interpreting and applying the disaggregate analysis results.

The disaggregate analysis indicated larger crash reductions of all types for rural areas, four-legged intersections, and intersections with two-lane major roads. For total entering volume and expected crashes before treatment, the disaggregate analysis indicated the strategy is more effective on average for intersections with lower traffic volumes and fewer expected crashes per year. However, as noted above, this effect may be due to other correlated variables.

Economic Analysis

The research team conducted an economic analysis to estimate the B/C ratio for implementing various low-cost pavement marking and signing improvements at stop-controlled intersections. The research team used the statistically significant aggregate reduction in total crashes to calculate the conservative value of benefits for an average intersection.

Based on work order cost data for more than 800 unsignalized intersections provided by SCDOT, the economic analysis assumed an average total construction cost of $5,900. 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. In addition, annual maintenance and operations costs were not available but were 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 approximately 7 years. Pavement markings were assumed to last roughly 7 years and signs roughly 10 years, for an approximate average of 7 years for the overall project. A conservative analysis using a service life of 3 years was also conducted.

Using comprehensive crash cost estimates for fatal, injury, and property-damage-only crashes and the severity distribution at treatment sites, the research team estimated the cost for an average crash at a stop-controlled intersection and updated this value to 2015 U.S. dollars (USD) at the time of analysis using the value of a statistical life provided in a 2015 USDOT memorandum. The team applied the ratio of the 2015 value of $9.4 million to the 2001 value of $3.8 million, yielding an average cost of $132,071 in 2015 USD.[9,10] 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.[10]

The research team calculated total crash reduction 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 119.7 crashes per year for the sample sites, or an average reduction of 0.3 crashes per site per year across the 434 treatment sites. Similarly, the treatments reduced fatal and injury crashes by 45 crashes per year across the sample sites, or an average reduction of 0.1 fatal and injury crashes reduced per site per year.

To calculate the annual economic benefits, the research team multiplied 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.

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

Table 2. B/C ratios.

Service Life	Lower Bound	Average B/C	Upper Bound
3 years	7.1	12.4	17.5
7 years	14.5	25.5	35.9

Summary and Conclusions

This study was a rigorous before–after evaluation of the safety effectiveness, as measured by crash frequency, of systemic low-cost improvements at stop-controlled 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

Table 3. Recommended CMFs.

Variable	Total	Fatal and Injury	Rear-End	Right-Angle	Nighttime
CMF	0.917	0.899	0.933	0.941	0.853
Standard error	0.017	0.028	0.030	0.026	0.031

multiple low-cost treatments are most effective. Variables of interest included area type, number of legs, lane configuration of the main line and the cross street, traffic volumes, and expected crashes without treatment. The disaggregate analysis indicated larger crash reductions of all types for rural areas, four-legged intersections, and intersections with two-lane major roads. For total entering volume and expected crashes before treatment, the disaggregate analysis indicated the strategy is more effective on average for intersections with lower traffic volumes and fewer expected crashes per year. However, it is important to be cautious in interpreting and applying these disaggregate analysis results, which are likely confounded by multiple correlative effects.

The B/C ratio, estimated with conservative cost and service life assumptions and considering the benefits for total crashes, is 12.4:1. With the USDOT recommended sensitivity analysis, these values could range from 7.1:1 up to 17.5:1. 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 stop-controlled intersections.

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Key Words—Stop-controlled intersection, signing, pavement marking, low-cost, safety improvements, safety evaluations, empirical Bayesian.

DECEMBER 2017

FHWA-HRT-17-087
HRDI-20/12-17(200)E