TECHBRIEF

Safety Evaluation of Flashing Beacons at Stop-Controlled Intersections

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This document is a technical summary of the Federal Highway Administration report, *Safety Evaluation of Flashing Beacons at Stop-Controlled Intersections*, FHWA-HRT-08-044.

Objective

The Federal Highway Administration (FHWA) organized 26 States to participate in the FHWA 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 evaluated for this study was flashing beacons at stop-controlled intersections. This strategy is intended to reduce the frequency of crashes related to drivers' lack of awareness of stop control at unsignalized intersections. The safety effectiveness of this strategy has not been thoroughly documented, and this study was an attempt to provide an evaluation through scientifically rigorous procedures. Three types of flashing beacons—intersection control beacons, beacons mounted on STOP signs, and actuated beacons—were considered collectively at stop-controlled intersections. Although these could be considered three distinct safety strategies with different expected performance, due to sample size limitations, they were analyzed collectively in this study.

Introduction

Intersections account for a small portion of the total highway system, yet in 2005, approximately 2.5 million intersection-related crashes occurred. This number represents 41 percent of all reported crashes. In addition, 8,655 fatal crashes (22 percent of the total 39,189 fatal crashes) occurred at or within an intersection environment.[1]

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Driver compliance with the intersection traffic control is vital to intersection safety. The typical location of unsignalized intersections, however, presents several challenges. Unsignalized intersections are usually located along low- to moderate-volume roads in rural and suburban areas that are generally associated with high-speed travel.[2] Many unsignalized intersections may be unexpected or may not be visible to approaching drivers, particularly those drivers on the major road; therefore, enhancing the visibility of unsignalized intersections with flashing beacons has the potential to reduce the number of crashes associated with drivers' lack of awareness such intersections.

Flashing beacons may be particularly beneficial for unsignalized intersections where angle collisions due to lack of driver awareness of intersections are more common.[2] Flashing beacons can be designed in such a way that they flash all the time or only when a sensor detects a vehicle approaching the intersection (an actuated beacon). Beacons can be installed either overhead, as shown in figure 1, or mounted directly onto a STOP sign, as shown in figure 2. Some actuated overhead beacons are supplemented with a sign that indicates, "Vehicles Entering When Flashing."

The flashing beacons can be classified into the following three groups:

1. Intersection control beacons are mounted over the intersection and are referred to as "standard overhead beacons" in this publication.
2. STOP sign mounted flashing beacons, which are referred to as "standard STOP sign mounted beacons" in this publication.
3. Actuated flashing beacons, including both those that are mounted over the intersection and those mounted on signs are referred to as "actuated beacons" in this publication.

Figure 1. Example of Standard Overhead Flashing Beacon.

Figure 2. Example of a STOP Sign Mounted Flashing Beacon.

Collectively, these groups are referred to as flashing beacons in this publication.

A literature review was conducted to identify studies that have evaluated flashing beacons at stop-controlled intersections. Based on the studies reviewed, the safety effectiveness of flashing beacons at stop-controlled intersections has not been adequately quantified. Two studies were based on a limited sample and did not apply state-of-the-art methods to account for potential effects of regression-to-the-mean.[3,4] A third study attempted to use the Empirical Bayes (EB) method to account for regression-to-the-mean but did not properly account for changes in traffic volume.[5] A thorough investigation that properly accounts for both regression-to-the-mean and changes in traffic volume is needed to evaluate the effectiveness of flashing beacons in reducing crash frequency and severity for different configurations of unsignalized intersections.

Methodology

Geometric, traffic, and crash data were obtained at stop-controlled intersections equipped with flashing beacons for 64 sites in North Carolina and 42 sites in South Carolina. These States were selected for the study because they had information about the location of these treatments and when they were installed. In both States, State agency personnel provided data on sites that had been treated with flashing beacons. These sites were treated because of a large number of angle crashes involving drivers who had difficulty recognizing the stop control condition. Geometric, traffic, and crash data were also obtained for reference sites with characteristics similar to the strategy sites in North Carolina and South Carolina.

EB methods were incorporated in a before-after analysis to determine the safety effectiveness of flashing beacons. The EB methodology for observational before-after studies[6] was used for the evaluation because it helps to address the following issues:

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

Safety performance functions (SPFs) were calibrated separately for each State for use in the EB methodology. Generalized linear modeling was used to estimate model coefficients using the PROC GLIMMIX procedure in Statistical Analysis Software® (SAS®)[7] and assuming a negative binomial error distribution, which is consistent with the state of research in developing these models. The over-dispersion parameter (k) is estimated by an iterative process assuming a negative binomial error structure. The over-dispersion parameter relates the mean and variance of the SPF estimate. The value of k is such that the smaller its value, the better a model is for a given set of data.

For both North Carolina and South Carolina, SPFs were developed for the following crash types:

- Total intersection crashes.
- Total intersection injury and fatal crashes (including K, A, B, and C).
- Total intersection angle crashes.
- Total intersection rear-end crashes.

The full report includes a detailed explanation of the methodology, including a description of how the estimate of percent reduction is calculated.

Results

Based on the data, results for North Carolina and South Carolina are presented in the following sections. The 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 flashing beacons.

Table 1. Combined Results for Flashing Beacon Sites—All Beacon Types Combined.				
	Angle	**Rear-end**	**Injury & Fatal (K, A, B, C)**	**All Crash Types and Severities**
EB estimate of crashes expected in the after period without strategy	689.2	221.6	648.8	1,297.0
Count of crashes observed in the after period	598	205	583	1,232
Estimate of percent reduction in crashes (standard error)	**13.3% (4.6)**	7.9% (8.9)	**10.2% (4.8)**	5.1% (3.6)
Estimate of reduction in crashes per site-year	0.21	0.04	0.15	0.15

NOTE: Bold denotes results that are statistically significant at the 95% confidence level.

Aggregate Analysis

The aggregate results are shown in table 1. All three types of flashing beacons are combined in these results for both States. Results that are statistically significant at the 95-percent confidence level are shown in bold. The tables show the EB estimate of the crashes expected in the after period if the treatment had not been installed, the actual number of crashes in the after period, and two measures of change. The first measure of safety effect is the estimated percent change due to the particular safety improvement strategy along with the standard error (S.E.) of this estimate; a negative value indicates an increase in crashes. The second measure of safety effect is the change in the number of crashes per site-year. This is the difference between the EB estimate of crashes expected in the after period and the count of observed crashes in the after period, divided by the number of site-years during the after period. The results in table 1 for the two States indicate statistically significant reductions in angle and injury and fatal crashes.

Disaggregate Analysis

Table 2 presents the results of the disaggregate analysis. Results that are statistically significant at the 95-percent confidence level are shown in bold. The disaggregate analysis was conducted to see if the effects in table 1 are more or less prominent under specific conditions. In reviewing these results, it should be noted that disaggregate analyses are based on smaller sample sizes than aggregate analyses, and smaller samples lead to larger S.E. and less precise results.

Because angle crashes are the main focus of this treatment, the disaggregate analysis is focused on this crash type. The first column of table 2 shows the group, the States considered (NC, SC, or NC and SC), and the number of sites in that particular group.

Overall, the results indicate a tendency for angle crashes to decrease following the introduction of flashing beacons except in urban areas; however, the increase in crashes in urban areas is highly insignificant. The following is a summary of the results regarding specific conditions:

- *Area type:* Flashing beacons seem to be more effective at rural and suburban locations. The sample size for suburban and urban intersections is quite low, resulting in effects that are highly insignificant; therefore, this result needs to be applied with caution.
- *Traffic control (two-way and four-way stop-controls):* Flashing beacons may be more effective at reducing angle crashes at four-way stop-controlled intersections compared to two-way stop-controlled intersections; however, the reduction in angle crashes at four-way stop-controlled intersections is insignificant.
- *Beacon type and location:* Beacon types include standard beacons where the beacon flashes all the time and actuated beacons. Some

Table 2. Results of the Disaggregate Analysis for Angle Crashes.			
Group (Sites)	**EB estimate of crashes expected in the after period without strategy**	**Count of crashes observed in the after period**	**Estimate of percent reduction (standard error)**
Rural Sites in NC and SC (76)	512.8	433	**15.7% (5.3)**
Suburban Sites in NC (14)	143.1	127	11.8% (10.2)
Urban Sites in NC and SC (16)	33.2	38	-12.3% (23.4)
Two-way stop in NC and SC (95)	654.9	572	**12.7% (4.7)**
Two-way stop in SC (31)	122.3	136	-10.4% (13.4)
Four-way stop in SC (11)	34.3	26	27.8% (20.5)
Standard Overhead in NC and SC (84)	540.6	477	**11.9% (5.4)**
Standard STOP Sign mounted in NC and SC (5)	16.5	7	**58.2% (16.3)**
All Standard in NC and SC (89)	557.1	484	**13.3% (5.2)**
Actuated in NC (17)	132.0	114	14.0% (9.8)

NOTE: The negative sign indicates an increase in crashes. Bold denotes results that are statistically significant at the 95% confidence level.

of the actuated flashers are supplemented with a sign that reads, "Vehicles Entering When Flashing." Standard beacons can be located overhead or on a STOP sign. There seems to be a signficant reduction in crashes at sites with standard beacons mounted on STOP signs. However, only five sites belong to this category, and so, it is not possible to make definitive conclusions regarding beacon location.

The three types of beacons analyzed, overhead beacons, beacons mounted on STOP signs, and actuated beacons, could be considered three distinct countermeasures with differing levels of safety effectiveness. There is anecdotal evidence that suggests that the overhead beacons have been misinterpreted as indicating a four-way stop at locations where there was actually only a two-way stop, thereby causing drivers to pull out in front of approaching vehicles because they assumed those vehicles would stop. This has not been reported as an issue at locations with STOP sign mounted beacons. The project team attempted to discern the different safety effects of the three types of beacons, as shown in table 2. However, there was not a large enough sample size for each of the three countermeasures to produce significant results for each of the individual analysis. Due to the limited number of sites in both States, it was also not possible to look at the safety effect of combinations of factors (e.g., beacon type and area type). The effect of annual average daily traffic (AADT) was explored in the disaggregate analysis, but this variable does not appear to have an impact on the strategy effectiveness.

Economic Analysis

An analysis was conducted to study the economic feasibility of this strategy. It was accomplished by estimating the life cycle annual cost of the strategy and comparing this to the expected annual crash cost savings per intersection. In estimating the life cycle annual costs, a discount rate of 7 percent (suggested by Office of Budget and Management) was used. Crash costs were estimated from the most recent FHWA unit crash cost data for unsignalized intersections.[8] Separate calculations were done for standard and actuated beacons because of the significant difference in the installation costs for these types of beacons. The maintenance and utility costs for both beacon types range from $400 to $720 per year (an average of $560). The life of a flashing beacon is at least 10 years.

Based on information from North Carolina and South Carolina, the installation costs for standard beacons, including overhead and STOP sign mounted, range from $2,000 to $27,500, with an average of about $9,000. This information was used to estimate the life-cycle costs for the standard beacons as follows:

High estimates: $27,500 installation, $720 for maintenance; life-cycle costs = $4,636

Average estimates: $9,000 installation, $560 for maintenance; life-cycle costs = $1,841

The installation costs for actuated flashing beacons range from $10,000 to $100,000, with an average of about $23,000. This information was used to estimate the life cycle costs for the actuated beacons as follows:

High estimates: $100,000 installation, $720 for maintenance; life-cycle costs = $14,958

Average estimates: $23,000 installation, $560 for maintenance; life-cycle costs = $3,835

The crash saving benefit was estimated by considering the effects on angle and nonangle crashes. Based on the results in table 4, it is assumed that these effects are similar enough for the two beacon types for the combined results in table 3 to be used. Those results show a reduction of 0.21 angle crashes per site-year. The effect on nonangle crashes was deduced from the numbers for total and angle crashes. From these, an increase of 0.06 crashes per site-year was obtained for nonangle crashes.

The most recent FHWA mean comprehensive costs per crash per year for unsignalized intersections are $13,238 for rear-end and $61,114 for angle crashes.[8] The comprehensive crash costs represent the present value, computed at a discount rate, of all costs over the victim's expected life span that result from a crash. The major categories of costs used in the calculation of comprehensive crash costs included medically-related costs, emergency services, property damage, lost productivity, and monetized quality-adjusted life years.[8] Angle and rear-end crashes are the two most common types of crashes at stop-controlled intersections, and the overall severity of nonangle crashes is quite similar to rear-end crashes; therefore, the cost for nonangle crashes was assumed to be equal to the cost of rear-end crashes. Using these comprehensive crash costs, the savings due to the reduced crashes was $12,040 per site-year (0.21 of $61,114 minus 0.06 of $13,238).

Using the life-cycle cost estimated for standard beacons based on the higher installation and maintenance costs, this savings translates to a 2.6:1 benefit cost ratio ($12,040/$4,636). If a life-cycle cost of $1,841 is used (based on average installation and maintenance costs), a 6.5:1 benefit cost ratio is achieved.

For the actuated beacons, a benefit cost ratio of 3.1:1 is achieved if average installation and maintenance costs are used. If the higher installation and maintenance costs are used, the costs exceed the benefit. Further calculations reveal that for actuated beacons that cost less than $79,000, the benefit exceeds the costs; for installations less than approximately $37,000, a 2:1 benefit is achieved.

Conclusion

Flashing beacons at unsignalized intersections can be a cost-effective safety improvement, particularly for lower cost, nonactuated installations. The combined results indicate a significant reduction in angle crashes as well as

Table 3. Expected Crash Reductions for Flashing Beacons.

Crash Type	Point Estimate	Standard Error	Conservative Estimate
Angle Crashes	13.3%	4.6	**4.3%**
Fatal and Injury Crashes	10.2%	4.8	**1%**

NOTE: The conservative estimates are based on the lower 95% confidence interval and are calculated as the point estimate minus 1.96 times the standard error.

injury and fatal crashes. Based on the conservative lower 95-percent confidence interval of the safety effect estimates, reductions of at least 4 percent for angle crashes and 1 percent for fatal and injury crashes can be expected with the installation of flashing beacons, as presented in table 3. The lower 95-percent confidence limit provides a conservative estimate, and the disaggregate analysis indicates situations where greater reductions may be expected. The safety effect may be larger for STOP sign mounted beacons; however, there was not a large enough sample size to make this determination. It is likely that flashing beacons will be most effective at rural intersections and locations with a high frequency of target collisions (i.e., right-angle, injury, and rear-end), particularly where driver awareness may be an issue. However, it may be necessary to use the point estimate (13-percent reduction for angle crashes and 10-percent reduction for injury and fatal crashes) when comparing various potential countermeasures, especially when confident limits are not available for potential strategies. Doing so allows all countermeasures to be treated equally when making a cost-benefit comparison.

The economic analysis based on the combined results for angle and nonangle accidents from both States indicates that standard flashing beacons and the less expensive actuated ones are economically justified but that a benefit cost ratio of 2:1 may not be achievable for the more expensive actuated beacons.

Further research on the impacts of the location of the beacons, overhead or mounted on a STOP sign, could provide additional insights.

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