TECH BRIEF
February 2018

Safety Effectiveness of Stop-Sign Beacons - A Cross-Sectional Study

Authors

Shauna L. Hallmark
Director, Institute for Transportation
(orcid.org/0000-0002-7304-8430)
515-294-5249, shallmar@iastate.edu

Amrita Goswamy
Graduate Research Assistant
(orcid.org/0000-0003-0113-3094)

Michael Pawlovich
Lecturer, South Dakota State University
(orcid.org/0000-0001-9659-0348)

Sponsors

Iowa Department of Transportation
Midwest Transportation Center
U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology (Part of DTRT13-G-UTC37)
Federal Highway Administration
(InTrans Project 14-509)

For More Information

Center for Transportation Research and Education, Iowa State University
2711 S. Loop Drive, Suite 4700
Ames, IA 50010-8664
515-294-8103 / intrans.iastate.edu

ctre
Center for Transportation Research and Education

MIDWEST TRANSPORTATION CENTER
MTC

IOWA STATE UNIVERSITY
Institute for Transportation

Introduction

Rural intersections account for 16% of fatalities in rural areas (IIHS 2016). Rural intersection crashes are frequently a result of drivers' failing to yield to the right of way.

Failure to yield right-of-way (FTYROW) may be due to speeding, which can result in failure to react in time or may be due to failure to recognize the presence of the intersection or traffic control due to sight distance issues or driver inattention. Retting et al. (2003) investigated crashes at stop-controlled intersections in four cities. They found that stop sign violations accounted for about 70% of crashes.

Both older and younger drivers have been attributed responsibility in failure to yield crashes at intersections. Retting et al. (2003) reported that younger drivers (< 18) and older driver (65+) were more likely to be at fault at stop-controlled intersections.

Raju Thapa/Institute for Transportation

Stop-sign-mounted beacons draw attention to the presence of the intersection and/or traffic control, encouraging improved driver response

Massie et al. (1993) created a collision typology to assess crash types. The researchers investigated 50 crashes involving failure to yield and found older drivers were more likely to stop first and then pull out and collide with another vehicle, while younger drivers were more likely not to stop.

Intersection characteristics such as sight distance, skew angle, presence of horizontal or vertical curvature, and presence of median or lighting have also been correlated to failure to yield and intersection crash risk (Donnell et al. 2002, Burchett and Maze 2006).

Beacons are one countermeasure that have been utilized to reduce rural intersection crash risk. Beacons draw attention to the presence of the intersection and/or traffic control, encouraging improved driver response. The different types of beacons include intersection control beacons mounted over the intersection (also referred to as overhead flashing beacons), standard stop-sign-mounted beacons, and actuated flashing beacons (typically placed on the stop sign but actuated only when speed is over a certain threshold).

The most common intersection beacon configuration is an overhead flashing beacon, which flashes red to drivers with stop-controlled approaches and yellow for major road approaches. Several studies have evaluated overhead flashing beacons, and, in general, they have been shown to reduce crashes. However, some concern has been expressed that drivers are confused by overhead flashing beacons and, in some cases, believe the overhead beacons indicate an all-way stop.

Standard stop-sign beacons are usually mounted on a stop sign. In some cases there may be a warning beacon upstream.

Background for Project Scope

Agencies in Iowa have utilized both overhead flashing beacons and stop-sign-mounted beacons. Overhead flashing beacons are the predominant type, although many of these are being replaced through a state-funded program.

While several studies have shown that overhead flashing beacons are effective, some concern exists that the countermeasure may cause driver confusion. When a driver along a minor stop-controlled approach encounters an overhead flashing beacon with multiple faces, they may falsely interpret the red flashing beacon to be displayed for all approaches, indicating all-way stop control. In this situation, even when drivers come to a complete stop, they may assume oncoming traffic will also stop.

Overhead flashing beacons also require some type of overhead support structure (and typically span wires run from poles).

For both reasons, the Iowa Department of Transportation (DOT) is advocating the use of stop-sign-mounted beacons rather than overhead flashing beacons.

Problem Statement and Research Description

Given that little information is available about stop-sign-mounted beacons as a countermeasure, data for intersections with and without stop-sign-mounted beacons (i.e., treatment and control sites) were identified and a cross-sectional analysis was conducted. Ideally a before-and-after analysis would have been conducted. However, most agencies did not retain records of beacon installation dates. As a result, a standard before-and-after analysis, whether naive or empirical Bayes (EB), was not plausible.

Previous Studies

Only three studies were found that evaluated the effectiveness of stop-sign beacons.

Srinivasan et al. (2008) evaluated the impact of flashing beacons at stop-controlled intersections in North and South Carolina. Several types of beacons were studied including standard stop-sign-mounted flashing beacons, which were evaluated for five treatment sites. A before-and-after EB method was used to study safety effectiveness. The researchers found a 58.2% reduction in angle crashes.

Janoff and Hill (1986) studied the effectiveness of flashing beacons in reducing crashes at hazardous rural curves. Crash data for a two-year before-and-after period were analyzed for a rural highway curve in Texas that had been treated with a single flashing beacon. The analysis showed a 50% reduction in total accidents. The benefit-cost ratio was found to be in excess of 50:1 for the flashing beacon installation.

Brewer and Fitzpatrick (2004) investigated various treatments for rural highways and intersections. They found that a flashing beacon mounted on a STOP AHEAD sign for a single intersection had a crash reduction from 0.06 to 0.03 crashes/month for the three years before and three years after installation.

Identification of Sites

The Institute of Transportation (InTrans) and the Iowa DOT developed an intersection database for the state as part of a previous project. Intersection location on most public roadways were identified and characteristics collected. These characteristics included type of traffic control (i.e., stop, yield, and signal), presence of overhead lighting, and many others. Intersections are spatially located and can be queried in ArcMap so that intersections with the characteristics of interest can be identified.

Presence of beacons was not specifically included as a feature of interest. However, an indication of beacon presence was frequently indicated in the notes section. The notes field was searched for key words such as "flashing" or "beacon" and then intersections with potential beacons were flagged. Next, Google Street View was consulted and the presence of stop-sign-mounted beacons was confirmed.

In the course of identifying control intersections by reviewing nearby intersections, additional locations with stop-sign-mounted beacons were found. This resulted in more than 40 intersections with at least one stop-sign-mounted beacon.

Once an initial set of locations was identified, additional data elements not included in the intersection database, such as presence of turn lanes, were extracted from other sources such as Google Street View, Microsoft Birdseye, Google Aerial View, and Bing Maps. Google Street View was also used to confirm that the sites were devoid of any other advance warning signs besides the flashing beacons.

Approach data were aggregated for each of the intersections depending upon the number of approaches associated with an intersection. For example, a combined indicator variable was created for the intersections that had paved major road and gravel/unpaved minor road approaches. Another combined indicator variable designated an intersection of two-way major road and one-way minor road approaches.

Iowa county engineers and Iowa DOT District offices were consulted to confirm presence and acquire installation dates. However, most agencies did not retain records of beacon installation dates. As a result, a standard before-and-after analysis, whether naive or EB, was not plausible.

To facilitate the cross-sectional analysis, due to the unconfirmed installation dates, the data for a particular intersection were only included when presence of a stop-sign beacon was confirmed during a particular period. For instance, if presence was confirmed starting in 2008, data were included for 2008 forward. When the installation date was known, that date was used as the starting point.

In other cases, the date where an image was available to confirm the presence of a beacon was used. For instance, if a Google Street View image showed a beacon in 2008, this became the assumed starting date.

Starting dates varied from 2008 to 2012. Thus, the researchers made sure that all of the beacons were present for the entire study period of 2012 through 2016 (five years).

Control locations were selected for each treatment intersection. The first step in identifying candidate sites was to check intersections surrounding the treatment intersection. Several key features were used to select a control intersection that matched each treatment intersection in terms of roadway configuration, presence of lighting, presence of advance transverse rumble strips, and number of approaches.

Several treatment locations had highly atypical geometry and control intersections could not be identified. These locations were not included in the analysis, resulting in 40 total treatment intersections for analysis.

In a few circumstances, more than one control intersection was manually identified for a treatment intersection. Intersection and approach characteristics were also extracted for control intersections using the methodology detailed for treatment intersections.

The Iowa DOT maintains a roadway inventory, the Geographic Information Management System (GIMS) database, which was used to obtain the traffic volume data for each of the approach roadways for the intersections. Average annual daily traffic (AADT) was available for every approach. Average minor and major road AADTs were calculated for each intersection for the five-year period.

The Iowa DOT also collects the spatial location of all reported crashes within the state. Crashes occurring within 250 feet of each intersection, as per standard Iowa practice, were obtained for 2012 through 2016 (five years). However, as noted earlier in this section, data for treatment intersections were only included for the years going forward from when the presence of the beacon at each intersection was confirmed.

Time of day is indicated in the crash database. Crashes coded for Light Conditions as dusk, dawn, or unknown, as well as non-reported crashes were not included in the study. Crashes coded as dark-roadway lighted, dark-roadway not lighted, or dark-unknown lighting were considered nighttime crashes. As a result only crashes noted as daylight were included as daytime crashes.

Methodology and Results

The researchers conducted a cross-sectional analysis, which is an acceptable alternative when before data or known before periods are lacking.

A cross-sectional analysis involves comparison of the safety (crash) performance at a set of treatment sites against a set of comparable control sites. Essentially, the before-and-after reduction is replaced with the assumption that reductions at comparable treatment and comparable control sites would be equivalent other than the effect of the treatment. Thus, if the reduction at the treatment sites differs from the control sites, the difference can be assumed to be due to the treatment.

However, a key potential weakness of cross-sectional studies is the similarity of the treatment and control sites. If comparable control sites cannot be identified, the premise of cross-sectional studies fails. This is particularly true since many agencies install the treatment at high crash locations, which may look similar to control intersections that have similar characteristics but are not high crash locations.

A before-and-after study has the ability to highlight these differences that are lacking in a cross-sectional study. The results of the initial cross-sectional analysis that was conducted were inconclusive. This was largely due to the fact that countermeasures are biased to intersections with safety issues. As a result, a cross-sectional analysis may not be able to differentiate the effect of the countermeasures.

A simple statistical comparison as described below indicated that crashes during the nighttime at treatment sites were disproportionately lower than control sites. As a result, daytime crashes were used as measure of exposure and the impact of beacons on nighttime crashes was investigated.

Comparing the ratio of night to day crashes has been widely used to estimate the impact of street lighting. Jackett and Frith (2013) and others (Bhagavathula et al. 2015, Isebrands et al. 2010) used the night-to-day crash ratio to assess road luminance. Donnell et al. (2010) utilized a similar method to compare across lighting studies.

Simple Statistics

Night-to-day crash ratios were used to evaluate the safety effects of roadway lighting. The night-to-day crash ratios were calculated for treatment and control intersections. As noted in Table 1, the night-to-day crash ratio for treatment sites with stop-sign beacons was 0.31 while the ratio for control sites was 0.56.

Table 1. Night-to-day crash ratios

Site Type	Daytime Crashes (D)	Nighttime Crashes (N)	N/D
Control	108	61	**0.56**
Treatment	162	50	**0.31**

This indicates about 0.31 of nighttime crashes result for every day crash at treatment sites while about 0.56 of nighttime crashes occur at control sites for every day crash. As a result, this simple comparison shows that the ratio of night to day crashes at treatment sites is 25% lower than for control sites.

Cross-Sectional Models

Cross-sectional crash models using negative binomial generalized linear regression analysis were developed with an indicator variable for the presence and absence of stop-sign beacons. All models were fit using the statistical software R.

Separate models for nighttime and daytime crashes were evaluated. The parameter estimates, standard errors of the statistically significant variables (at a 90% confidence level) in the cross-sectional models, and the goodness of fit of each of the crash models are shown in Table 2.

Percent change in expected crash frequency given a 1% change in a continuous explanatory variable were calculated. For log-log functional form, it is simply calculated as the parameter estimate.

As shown, a 1% increase in major road AADT is associated with an approximate 0.7 to 0.9% increase in crash frequency. A 1% increase in minor road average AADT is associated with an increase in the daytime and nighttime crash frequency of about 0.2 to 0.3%.

This finding indicates that the major road traffic volume has a greater effect on intersection crashes than the minor road traffic volume. These results are in line with previous studies (Donnell et al. 2010).

Percent change in expected crash frequency was calculated for indicator variables also; this was calculated as change in crashes when the indicator variable changes from zero to one. Percent change for continuous variables = $(\exp(\beta) - 1) \times 100$.

Table 2. Daytime and nighttime crash frequency models

Crash Type	Variable	Daytime Crashes			Nighttime Crashes		
		Parameter Estimate	Std. Error	p-value	Parameter Estimate	Std. Error	p-value
Total	(Intercept)	-8.053	1.143	0.000*	-4.710	0.902	0.000*
	Stop-Sign Beacon (Treatment)	**0.304**	**0.206**	**0.146**	**-0.198**	**0.160**	**0.219**
	Ln Average Minor AADT	0.229	0.085	0.008*	0.015	0.057	0.793
	Ln Average Major AADT	0.900	0.125	0.000*	0.613	0.099	0.000*
	Advance Rumble Strips	1.002	0.467	0.035*	-1.079	0.851	0.209
	Crosswalk present	na	na	na	-0.276	0.140	0.052*
	AIC	329.840			212.920		
Injury	(Intercept)	-6.495	1.409	0.000*	-7.620	2.444	0.003*
	Stop-Sign Beacon (Treatment)	**0.032**	**0.274**	**0.906**	**-0.778**	**0.439**	**0.080**
	Ln Average Minor AADT	0.231	0.115	0.049*	-0.089	0.132	0.501
	Ln Average Major AADT	0.691	0.155	0.000*	0.864	0.260	0.001*
	3-leg minor road stop	-1.129	0.331	0.001*	na	na	na
	4-leg all-way stop	-0.714	0.500	0.158	1.110	0.803	0.171
	Crosswalk present	-0.534	0.275	0.056*			
	AIC	228.200			111.380		
PDO	(Intercept)	-8.513	1.078	0.000*	-5.899	1.143	0.000*
	Stop-Sign Beacon (Treatment)	**0.382**	**0.179**	**0.036**	**-0.050**	**0.211**	**0.815**
	Ln Average Minor AADT	0.254	0.077	0.002*	0.039	0.078	0.618
	Ln Average Major AADT	0.875	0.118	0.000*	0.686	0.124	0.000*
	Advanced Rumble Strips	0.778	0.470	0.102	na	na	na
	4-leg all-way stop	-0.444	0.312	0.159	na	na	na
	AIC	251.080			203.240		

* indicate significance at 1% or 5% or 10% levels
PDO: Property damage only

It was seen that the treatment elasticities change sign (±) when comparing the expected daytime and nighttime crash frequencies across all models. This suggests that the presence of treatment or stop-sign beacons is associated with a 3 to 46% increase in daytime crashes across all severity models and is associated with a 5 to 54% reduction in nighttime crashes.

More desirably, injury nighttime crashes decreased by 54% (statistically significantly at 0.1 alpha level) and total nighttime crashes decreased by 18%. Property damage crashes were reduced by 5%. These results indicate that the treatment has the potential to decrease severe crashes.

Advance stop sign rumble strips did not have any positive effect on daytime total or property-damage-only (PDO) crashes. However, the rumble strips reduced total nighttime crashes by 66%. The rumble strips did not significantly affect nighttime PDO or injury crashes.

Summary Conclusions and Discussion

This study examined the safety effectiveness of stop-sign-beacon installation in Iowa. The study developed crash frequency models for several injury combinations for nighttime and daytime crashes using the AADTs of minor and major roads at approaches with stop-sign-mounted beacons.

A cross-sectional study was conducted given that agencies did not retain installation dates. As a result, a before-and-after analysis could not be conducted. A cross-sectional analysis involves comparison of the safety (crash) performance at a set of treatment sites against a set of comparable control sites. Thus, if the reduction at the treatment sites differs from the control sites, the difference can be assumed to be due to the treatment.

An initial evaluation attempted to compare locations with stop-sign beacons against locations without them. However, results were not conclusive, as can be the problem with cross-sectional studies when locations with higher crash frequency receive a treatment and are then compared after the fact to control intersections, which have similar characteristics but are not high crash locations. A before-and-after study has the ability to highlight these differences, which is lacking in a cross-sectional study.

After examining initial models, the researchers noted that the ratio of nighttime to daytime crashes was lower at treatment locations. As a result, models were developed to evaluate daytime and nighttime crashes separately.

Results indicated that the presence of stop-sign beacons is associated with a 3 to 46% increase in daytime crashes across all severity models, and a 5 to 54% reduction in nighttime crashes. More desirably, injury nighttime crashes decreased by 54% and total nighttime crashes were reduced by 18%. PDO crashes were reduced by 5%.

These results indicate that the treatment has the potential to decrease severe nighttime crashes. Since the study was cross-sectional and locations that received the treatment may have been higher crash locations, it should not be interpreted that the presence of the beacons increased daytime crashes.

Daytime crashes were essentially used as a control to evaluate nighttime crashes. Results do suggests that stop beacons are particularly effective at nighttime. This may be due to the fact that they are more visible and thus more likely to get a driver's attention.

Acknowledgments

The team would like to thank the Iowa DOT, the Midwest Transportation Center, and the U.S. DOT Office of the Assistant Secretary for Research and Technology (USDOT/OST-R) for sponsoring this research and to acknowledge that the Iowa DOT used FHWA state planning and research funds to help fund this work.

References

Bhagavathula, R., R. Gibbons, and C. Edwards. 2015. Relationship between Roadway Illumination Level and Nighttime Rural Intersection Safety. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2485, pp. 8–15.

Brewer, M. A. and K. Fitzpatrick. 2004. *Preliminary Evaluations of Safety Treatments on Rural Highways in Texas*. Texas Transportation Institute, Texas A&M University System, College Station, TX.

Burchett, G. D. and T. H. Maze. 2006. Rural Expressway Intersection Characteristics as Factors in Reducing Safety Performance. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1953, pp. 71–80.

Donnell, E. T., D. W. Harwood, K. M. Bauer, J. M. Mason, Jr., and M. T. Pietrucha. 2002. Cross-Median Collisions on Pennsylvania Interstates and Expressways. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1784, pp. 91–99.

Donnell, E. T., R. J. Porter, and V. N. Shankar. 2010. A Framework for Estimating the Safety Effects of Roadway Lighting at Intersections. *Safety Science*, Vol. 48, No.10, pp. 1436–1444.

IIHS. 2016. *Roadway and Environment*. Insurance Institute for Highway Safety, Highway Loss Data Institute, Arlington, VA. www.iihs.org/iihs/topics/t/roadway-and-environment/fatalityfacts/roadway-and-environment.

Isebrands, H., S. Hallmark, W. Li, T. McDonald, R. Storm, and H. Preston. 2010. Roadway Lighting Shows Safety Benefits at Rural Intersections. *Journal of Transportation Engineering*, Vol. 136, No. 11, pp. 949–955.

Jackett, M. and W. Frith. 2013. Quantifying the Impact of Road Lighting on Road Safety—A New Zealand Study. *International Association of Traffic and Safety Sciences (IATSS) Research*, Vol. 36, No. 2, pp. 139–145.

Janoff, M. S. and J. G. Hill. 1986. Effectiveness of Flashing Beacons in Reducing Accidents at a Hazardous Rural Curve. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1069, pp. 80–82.

Massie, D. L., K. L. Campbell, and D. F. Blower. 1993. Development of a Collision Typology for Evaluation of Collision Avoidance Strategies. *Accident Analysis and Prevention*, Vol. 25, No. 3, pp. 241–257.

Retting, R. A., H. B. Weinstein, and M. G. Solomon. 2003. Analysis of Motor-Vehicle Crashes at Stop Signs in Four U.S. Cities. *Journal of Safety Research*, Vol. 34, No. 5, pp. 485–489.

Srinivasan, R., D. Carter, K. Eccles, B. Persaud, N. Lefler, C. Lyon, and R. Amjadi. 2008. *Safety Evaluation of Flashing Beacons at STOP-Controlled Intersections*. FHWA-HRT-08-044. Federal Highway Administration, Turner-Fairbank Highway Research Center, McLean, VA.

About the Center for Transportation Research and Education

The mission of the Center for Transportation Research and Education (CTRE) at Iowa State University is to develop and implement innovative methods, materials, and technologies for improving transportation efficiency, safety, reliability, and sustainability while improving the learning environment of students, faculty, and staff in transportation-related fields.

About the Midwest Transportation Center

The Midwest Transportation Center (MTC) is a regional University Transportation Center (UTC) sponsored by the U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology (USDOT/OST-R). The mission of the UTC program is to advance U.S. technology and expertise in the many disciplines comprising transportation through the mechanisms of education, research, and technology transfer at university-based centers of excellence. Iowa State University, through its Institute for Transportation (InTrans), is the MTC lead institution.