HSIS Highway Safety Information System

An Analysis Tool for Making Informed Safety Decisions

Safety Evaluation of Converting Traffic Signals from Incandescent to Light-Emitting Diodes

Background

Across the Nation, many agencies have been replacing conventional incandescent light bulbs in traffic signals with light-emitting diodes (LED) (see figure 1 and figure 2). LEDs are primarily installed to reduce energy consumption and decrease maintenance. In addition, LEDs are expected to last much longer compared with incandescent bulbs and tend to age gradually.(1) However, a recent study revealed several potential problems with LEDs, including their inability to melt snow and issues related to visual discomfort caused by glare at night.(2)

Two recent studies, one in Middleton, OH, and the other in Memphis, TN, evaluated the safety effects of converting from incandescent bulbs to LEDs.(3,2) The Ohio study concluded that the LED conversion resulted in a 71-percent increase in crashes, while the Tennessee study concluded that the LED conversion resulted in a 47-percent increase in crashes. Both studies used before–after empirical Bayes (EB) evaluation techniques, but methodological issues associated with these two studies, which are discussed by Srinivasan et al., necessitate a cautious approach to interpreting and applying the results.(4) One of the most significant issues that these studies have in common is a very limited sample size—both studies use data from only eight intersections where incandescent bulbs were replaced by LEDs and two comparison/reference sites.

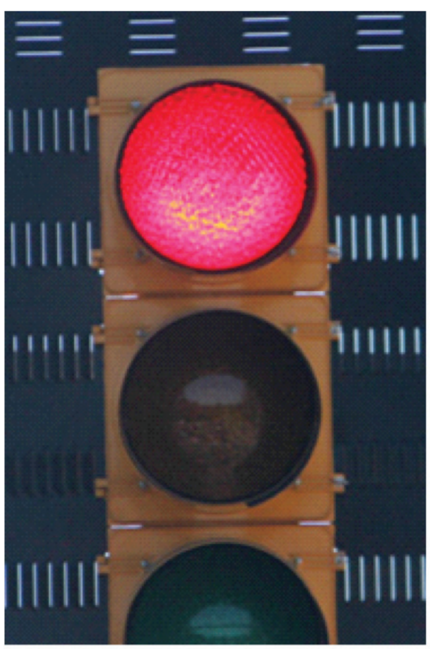

Figure 1. Photo. Incandescent signal head.

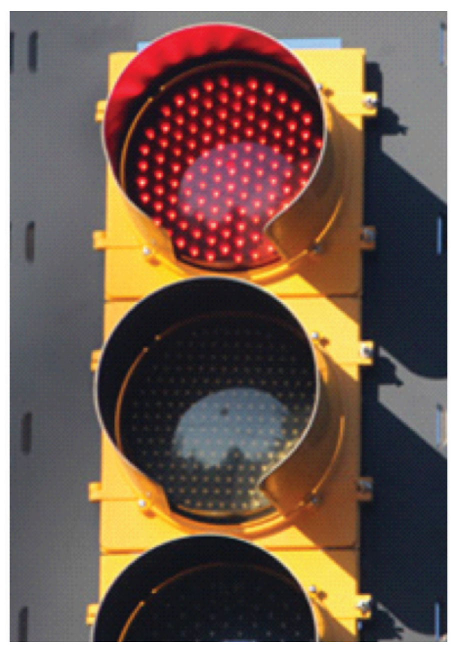

Figure 2. Photo. LED signal head.

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Objectives

It is clear that LEDs are superior in terms of energy consumption and service life. In fact, this economic benefit is the primary reason for the changeover to the LEDs. While agencies do not typically make this change on the basis of expected safety benefits, they certainly do not expect a safety detriment. The effect on traffic safety has not yet been adequately determined. The objective of this study was to determine whether the conversion of traffic signals from incandescent bulbs to LEDs has an effect on the number of crashes, and, if so, to quantify that effect in terms of a crash modification factor (CMF). This evaluation used data from Charlotte, NC. In 2008, the Charlotte Department of Transportation (CDOT) contracted a firm to change the city's signalized intersections from incandescent bulbs to LEDs. CDOT instructed contractors to change out all bulbs at an intersection, even if LEDs were already present. Most of the intersections were converted in 2008 and 2009.

Methodology

This study used an EB before–after evaluation that compared the actual number of crashes that occurred after the implementation of the LEDs with the estimate of the expected number of crashes in the after period if the LEDs had not been implemented. The EB method has been identified as the state of the art for conducting before–after evaluations. The EB method has been found to be effective in addressing possible bias owing to regression to the mean (RTM) if locations with a high number of accidents were selected. It also overcomes the difficulties of using crash rates in normalizing for volume differences between the before and after periods and is effective in accounting for trends owing to changes in crash reporting practices, weather, driver behavior, demographics, vehicle population, and technology over time.

Because the treatment involved a "blanket" LED conversion at all signalized intersections in Charlotte (rather than a selected group), any possible bias owing to RTM was minimal. Thus there was no need to identify an untreated "reference group" as is typically done to account for RTM in before–after studies. However, a comparison group was necessary to account for trends in crashes owing to changes in crash reporting practices, weather, driver behavior, demographics, vehicle population, and technology over time. Because all the signalized intersections were treated, it was impossible to identify a sample of untreated signalized intersections for the comparison group. The following options were considered for identifying an appropriate comparison group:

1. Stop-controlled intersections within Charlotte.
2. Signalized intersections from a city outside of Charlotte.
3. Other facilities within Charlotte, e.g., non-intersection roadway segments.

Option 2 would have required an assumption that the trends in these signalized intersections outside Charlotte are similar to the trends within Charlotte. Option 3 would have required an assumption that the trends at these other facilities (e.g., non-intersection locations) are similar to the trends at intersections. Option 1 would indicate trends of crashes within Charlotte (a drawback of option 2) and crashes related to intersections (a drawback of option 3), and thus was considered the best choice under the circumstances. A similar approach had been successfully used for a Federal Highway Administration (FHWA) safety evaluation of red light cameras.[5] In that study, because the presence of red light cameras at some intersections was expected to affect behavior at most signalized intersections in their vicinity, the researchers used a comparison group of unsignalized intersections from each jurisdiction to account for annual trends. The steps involved in this current EB evaluation, including the estimation of safety performance functions and annual calibration factors, can be found in Srinivasan et al.[4]

Data Collection

Site Identification

Treatment Sites

The treatment sites consisted of signalized three- and four-leg intersections that underwent conversion from incandescent to LED bulbs. Treatment sites were identified based on contractor notes obtained from CDOT staff. The initial list of treated intersections consisted of 550 sites that were converted between January 2008 and September 2009. These sites were filtered to remove intersections where other changes may have occurred at about the same time that the LED bulbs were installed. The sites were also filtered to remove sites with red light cameras, sites at freeway ramps, sites with flashing yellow arrows, and sites with several other characteristics that might influence results. After all site drops, the treatment group consisted of 282 intersections.

Comparison Sites

The method chosen to identify unsignalized intersections for the comparison group was to select from the geographic information system (GIS) intersection inventory data provided to the Highway Safety Information System (HSIS) by CDOT. The 2008 inventory shows more than 26,000 unsignalized intersections. Of these, 8,100 lie on major (non-local roads), which indicates that they are more suitable for comparison with the major signalized intersections. In addition, there was a much greater chance of having traffic volume information for the major road of the intersection.

This initial selection was followed by a more detailed investigation to collect intersection characteristics data and determine which intersections were eligible for inclusion in the comparison group. The initial list was filtered by the applicable exclusion criteria used for the treatment sites (e.g., those locations that showed a major improvement during the analysis period), as well as other criteria specific to unsignalized intersections, such as the presence of flashing beacons. The final number of comparison intersections used was 3,375.

Treatment Information

The installation data for the treatment sites were obtained from CDOT staff. Initially, the data existed on worksheets (bulb change-out forms) that were filled out by the contractor responsible for converting the signal from incandescent bulbs to LEDs. Contractor notes indicated that all signal heads at an intersection were converted when the intersection was visited. The team manually entered the information into a spreadsheet for analysis. These data included installation date, location, and number of bulbs changed.

Intersection Characteristics

Although an inventory of intersections was available, the details about the intersection characteristics were sparse. Aside from the type of traffic control (signalized versus stop controlled), all other intersection characteristics of interest, such as number of lanes, traffic volumes, and speed limit were obtained by linking to the roadway (segment) file in the GIS that is maintained in the HSIS database. Because there is no reliable linkage variable between the intersection point and the roadway line segments, the linking was accomplished through a spatial join in the GIS. This produced an association between intersection legs (line segments) and the intersection (point). Some additional processing was necessary to use these data in the analysis and determine which legs were opposite each other.

Traffic Data

Traffic volume data (annual average daily traffic (AADT)) were obtained from HSIS for the years 2005 to 2010. The HSIS traffic volumes for Charlotte are based on a system of regular midblock 24- or 48-h counts performed by CDOT and converted to AADT. The counts are conducted on a rotating cycle such that each segment is counted once every 3 years. These point AADTs are distributed temporally (i.e., extrapolated backwards or forwards through time for years using a growth factor when counts were not conducted at the location) and geographically (i.e., the same AADT is carried down all segments of the road on which the count was taken).

The other source of traffic volume information was the turning movement counts that CDOT conducts at its intersections on a regular basis. These counts are performed manually at all signalized intersections as well as a few unsignalized ones. Both the turning movement counts and the segment AADTs were used in the development of safety performance functions for the analysis.

Crash Data

Crash data were obtained from HSIS for the years 2005 through 2010. Charlotte HSIS crash data are maintained spatially—every crash is geocoded and given latitude and longitude coordinates. For any crash occurring within 100 ft of an intersection, CDOT "snaps" it to the intersection, placing it exactly at the intersection of the road lines.

Initially, the project team attempted to use a spatial query in which a count of crashes at an intersection was determined by counting the number of crashes within a certain radial distance from the intersection point (e.g., 150 ft). The advantage of this spatial approach was that it gave the analyst the ability to specify the distance to be used in the analysis. However, this spatial query approach proved problematic in two ways:

1. **Crash mislocation.** Upon examination of the crash locations, it became clear that some crashes had been mislocated. Evidently, some transformation or conversion of the GIS data at some point in the past had caused some crashes to be "shifted" from their true location by approximately 100 ft (see figure 3).

While this could be somewhat rectified by using a larger spatial query radius, this change in radius conflicted with the second issue of double-counting.

2. **Double-counting.** If two intersections were near each other, the crashes lying between them would be double-counted (i.e., counted for both intersections) (see figure 4). Using smaller spatial query radii decreased the effect of this problem, but excluded those crashes that had been mislocated.

Thus, the team chose to use the location information in the crash record to determine which crashes occurred at which intersections. Each crash that was located on the map by CDOT staff has a street name or names to indicate where it occurred (in addition to the latitude/longitude coordinates). For crashes determined to be intersection-related (as determined by the Charlotte staff), the field value appears as, for example, "PROVIDENCE_RD_MCKEE_RD," indicating that the crash occurred at the intersection of Providence Road and McKee Road. This value was unique and so could be used to join crashes to intersections.

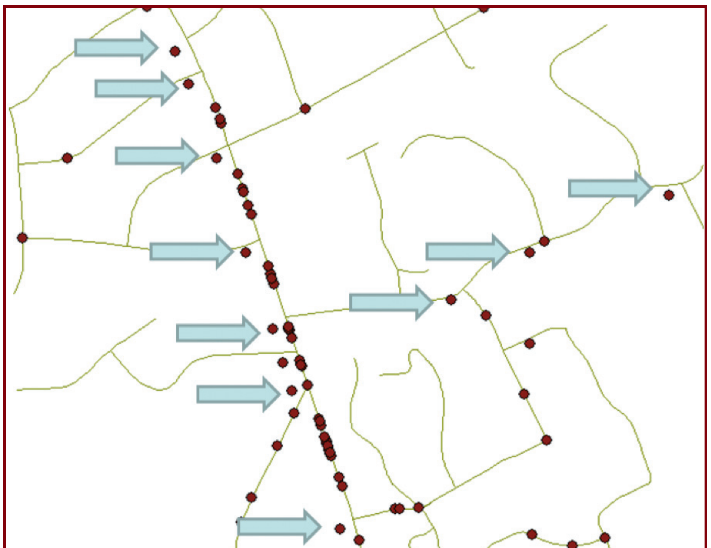

Figure 3. Illustration. Crash mislocation.

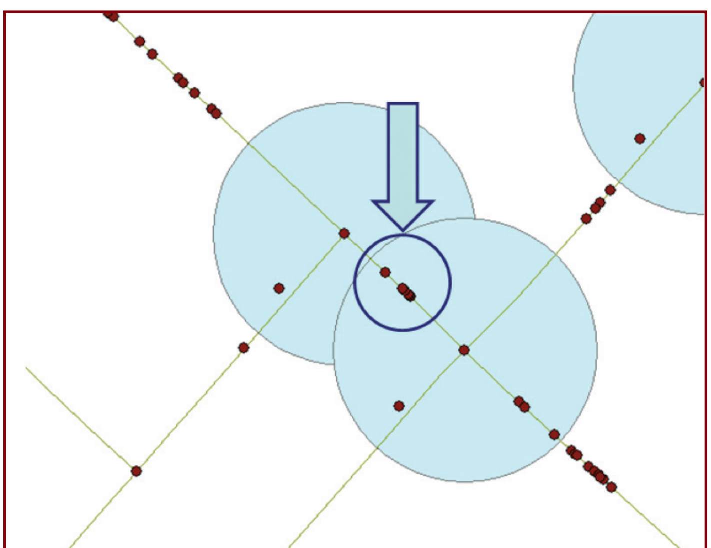

Figure 4. Illustration. Crash double-counting.

Evaluation and Results

Table 1 shows summary statistics for the 282 treatment sites (84 that were three-leg intersections and 198 that were four-leg intersections). The table shows the average traffic volume per intersection per year and average number of crashes (of different types) per intersection per year in the before and after periods. As shown in the table, eight different crash types were investigated:

- Total crashes.
- Injury and fatal crashes.
- Left turn, angle, and head-on crashes.
- Rear-end crashes.
- Total crashes during dark, dawn, and dusk.
- Injury and fatal crashes during dark, dawn, and dusk.
- Left-turn, angle, and head-on crashes during dark, dawn, and dusk.
- Rear-end crashes during dark, dawn, and dusk.

The initial goal was to investigate left-turn, angle, and head-on crashes separately. However, DOT staff indicated that some police officers code left-turn crashes as angle or head-on crashes. Consequently, these crash types were combined into one category. Another goal was to investigate the effect of the LEDs by time of day. However, time of day of the crash was not consistently coded during the before period. Hence, data on ambient lighting during the crash was used, and dark, dawn, and dusk were combined into one category.

When comparing the crashes per intersection per year in the before and after periods, there seems to be a reduction in almost all the crash types, even though the traffic volume changed very little during that period. However, this change obviously cannot be attributed solely to the treatment because it is very possible that the reductions could be the result of changes in crash reporting practices, weather, driver behavior, demographics, vehicle population, and technology over time; that is precisely the reason for including the comparison group of stop-controlled

Table 1. Summary statistics for treatment sites.		
VARIABLE	BEFORE	AFTER
Intersection Approach Through AADT (per intersection)	18,668	18,347
Intersection Approach Right Turn AADT (per intersection)	3,415	3,484
Intersection Approach Left Turn AADT (per intersection)	3,644	3,697
Total crashes per intersection per year	8.15	6.40
Injury and fatal crashes per intersection per year	2.55	2.39
Left-turn, angle, and head-on crashes per intersection per year	2.80	2.19
Rear-end crashes per intersection per year	3.09	2.54
Dawn, Dusk, and Dark: Total crashes per intersection per year	2.06	1.79
Dawn, Dusk, and Dark: Injury and fatal crashes per intersection per year	0.64	0.64
Dawn, Dusk, and Dark: Left-turn, angle, and head-on crashes per intersection per year	0.78	0.64
Dawn, Dusk, and Dark: Rear-end crashes per intersection per year	0.64	0.60

Note: In 2007, crash type information was not coded consistently. Hence, the summary statistics for rear-end, left-turn, angle, and head-on crashes do not include data from 2007

intersections. In fact, the total numbers of crashes at the comparison sites by year are:

- 2005: 4,714.
- 2006: 5,033.
- 2007: 4,649.
- 2008: 4,488.
- 2009: 3,836.
- 2010: 3,403.

It is clear that the number of crashes decreased substantially in 2009 and 2010, although, collectively, these stop-controlled intersections experienced very few changes (apart from changes in traffic volumes) during this period.

Discussion of Results

Table 2 shows the results of the evaluation conducted using the EB method. Included are the EB expected crashes in the after period without the treatment, the observed crashes in the after period, the CMF, and the standard error of the CMF. A CMF greater than one implies that the treatment may lead to an increase in crashes, whereas a CMF less than one implies that the treatment may lead to a reduction in crashes.

As shown in Table 2, for three-leg intersections, the CMFs for the various crash types and times of day range from 1.016 to 1.177, indicating a possible increase in crashes after the conversion to LEDs. However, none of the CMFs are statistically different from 1.0 at the 0.05 significance level. For four-leg intersections, the CMFs range from 0.827 to 1.091, and five out of the eight CMFs are less than 1.0. The CMFs for rear-end crashes during day and night and rear-end crashes during dawn, dusk, and dark time periods are lower than 1.0 and statistically significant, indicating a safety benefit from the changeover to LEDs for this crash type.

The reason for the difference in the effectiveness of LEDs for three-leg and four-leg intersections is not known at this time. The analysis also revealed that there is wide variation in the individual CMFs across the sites, indicating substantial differences among the different sites in terms of the safety effects of the LEDs. Future research should investigate whether LEDs are more or less beneficial depending on the characteristics of the intersection, including type of area, sight distance, intersection lighting, traffic volume, and phasing scheme. This research could lead to crash modification functions that may provide further insight into the safety aspects of LEDs.

Table 2. Results of before–after evaluation

INTERSECTION TYPE	TIME PERIOD	CRASH TYPE	EEB EXPECTED CRASHES IN AFTER PERIOD WITHOUT TREATMENT	OBSERVED CRASHES IN AFTER PERIOD	CMF	STANDARD ERROR OF CMF
Three-Leg (84 sites)	Day and Night	**TOTAL**	516.9	539	1.042	0.051
		Injury and fatal	175.9	206	1.170	0.094
		Left turn, angle, and head on	159.1	162	1.016	0.094
		Rear end	213.3	236	1.105	0.084
	Dawn, Dusk, and Dark	**TOTAL**	120.6	134	1.109	0.106
		Injury and fatal	40.0	45	1.122	0.179
		Left turn, angle, and head on	33.2	36	1.078	0.194
		Rear end	41.5	49	1.177	0.182
Four-Leg (198 sites)	Day and Night	**TOTAL**	2006.3	1971	0.982	0.026
		Injury and fatal	698.8	732	1.047	0.045
		Left turn, angle, and head on	638.5	697	1.091	0.049
		Rear end	918.3	760	0.827†	0.036
	Dawn, Dusk, and Dark	**TOTAL**	612.1	567	0.926	0.044
		Injury and fatal	197.9	205	1.035	0.081
		Left turn, angle, and head on	221.7	213	0.959	0.075
		Rear end	226.7	188	0.828†	0.069

†Statistically different from 1.0 at the 0.05 significance level.

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For More Information

The research was conducted by Raghavan Srinivasan, Daniel Carter, Sarah Smith, and Bo Lan, of the University of North Carolina Highway Safety Research Center. Further details about the evaluation can be found in *Safety Evaluation of Converting Traffic Signals from Incandescent to LED Bulbs,* which was presented at the 2013 Annual Meeting of the Transportation Research Board.[4] For more information about HSIS, please contact HSIS program managers Carol Tan, (202) 493-3315, carol.tan@dot.gov, or Ana Maria Eigen, (202) 493-3168, ana.eigen@dot.gov, at the FHWA.

The Highway Safety Information System (HSIS) is a safety database that contains crash, roadway inventory, and traffic volume data for a select group of States and cities. The participating States of California, Illinois, Maine, Minnesota, North Carolina, Ohio, and Washington and the city of Charlotte were selected based on the quality of their data, the range of data available, and their ability to merge the data from various files. The HSIS database also contains historic data from Michigan and Utah. The HSIS is issued by FHWA staff, contractors, university researchers, and others to study current highway safety issues, direct research efforts, and evaluate the effectiveness of crash countermeasures.

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Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2298

AUGUST 2013
FHWA-HRT-13-070
HRDS-20/08-13(750)E