SAFETY EVALUATION OF RED-LIGHT INDICATOR LIGHTS (RLILS) IN FLORIDA

Scott Himes, corresponding author
VHB
4000 WestChase Boulevard, Suite 530
Raleigh, NC 27607
Phone: (919) 334-5608; e-mail: shimes@vhb.com

Frank Gross
VHB
4000 WestChase Boulevard, Suite 530
Raleigh, NC 27607
Phone: (919) 334-5602; e-mail: fgross@vhb.com

Kimberly Eccles
VHB
4000 WestChase Boulevard, Suite 530
Raleigh, NC 27607
Phone: (919) 334-5601; e-mail: keccles@vhb.com

Bhagwant Persaud
Department of Civil Engineering, Ryerson University
350 Victoria Street
Toronto, Ontario M5B 2K3, Canada
Phone: (416) 979-5000, Ext. 6464; e-mail: bpersaud@ryerson.ca

Word count: 5,308 words text plus 6 Tables and 1 Figure at 250 words (each) = 7,058 words
Submission date: August 1, 2016
ABSTRACT

Red-Light Indicator Lights (RLILs) are auxiliary lights mounted on signal heads, mast arms, or poles and directly connected to a traffic-control signal. The RLIL activates at the onset of the red phase and allows an enforcement officer to observe red-light running from downstream of the intersection. This strategy is intended to reduce the frequency of crashes resulting from drivers disobeying traffic signals by providing a safer and more efficient means for police to enforce the red interval. Geometric, traffic, and crash data were obtained at treated four-leg signalized intersections in Florida. To account for potential selection bias and regression-to-the-mean, an empirical Bayes (EB) before-after analysis was conducted, utilizing reference groups of untreated four-leg signalized intersections with similar characteristics to the treated sites. The analysis also controls for changes in traffic volumes over time and time trends in crash counts unrelated to the treatment. Results indicate statistically significant crash reductions for most crash types. Disobeyed signal crashes have an estimated crash modification factor (CMF) of 0.71. Total crashes, fatal and injury crashes, right-angle, and left-turn crashes have estimated CMFs of 0.94, 0.86, 0.91, and 0.60, respectively. The benefit-cost ratio estimated with conservative cost and service life assumptions is 92:1 for four-leg signalized intersections. The results suggest that the treatment, even with conservative assumptions on cost, service life, and the value of a statistical life, can be cost effective. In addition to the crash-related benefits, RLILs can improve the efficiency and safety of red-light running enforcement efforts. While this study did not evaluate the efficiency and safety impacts with respect to enforcement, it should be noted that RLILs do allow police to observe violators from a downstream position, eliminating the need for a second observer (upstream) and the need to pursue a violator through the red-light.

Key words: red-light indicator lights; four-leg signalized intersections; empirical Bayes; safety evaluation; crash modification factors
INTRODUCTION
The National Cooperative Highway Research Program (NCHRP) has published a series of
guides to advance the implementation of countermeasures targeted to reduce crashes and injuries
in 22 key emphasis areas that affect highway safety. Each guide addresses one of the emphasis
areas and includes an introduction to the problem, a list of objectives for improving safety, and
strategies for each objective. Each strategy is designated as proven, tried, or experimental and
many have not been rigorously evaluated, especially the approximately 80 percent considered as
tried or experimental.

In 2005, to support the implementation of the guides, the FHWA organized a pooled fund
study to evaluate low-cost safety strategies as part of this strategic highway safety effort. Over
the years the pooled fund has grown in size and includes 40 states as of 2016. The purpose of the
Pooled Fund Study is to evaluate the safety effectiveness of several tried and experimental, low-
cost safety strategies through scientifically rigorous crash-based studies. The use of RLILs was
selected as a strategy to be evaluated as part of this effort.

This strategy involves installing RLILs, also known as signal indicator lights,
enforcement lights, rat lights or boxes, or tattletale lights—at traffic signals. RLILs are mounted
on the signal head or on the mast arm. The indicator activates simultaneously with the red
interval, allowing an enforcement officer downstream to identify if a vehicle has violated the red
interval.

In its series on Innovative Intersection Safety Treatments, the Federal Highway
Administration (FHWA) presented a summary on enforcement lights (I). The summary indicates
that enforcement lights can provide safety, efficiency, and/or cost benefits compared to other
enforcement methods, including the following:

- Allowing red-light running monitoring from downstream of any leg of an intersection.
- Eliminating the need for unsafe pursuit from an officer positioned upstream. The officer
  would normally need to cross the intersection during the red interval.
- Allowing one officer to conduct downstream enforcement (instead of requiring two
  officers), resulting in increased efficiency.
- Having lower installation and maintenance costs than automated enforcement systems
  (e.g., red-light photo enforcement).
- Not using controversial automated photography.

The FHWA summary also includes several implementation considerations. Since RLILs are not
traffic control devices, there are no compliance issues with the Manual on Uniform Traffic
Control Devices. However, it is worthwhile to consider several points regarding implementation:

- RLILs should be visible to downstream enforcement officers but should minimize
  confusion or distraction to drivers. Covering the indicator in one or more directions may
  help reduce confusion and distraction.
- RLILs should be high enough to be visible over large vehicles and should be out of reach
  of vandals.
- Wiring should connect to the controller output for the red interval to power the RLIL simultaneously.
- Warning and regulatory signs may supplement RLILs to remind drivers of enforcement or fines.
- Judicial support for prior acceptance of the citations given based on the RLILs is critical.
- Public awareness campaigns and increased enforcement may amplify their effectiveness.

The one study of significance to date was by Reddy et al. who evaluated 17 signalized intersections in Hillsborough County, Florida to determine the effectiveness of white lights in reducing red-light violations and associated crashes (2). The authors noted that white enforcement lights allow police officers to operate more effectively, since the required manpower can be cut in half. They also noted that police officers found the white lights made the task of red-light enforcement simpler and safer. A review of the crash data indicated an average of 828 crashes per year at the treatment sites before treatment and 860 crashes per year after treatment. Further analysis determined an average of 56 disregarded traffic signal crashes per year in the before period and 52 crashes per year in the after period. Considering only the approaches with white lights, red-light running crashes decreased from 40.17 crashes per year to 28 crashes per year after treatment. The authors noted an increase in all crashes countywide during the study period, while the trend in red-light running crashes stopped increasing in 2002, the year that white light installation began. They observed red-light violations in the AM and PM peak hours for 5 months prior to installation and 3 months after installation. The number of red-light running citations increased from 17,561 per year to 24,551 per year after treatment. The red-light violation data collected at the study intersections showed a statistically significant reduction at the 90-percent confidence level in violations, from 759 to 567 after white light installation. Due to high variation, the results from the analyses of crash data are less conclusive than the results of the violation data, so it can be said that there is still a need for reliable crash modification factors for this treatment.

**OBJECTIVE**

The objective of this research was to examine the impacts of RLIL application at four-leg signalized intersections. More specifically, the objective was to estimate the safety effectiveness of this strategy as measured by crash frequency using an empirical Bayes (EB) study design, and to investigate the influence of factors that may impact the safety effectiveness estimates. Target crash types included total crashes (all types and severities combined), injury crashes (i.e., K, A, B, and C injuries on the KABCO scale), right-angle crashes, and disobeyed traffic signal crashes. Additionally, left-turn, rear-end, and nighttime crashes were examined. The evaluation of overall effectiveness included the consideration of the installation, maintenance, and operating costs and crash savings in terms of the benefit-cost ratio.
The EB methodology for observational before-after studies as prescribed by Hauer (3) was used for the evaluation. 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, SPFs are used to account for time trends and simultaneously overcome the difficulties of using crash rates in normalizing for volume differences between the before and after periods.

In the EB approach, the change in safety for a given crash type at a site is given by:

\[ \Delta \text{Safety} = \lambda - \pi \]  

where:

\( \lambda \) = expected number of crashes that would have occurred in the after period without the strategy.

\( \pi \) = number of reported crashes in the after period.

In applying Hauer’s methodology for estimating \( \lambda \), the effects of regression-to-the-mean and changes in traffic volume were explicitly accounted for using SPFs, relating crashes of different types to traffic flow and other relevant factors for each jurisdiction based on untreated sites (reference sites). Annual SPF multipliers were calibrated to account for temporal effects on safety (e.g., variation in weather, demography, and crash reporting).

In the EB procedure, the SPF is used to first estimate the number of crashes that would be expected in each year of the before period at locations with traffic volumes and other characteristics similar to the one being analyzed (i.e., reference sites). The sum of these annual SPF estimates \( P \) is then combined with the count of crashes \( x \) in the before period at a strategy site to obtain an estimate of the expected number of crashes \( m \) before strategy. This estimate of \( m \) is:

\[ m = w(P) + (1 - w)(x). \]  

where \( w \) is estimated from the mean and variance of the SPF estimate as:

\[ w = \frac{1}{1 + kP}, \]  

where:

\( k \) = constant for a given model and is estimated from the SPF calibration process with the use of a maximum likelihood procedure. In that process, a negative binomial distributed error structure is assumed with \( k \) being the overdispersion parameter of this distribution.

A factor is then applied to \( m \) to account for the length of the after period and differences in traffic volumes between the before and after periods. This factor is the sum of the annual SPF predictions for the after period divided by \( P \), the sum of these predictions for the before period. The result, after applying this factor, is an estimate of \( \lambda \). The procedure also produces an estimate of the variance of \( \lambda \).
The estimate of $\lambda$ is then summed over all sites in a strategy group of interest (to obtain $\lambda_{\text{sum}}$) and compared with the count of crashes observed during the after period in that group ($\pi_{\text{sum}}$). The variance of $\lambda$ is also summed over all sites in the strategy group.

The Index of Effectiveness ($\theta$), which is also the CMF, is estimated as:

$$\theta = \frac{\pi_{\text{sum}}}{\lambda_{\text{sum}}} \cdot \frac{1}{1 + \left(\frac{\text{Var}(\lambda_{\text{sum}})}{\lambda_{\text{sum}}^2}\right)}$$

The standard deviation of $\theta$ is given by:

$$\text{StDev}(\theta) = \sqrt{\frac{\theta^2 \left( \text{Var}(\pi_{\text{sum}}) + \text{Var}(\lambda_{\text{sum}}) \right)}{\left( \frac{\pi_{\text{sum}}^2}{\lambda_{\text{sum}}^2} \right)^2 \left( 1 + \frac{\text{Var}(\lambda_{\text{sum}})}{\lambda_{\text{sum}}^2} \right)^2}}$$

The percent change in crashes is $100(1 - \theta)$; thus a value of $\theta = 0.7$ with a standard deviation of 0.12 indicates a 30 percent reduction in crashes with a standard deviation of 12 percent.

### DATA COLLECTION

FDOT provided the majority of the data for this strategy, including treatment sites, information regarding the enforcement lights (e.g., manufacturer specifications and law enforcement practices), screening for construction activity for many treatment sites, and access to its mainframe. This allowed the research team to query crash, roadway, and traffic data. Several city traffic engineering departments and police departments also provided information.

The FDOT central office undertook an initiative to deploy enforcement lights at signalized intersections. It provided the FDOT districts with enforcement light equipment (e.g., mounts, bulbs) and lists of intersections for potential installations. Districts 1, 2, and 5 were able to implement this treatment widely. The engineering departments of these districts provided the following data for this evaluation:

- Treatment locations.
- Installation dates.
- Movements monitored (e.g., NB thru, WB left).
- Enforcement light type (i.e., white incandescent or blue LED).

After receiving lists of all the potential treatment sites from the districts, the research team selected treatment sites appropriate for this study. The research team examined the number of approaches using aerial imagery of the potential treatment sites and observed that only a small proportion were three-leg intersections. Such a small sample size would not likely produce statistically robust results; consequently, the research team removed the three-leg treatment...
intersections from further consideration in this study. The final treatment group for this strategy was composed of 108 four-leg signalized intersections located in three districts in Florida (Districts 1, 2, and 5). There were an additional 30 reference sites selected, representing similar four-leg signalized intersections without RLILs.

Crash data were queried from the CAR system for treatment and reference sites. The study period included data from January 1, 2003 to December 31, 2012. The influence area was defined by a 250-ft radius around each intersection. The crash reports from the CAR system also contain traffic volume data, provided as annual average daily traffic, for the mainline and cross-streets of the intersections. Additionally, the 2012 Florida Transportation Information DVD provided traffic volumes for State roadways where no crashes occurred. Finally, the research team estimated traffic volumes for cross-streets with missing data based on nearby traffic counts, surrounding land use, roadside development, and interconnectivity.

FDOT provided estimates of the costs and service lives of the treatments for use in conducting a B/C analysis of the treatment. The RLIL sets (including housing) cost approximately $50 to $150 for traditional (rather than LED) bulbs. Generally, 4 to 8 indicator sets are needed for a major intersection to cover all signals and intervals for a total intersection cost of $200 to $1,200. Cost depends substantially on whether LED or traditional bulbs are used; LED bulbs cost approximately three times as much initially but require much less power. The power cost is generally negligible in comparison to the power used by the signal, into which the indicator is directly wired. Therefore, the analysis ignores the power cost. Additionally, installation cost and service life data were explored through different vendors, State departments of transportation (DOTs), and newspaper articles (1, 4-9). The cost of lights were dependent on color and hardware required for installation. The research team estimated the lights to cost between $77 and $300 per light. Furthermore, the installation of the indicator lights requires labor and equipment, and the cost is dependent on where the lights are mounted (e.g., on back of signal head or on pole). The cost per intersection ranges from $1,000 to $3,000 for installation. The State DOTs reported the life span of the indicator lights to be between 5 and 10 years.

Table 1 provides summary information for the data collected for the treatment and reference sites. Installations ranged from 2004 to 2010. The before and after periods varied by location with the installation year marking the change from before to after. Before periods started as early as 2003 and ended as late as 2009. After periods started as early as 2005 and ended in 2012. The information in Table 1 should not be used to make simple before-after comparisons of crashes per site-year since it does not account for factors other than the strategy that may cause a change in safety between the before and after periods. Such comparisons require an EB analysis, as presented later.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of sites</td>
<td>108</td>
<td>30</td>
</tr>
<tr>
<td>Site-years before</td>
<td>365</td>
<td>300</td>
</tr>
<tr>
<td>Site-years after</td>
<td>599</td>
<td></td>
</tr>
<tr>
<td>Before total crashes (per site-year)</td>
<td>10.085</td>
<td>4.490</td>
</tr>
<tr>
<td>After total crashes (per site-year)</td>
<td>8.367</td>
<td></td>
</tr>
<tr>
<td>Before fatal &amp; injury crashes (per site-year)</td>
<td>5.167</td>
<td>2.453</td>
</tr>
<tr>
<td>After fatal &amp; injury crashes (per site-year)</td>
<td>4.025</td>
<td></td>
</tr>
<tr>
<td>Before right-angle crashes (per site-year)</td>
<td>1.986</td>
<td>0.720</td>
</tr>
<tr>
<td>After right-angle crashes (per site-year)</td>
<td>1.548</td>
<td></td>
</tr>
<tr>
<td>Before left-turn crashes (per site-year)</td>
<td>0.981</td>
<td>0.400</td>
</tr>
<tr>
<td>After left-turn crashes (per site-year)</td>
<td>0.509</td>
<td></td>
</tr>
<tr>
<td>Before rear-end crashes (per site-year)</td>
<td>4.386</td>
<td>1.934</td>
</tr>
<tr>
<td>After rear-end crashes (per site-year)</td>
<td>3.888</td>
<td></td>
</tr>
<tr>
<td>Before nighttime crashes (per site-year)</td>
<td>3.219</td>
<td>1.113</td>
</tr>
<tr>
<td>After nighttime crashes (per site-year)</td>
<td>2.496</td>
<td></td>
</tr>
<tr>
<td>Before disobeyed crashes (per site-year)</td>
<td>0.819</td>
<td>0.293</td>
</tr>
<tr>
<td>After disobeyed crashes (per site-year)</td>
<td>0.586</td>
<td></td>
</tr>
<tr>
<td>Before Major AADT (vehicles per day)</td>
<td>Avg. 35,841 Min. 5,900 Max. 80,500</td>
<td>Avg. 34,008 Min. 10,900 Max. 80,500</td>
</tr>
<tr>
<td>After Major AADT (vehicles per day)</td>
<td>Avg. 34,084 Min. 5,000 Max. 79,000</td>
<td></td>
</tr>
<tr>
<td>Before Minor AADT (vehicles per day)</td>
<td>Avg. 13,934 Min. 845 Max. 62,666</td>
<td>Avg. 8,180 Min. 910 Max. 40,850</td>
</tr>
<tr>
<td>After Minor AADT (vehicles per day)</td>
<td>Avg. 12,146 Min. 867 Max. 59,000</td>
<td></td>
</tr>
</tbody>
</table>
DEVELOPMENT OF SAFETY PERFORMANCE FUNCTIONS

This section presents the SPFs developed for use in the EB methodology to estimate the safety effectiveness of this strategy. Generalized linear modeling was used to estimate model coefficients 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 dispersion parameter, $k$, was estimated iteratively from the model and the data. For a given dataset, smaller values of $k$ indicate relatively better models.

The form of the SPF for total crashes for reference sites, which is presented in Table 2, is given by equation 6:

$$\frac{\text{Crashes}}{\text{year}} = e^{a} \times \text{TotalEnter}^{b} \times \text{PropAADTMin}^{c} \times e^{(\text{ShldT1} + \text{Curve} \times f)}$$

Where:

- $TotalEnter =$ total entering volume (b).
- $PropAADTMin =$ proportion of entering volume from minor route (c).
- $ShldT1 =$ indicator for paved shoulder type (d).
- $Curve =$ indicator for intersection being on a horizontal curve (f).

$a, b, c, d, f =$ parameters estimated in the SPF calibration process.

Additionally, the following parameter is provided for each SPF:

- $k =$ the overdispersion parameter of the model (used in Equation 3).

### TABLE 2 Parameter Estimates and Standard Errors for Florida Signalized Intersection SPF for Total Crashes

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>$a$</th>
<th>$b$</th>
<th>$c$</th>
<th>$d$</th>
<th>$f$</th>
<th>$k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>-4.217</td>
<td>0.513</td>
<td>1.757</td>
<td>-0.343</td>
<td>-0.365</td>
<td>0.195</td>
</tr>
<tr>
<td>Standard error</td>
<td>(1.047)</td>
<td>(0.098)</td>
<td>(0.422)</td>
<td>(0.098)</td>
<td>(0.109)</td>
<td></td>
</tr>
</tbody>
</table>

Note: The letters for parameters in table 10 correspond to those in equation 6.

Additionally, the research team considered crash sample size for reference sites in the development of SPFs. Since total crashes ranged from a minimum of 110 crashes in 2008 to a maximum of 162 in 2004, the research team developed an SPF for total crashes. For all other crash types, there were too few crashes per year to develop separate reliable SPFs. Therefore, the research team used the total crashes SPF for other crash types, along with a proportion factor relating the crash type in question with total crashes. The research team multiplied the prediction
from the SPF by the proportion factor to determine the number of predicted crashes of each specific crash type. The following is a list of crash type proportions:

- Fatal and injury crashes = 0.570.
- Right-angle crashes = 0.152.
- Left-turn crashes = 0.132.
- Rear-end crashes = 0.391.
- Disobey signal crashes = 0.048.
- Nighttime crashes = 0.305.

Annual factors (i.e., multipliers) were used to adjust the prediction based on estimates from the total crashes SPF. For multipliers greater than 1.00, more crashes are predicted for that year than the base year, which was assumed to be 2003. For multipliers less than 1.00, fewer crashes are predicted for that year than the base year. Annual multipliers ranged from 0.96 to 1.43.

Based on the large difference in crash rates between the treatment and reference sites (see Table 1), a decision was made to calibrate the SPF to the treatment site data just before treatment since the difference in crash rates was too large for regression-to-the-mean bias to explain. Therefore, the research team used the treatment sites to account for the under-prediction, using only the final year of crash data before treatment installation to calibrate the SPF. This is consistent with the approach used by Srinivasan et al. and is based on the logic that if sites were selected for treatment based on a high count, that selection would have been done some time prior to the treatment implementation. Second, there is a lag between the end of a calendar year and the availability of crash data for that year. As such, it is unlikely that crash data were available for inclusion in the site selection process for the year prior to RLIL installation.

In the study by Srinivasan et al., the authors calibrated SPFs to be more representative of the treatment group using before period data. The authors plotted 6 consecutive years of crash data for treatment sites to look for evidence of randomly high crashes during the before period. The plot showed that the counts 2, 3, and 4 years before treatment were higher than 1, 5, and 6 years before treatment. The authors selected five or more years before treatment to calibrate the SPF.

Figure 1 provides a plot of the before-period crashes at the treatment sites for the current study. Figure 1 is based on 40 of 108 sites for which 4 years of before data were available (crash data were not available for 4 years before treatment for 68 sites). The plot indicates that the year before installation is the least prone to randomly high crash counts, as was also the case for the Srinivasan et al. data.

The large difference between predicted and observed crashes at treatment sites is similar in magnitude to the difference found by Srinivasan et al.
FIGURE 1 Crash Totals by Year Before Treatment

The research team developed calibration factors by dividing the observed number of crashes for the year prior to treatment by the predicted number of crashes in the same year. This involved 2003 to 2009 data, because installations were from 2004 to 2010. The research team developed calibration factors separately by crash type, which is consistent with Srinivasan et al (10). The following is a list of calibration factors by crash type:

- Total crashes = 1.638.
- Fatal and injury crashes = 1.546.
- Right-angle crashes = 2.034.
- Left-turn crashes = 1.146.
- Rear-end crashes = 1.782.
- Disobey signal crashes = 3.083.
- Nighttime crashes = 1.639.
BEFORE-AFTER EVALUATION RESULTS

Aggregate Analysis

Table 3 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 all crash types considered.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Total</th>
<th>Fatal &amp; injury</th>
<th>Right-angle</th>
<th>Left-turn</th>
<th>Rear-end</th>
<th>Disobey signal</th>
<th>Night</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB estimate of crashes expected in the after period without strategy</td>
<td>5,337.4</td>
<td>2,816.0</td>
<td>1,023.3</td>
<td>507.3</td>
<td>2,291.6</td>
<td>470.8</td>
<td>1,673.8</td>
</tr>
<tr>
<td>Count of crashes observed in the after period</td>
<td>5,012</td>
<td>2,411</td>
<td>927</td>
<td>305</td>
<td>2,329</td>
<td>336</td>
<td>1,495</td>
</tr>
<tr>
<td>Estimate of CMF</td>
<td>0.939</td>
<td>0.856</td>
<td>0.905</td>
<td>0.600</td>
<td>1.016</td>
<td>0.713</td>
<td>0.892</td>
</tr>
<tr>
<td>Standard error of estimate of CMF</td>
<td>0.022</td>
<td>0.027</td>
<td>0.042</td>
<td>0.041</td>
<td>0.033</td>
<td>0.048</td>
<td>0.034</td>
</tr>
</tbody>
</table>

1(CMF estimates that are statistically significant at the 5% level are indicated in boldface)

The results in Table 3 indicate statistically significant reductions at the 95-percent confidence level for all crash types analyzed except for rear-end crashes, for which the negligible increase was not statistically significant even at an 80-percent confidence interval. The crash type with the smallest CMF (which translates to the greatest reduction) is left-turn crashes with a CMF of 0.60. For all crash types combined, a CMF of 0.94 was estimated. The CMFs for fatal and injury, right-angle, disobeyed signal, and nighttime crashes are 0.86, 0.91, 0.71, and 0.89, respectively. A CMF of 1.02 was estimated for rear-end crashes, which again is not statistically significant.

Disaggregate Analysis

The disaggregate analysis sought to identify those conditions under which the treatment is most effective. Since total, fatal and injury, right-angle, and disobeyed signal crashes are the focus of this treatment, these crash types are the focus of the disaggregate analysis. The research team identified several variables of interest, including treatment duration, level of enforcement, and major and minor approach traffic volumes.

For treatment duration, as shown in Table 4, RLILs become more effective with time. This is evident as the CMFs for total, fatal and injury, and right-angle crashes become smaller as additional time accumulates for the treatment. The CMFs for total crashes and right-angle crashes are not statistically significant after 1 or 2 years of implementation but become
significant after the second year of implementation. While CMFs become smaller over time for most crash types, the CMF for disobeyed signal crashes is significant and stable after the first year of installation.

For enforcement and education practices, the research team disaggregated the results by district, as shown in the last two columns of Table 4. Across all crash types, the CMFs were smallest for District 1. Local agencies in District 1 responded to the research team regarding the enforcement of the indicator lights. Several counties and cities reported initial advertisements in local newspapers and participation in awareness campaigns. Additionally, a few agencies in this district noted that they utilize the lights and have increased enforcement after their application. No agencies in Districts 2 or 5 reported awareness campaigns or increased enforcement. The CMF estimates for districts appear to support these implementation practices.

### TABLE 4 Results Disaggregated by Treatment Duration and District\(^1\)

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>Treatment Duration</th>
<th>CMF (s.e.)</th>
<th>District</th>
<th>CMF (s.e.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Crashes</td>
<td>1</td>
<td>1.024 (0.037)</td>
<td>1</td>
<td>0.736 (0.077)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.963 (0.027)</td>
<td>2</td>
<td>0.995 (0.033)</td>
</tr>
<tr>
<td></td>
<td>2+</td>
<td>0.939 (0.022)</td>
<td>5</td>
<td>0.934 (0.031)</td>
</tr>
<tr>
<td>Fatal and Injury Crashes</td>
<td>1</td>
<td>0.917 (0.047)</td>
<td>1</td>
<td>0.676 (0.082)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.888 (0.035)</td>
<td>2</td>
<td>0.895 (0.044)</td>
</tr>
<tr>
<td></td>
<td>2+</td>
<td>0.856 (0.027)</td>
<td>5</td>
<td>0.868 (0.037)</td>
</tr>
<tr>
<td>Right-Angle Crashes</td>
<td>1</td>
<td>0.989 (0.079)</td>
<td>1</td>
<td>0.756 (0.112)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.944 (0.057)</td>
<td>2</td>
<td>1.036 (0.075)</td>
</tr>
<tr>
<td></td>
<td>2+</td>
<td>0.905 (0.042)</td>
<td>5</td>
<td>0.856 (0.054)</td>
</tr>
<tr>
<td>Disobeyed Signal Crashes</td>
<td>1</td>
<td>0.748 (0.099)</td>
<td>1</td>
<td>0.368 (0.086)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.784 (0.074)</td>
<td>2</td>
<td>0.797 (0.088)</td>
</tr>
<tr>
<td></td>
<td>2+</td>
<td>0.713 (0.048)</td>
<td>5</td>
<td>0.750 (0.066)</td>
</tr>
</tbody>
</table>

\(^1\)(CMF estimates that are statistically significant at the 5% level are indicated in boldface)

As shown in Table 5, CMFs are significantly smaller for intersections with a total entering volume of less than 40,000 vehicles per day for total, fatal and injury, and right-angle crashes, as compared to intersections with a higher total entering volume. The strategy is more effective for disobeyed signal crashes at intersections with a higher total entering volume. In all cases, the differences are significant at the 95-percent confidence level. The same trend appears to be true for proportion of the total entering volume on the minor approach. For intersections with less than 20 percent of the entering volume from the minor road approaches, the CMFs for total, fatal and injury, and right-angle crashes are smaller. However, the difference is not
statistically significant at the 95-percent confidence level. These results are consistent with those found by disaggregating rural versus urban sites.

### TABLE 5 Results Disaggregated by Entering Volume and Proportion Entering on Minor

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>Entering Volume</th>
<th>CMF (s.e.)</th>
<th>Proportion from Minor</th>
<th>CMF (s.e.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Crashes</td>
<td>&lt; 40,000</td>
<td>0.749 (0.033)</td>
<td>&lt; 0.2</td>
<td>0.858 (0.041)</td>
</tr>
<tr>
<td></td>
<td>40,000 +</td>
<td>1.018 (0.029)</td>
<td>0.2 +</td>
<td>0.969 (0.026)</td>
</tr>
<tr>
<td>Fatal and Injury Crashes</td>
<td>&lt; 40,000</td>
<td>0.716 (0.041)</td>
<td>&lt; 0.2</td>
<td>0.813 (0.049)</td>
</tr>
<tr>
<td></td>
<td>40,000 +</td>
<td>0.916 (0.035)</td>
<td>0.2 +</td>
<td>0.873 (0.033)</td>
</tr>
<tr>
<td>Right-Angle Crashes</td>
<td>&lt; 40,000</td>
<td>0.749 (0.061)</td>
<td>&lt; 0.2</td>
<td>0.882 (0.074)</td>
</tr>
<tr>
<td></td>
<td>40,000 +</td>
<td>0.978 (0.055)</td>
<td>0.2 +</td>
<td>0.913 (0.050)</td>
</tr>
<tr>
<td>Disobeyed Signal Crashes</td>
<td>&lt; 40,000</td>
<td>0.911 (0.091)</td>
<td>&lt; 0.2</td>
<td>0.899 (0.092)</td>
</tr>
<tr>
<td></td>
<td>40,000 +</td>
<td>0.608 (0.054)</td>
<td>0.2 +</td>
<td>0.614 (0.054)</td>
</tr>
</tbody>
</table>

1(CMF estimates that are statistically significant at the 5% level are indicated in boldface)

### Economic Analysis

The research team conducted an economic analysis to estimate the B/C ratio for this strategy at four-leg signalized intersections. The team used the statistically significant reduction in total crashes as the benefit for this treatment strategy. On the cost side and in the absence of details of each installation, the analysis conservatively assumed that the cost of installing RLILs is $3,000 per intersection. In total, 108 intersections received RLIL treatments at an estimated cost of $324,000. The survey of vendors, DOTs, and newspaper articles indicated the cost of bulbs ranges from $50 to $300. The local agencies involved with the installation of RLILs noted that there was negligible cost for operation, since the bulbs are directly wired into the existing traffic signals. The minimal operational cost is offset by the reduced enforcement cost, which is not factored into this analysis in order to be more conservative.

The analysis assumed the useful service life for safety benefits was five years. This is based on information provided from vendors. This is likely conservative since five years is the minimum service life reported from several vendors, who indicated potential service lives up to 10 years.

The FHWA Office of Safety Research and Development suggests that, based on the Office of Management and Budget Circular A-4, a real discount rate of seven percent be applied to calculate the annual cost of the treatment for the five-year service life. With this information, the Capital Recovery Factor is 4.1 for all intersections.

For the benefit calculations, the most recent FHWA mean comprehensive crash costs
disaggregated by crash severity and crash geometry type were used as a base (11). Council et al. developed these costs based on 2001 crash costs. Table 6 presents the crash costs by type and severity from that report, and also provides the proportion of fatal and injury crashes and the proportion of property damage only crashes for each crash geometry type. Considering the proportion of crashes by type and severity, the unit cost (in 2001 dollars) for crashes at signalized intersections in this study was $51,395.

### Table 6 Crash Costs and Distributions by Crash Type and Severity

<table>
<thead>
<tr>
<th>Crash Geometry Type</th>
<th>Frequency</th>
<th>K/A/B/C Cost</th>
<th>PDO Cost</th>
<th>K/A/B/C %</th>
<th>PDO Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-vehicle rear-end</td>
<td>2,362</td>
<td>$48,236</td>
<td>$9,919</td>
<td>49.1</td>
<td>50.9</td>
</tr>
<tr>
<td>Multi-vehicle head-on</td>
<td>137</td>
<td>$131,356</td>
<td>$4,980</td>
<td>59.1</td>
<td>40.9</td>
</tr>
<tr>
<td>Multi-vehicle crossing path</td>
<td>1,593</td>
<td>$108,401</td>
<td>$8,598</td>
<td>50.6</td>
<td>49.4</td>
</tr>
<tr>
<td>Multi-vehicle sideswipe</td>
<td>222</td>
<td>$138,339</td>
<td>$5,905</td>
<td>18.5</td>
<td>81.5</td>
</tr>
<tr>
<td>Multi-vehicle backing</td>
<td>32</td>
<td>$53,966</td>
<td>$4,579</td>
<td>9.4</td>
<td>90.6</td>
</tr>
<tr>
<td>Single-vehicle struck parked vehicle</td>
<td>21</td>
<td>$108,300</td>
<td>$4,587</td>
<td>47.6</td>
<td>52.4</td>
</tr>
<tr>
<td>Single-vehicle struck pedestrian</td>
<td>84</td>
<td>$173,191</td>
<td>$5,432</td>
<td>82.1</td>
<td>17.9</td>
</tr>
<tr>
<td>Single-vehicle struck bicycle</td>
<td>64</td>
<td>$173,191</td>
<td>$5,432</td>
<td>87.5</td>
<td>12.5</td>
</tr>
<tr>
<td>Single-vehicle struck object</td>
<td>145</td>
<td>$237,600</td>
<td>$5,618</td>
<td>49.7</td>
<td>50.3</td>
</tr>
<tr>
<td>Single-vehicle rolled over</td>
<td>12</td>
<td>$324,366</td>
<td>$13,331</td>
<td>91.7</td>
<td>8.3</td>
</tr>
<tr>
<td>Other/Undefined</td>
<td>340</td>
<td>$316,501</td>
<td>$4,463</td>
<td>30.3</td>
<td>69.7</td>
</tr>
</tbody>
</table>

The unit cost in 2001 dollars was updated to 2014 dollars by applying the ratio of the U.S. DOT 2014 value of a statistical life of $9.2 million to the 2001 value of $3.8 million (12, 13). Applying this ratio of 2.42 to the unit cost resulted in an aggregate 2014 unit cost for total crashes of $124,377 for signalized intersections.

The research team calculated the total crash reduction by subtracting the actual crashes in the after period from the expected crashes in the after period had the treatment not been implemented. The research team then divided the total crash reduction by the average number of after-period years per site to compute the total crashes saved per year. The number of total crashes saved per year was 58.7 for all intersections. Considering the number of treated intersections, this resulted in an average savings of 0.54 crashes per intersection per year.

The annual benefits (i.e., dollar value of crash savings) were obtained by multiplying the crash reduction per site year by the cost of a crash, all severities combined. The B/C ratio is calculated as the ratio of the annual benefit to the annual cost. The B/C ratio is 92:1 for all signalized intersections. The U.S. DOT recommends that sensitivity analysis be conducted by assuming values of a statistical life of 0.57 and 1.41 times the recommended 2014 value (13). These factors can be applied directly to the estimated B/C ratios to get a range of 53:1 to 130:1.
for all signalized intersections. These results suggest that the strategy, even with conservative assumptions on cost, service life, and the value of a statistical life, can be cost effective for reducing total crashes at signalized intersections. While the resulting B/C ratio is very high, users should keep in mind the low-cost nature of this strategy, and that implementing other strategies with lower B/C ratios may result in larger reductions in crashes.

**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 RLILs. The study used data from Florida to examine the effects on specific crash types including total, fatal and injury, right-angle, left-turn, rear-end, nighttime, and disobeyed signal crashes. Based on the combined results, the research team recommends the CMFs shown in Table 3 for the various crash types.

A disaggregate analysis of the results indicated that RLILs are almost immediately effective, and the effect is sustained for disobeyed signal crashes. For other crash types, CMFs decrease over the first few years of treatment, indicating that they are more effective for reducing crashes as drivers become accustomed to them. The smallest CMFs were for District 1, the only district with agencies that noted enforcement and public awareness campaigns. There was no indication of a notable increase in the level of enforcement. There were consistent reports that enforcement was based on intersections with high crash counts and that it was not focused on intersections with red-light indicators only. Some agencies focused awareness campaigns on the indicator lights while others focused on red-light running in general. The research team found no significant difference between indicator types used.

Additionally, RLILs appear to be more effective for total, fatal and injury, and right-angle crashes at signalized intersections with lower total entering volume and a lower proportion of entering traffic from the minor road. The opposite was true for disobeyed signal crashes where RLILs appear to be more effective at signalized intersections with higher total entering volume and a higher proportion of entering traffic from the minor road.

The B/C ratio estimated with conservative cost and service life assumptions, and considering the benefits for total crashes, is 92:1 for all signalized intersections. With the U.S. DOT recommended sensitivity analysis, this value could range from 53:1 to 130:1. These results suggest that the strategy—even with conservative assumptions on cost, service life, and the value of a statistical life—can be cost effective. In addition to the crash-related benefits, RLILs can improve the efficiency and safety of red-light running enforcement efforts. While this study did not evaluate the efficiency and safety impacts with respect to enforcement, it should be noted that RLILs do allow police to observe violators from a downstream position, eliminating the need for a second observer (upstream) and the need to pursue a violator through the red-light.

**ACKNOWLEDGMENTS**

This work was managed by Ms. Roya Amjadi of the Federal Highway Administration. The authors wish to acknowledge her vision and guidance to the project. This work is based on data
provided by Florida. The following individuals contributed not only data but also their time and insight to make this study successful: Mr. Joseph Santos, FDOT, Mr. Benjamin Jacobs, FDOT, Mr. Scott Friedman, FDOT, Mr. C. Barry Wall, FDOT, Mr. Gil Ramirez, Brevard County, Lt. Jesse Baker, Groveland Police Department, Mr. Steve Tayes, City of Kissimmee, Mr. Robert Vilak, Marion County, Mr. Roger Smith, Orange County, and Mr. Garry Lester, Volusia County.

REFERENCES


