Safety Effectiveness and Crash Cost Benefit of Red Light Cameras in Missouri

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STRUCTURED ABSTRACT

Objective
Red light cameras (RLC) have generated heated discussions over issues of safety effectiveness, revenue generation, and procedural due process. This study focuses on the safety evaluation of RLC in Missouri, including the economic valuation of safety benefits. The publication of the national Highway Safety Manual (HSM) in 2010 produced statistical safety models for intersections and spurred the calibration of these models to local conditions.

Methods
This study adds to existing knowledge by applying the latest statistical methodology presented in the HSM and more current data. Driver behavior constantly changes due in part to driving conditions and the use of technology. The safety and economic benefit evaluation was performed using the Empirical Bayes method which accounts for regression to the mean bias. For the economic benefit evaluation, the KABCO crash severity scale and crash cost estimates were used. A total of 24 four-leg urban intersections were randomly selected from a master list of RLC in Missouri from 2006 to 2011. Additionally, 35 comparable non-treated intersections were selected for the analysis.

Results and Conclusions
The implementation of RLC reduced overall angle crashes by 11.6% while rear end crashes increased by 16.5%. The net economic crash cost-benefit of the implementation of RLC was $35,269 per site per year in 2001 dollars (approximately $47,000 in 2015 dollars). Thus RLC produced a sizable net positive safety benefit that is consistent with previous statistical studies.

KEYWORDS
Automated enforcement, intersection safety, crash frequency modeling, right angle crashes
INTRODUCTION

Automated enforcement systems such as red light cameras (RLC) have generated heated discussions over issues of transportation safety, economics, and laws. The objective of implementing RLCs at signalized intersections is to reduce red light running violations and the resulting crashes. This paper reviewed the RLC literature and examined RLC programs in Missouri.

Several studies have evaluated the effect of RLC on red light running frequency in cities such as Fairfax, VA (Retting et al. 1999), Oxnard, CA (Retting et al. 1999a) in the United States, and in other countries including Singapore, Great Britain, Australia, Netherlands, and Canada (Retting et al. 2003). The results of these studies indicate that the safety benefit of automated enforcement is a reduction in the number of red-light violations between 40-50% and spillover effects to non-RLC equipped intersections (Retting et al. 2003). Associated with the reduction in violations is the decrease in crash frequency. Several studies reported exaggerated and statistically biased estimates of the effectiveness of RLC. Some of these studies lacked methodological rigor and statistical significance, which fueled the counter-argument against benefits of RLCs. It was not until 2005 when a federally-funded study, conducted by nationally recognized safety experts, produced better information on RLC effectiveness (Council et al. 2005, Council et al. 2005a, Persaud et al. 2005). The study included significant data from seven jurisdictions and rigorous statistical methods. The implementation of RLC was found to have an overall positive effect on safety. Furthermore, recent studies in North Carolina, Virginia, and Arizona supported the findings of the national study (Miller et al. 2006, Shin and Washington 2007, Pulugurtha and Otturu 2014). Pulugurtha and Otturu (2014) found RLC had beneficial safety effects at intersections over a period of time after the automated enforcement was terminated. Hu et al. (2011) examined aggregated per capita fatal crashes in 99 large US cities, and found RLCs were associated with statistically significant reductions in city-wide rates of fatal red-light running crashes. The most recent meta-analysis of RLC conducted in 2013, reported that on average there was an increase in total crashes by 6%, decrease of right angle crashes by 13%, and increase of rear end crashes by 40%. Injury right angle crashes decreased by 33%, and injury rear end crashes increased by 19% (Høye 2013). Høye (2013) highlighted red light camera program studies that did not control for selection bias, and reported right angle crash reductions up to two times larger than other studies. The meta-analysis only included studies that controlled for regression to the mean and for publication bias.

When individual intersection performance is analyzed in addition to aggregate performance, it is possible to examine the appropriateness of RLC use at an individual site. Council et al. (2005) performed an exploratory analysis with net economic crash effects and found that RLCs were most effective when sites:

- were highly publicized with public information programs
- enforced higher fines
- had one or more left turn protected phases
- had shorter signal lengths and inter-green periods
- had reduced major road speed limit
- had a high proportion of traffic in the major road
- had a high ratio of right angle to rear end crashes
Despite general guidance on site selection for RLC treatment (Council et al. 2005), there is no specific quantitative measure or methodological procedure to determine best candidate locations. Therefore, the cumulative experience of RLC programs from different jurisdictions provides a good historical database of RLC site characteristics. With more recent data in Missouri and rigorous statistical methods, this study contributes to the existing knowledge with updated safety estimates for furthering the study of RLC. Specifically, this new study added significant variables that were omitted from previous studies, manually reviewed individual crash reports based on intersection functional areas, and used recent data from the past decade that captured changes in vehicular technology and driver behavior, e.g. the use of portable devices such as smart phones in vehicles. The labor-intensive crash review process was important, since crash locations in an electronic database may not distinguish a non-intersection related crash that just happened to occur near an intersection.

A commonly used argument against the use of RLC is that rear end crashes are increased while reducing right angle crashes. However, the severity of angle crashes and rear ends are very different, thus there is a need for an overall crash cost analysis (Council et al. 2005). In terms of economic benefits of RLC, crash costs can be quantified using aggregated economic costs across crash types and severity levels, including material and life losses. RLC were found to have a net economic benefit of approximately $38,000 per site per year—in 2001 dollars (Council et al. 2005, 2005a).

In the state of Missouri, the implementation of RLC has not been studied rigorously. Public perception in Missouri has been based mainly upon media coverage and court decisions. Only a few other states have applied rigorous techniques that accounted for sampling bias and regression to the mean. This paper presents the first RLC evaluation that used the Highway Safety Manual (HSM) (AASHTO 2010) methodology, including a comprehensive safety evaluation and crash cost-benefit analysis using the Empirical Bayes method (Hauer 1997). In this study, the SPFs of the HSM were all calibrated to Missouri conditions. In contrast, various studies (Persaud et al. 2005, Miller et al. 2006, Shin and Washington 2007, Pulugurtha and Otturu 2014) developed their own SPFs with limited datasets instead of calibrating functions from the HSM; the development of local SPFs is desirable but also complicated. Current guidance to develop jurisdiction specific SPFs requires 100 to 200 intersections; these intersections have to be similar in geometry, operations, and safety-related traits. The total group of intersections requires at least 300 crashes per year and more than 3 years of crash data. Also, the level of effort for data collection and preparation per SPF may be as high as 1,050 technical staff hours (Srinivasan et al. 2013). The calibration of SPFs from the HSM is a supported alternative when limited data and resources are available. The benefit of the HSM approach is the inclusion of many factors via Crash Modification Factors (CMF). Thus, the HSM considers factors such as pedestrians, alcohol establishments, schools, bus stops, signal control type, left turn phasing, right turns, and even lighting, while some previous SPFs included only a few variables such as amber duration and the number of lanes. The inclusion of more information regarding the surrounding intersection area could result in more accurate crash prediction by accounting for more confounding factors. Another contribution of this paper is the use of much more recent data (2006-2011) as compared to previous studies such as Persaud et al. (2005) (1995-2000), Miller et al. (2006) (2000-2005), Shin and Washington (2007) (1998-2003), and Pulugurtha and Otturu (2014).
(1998-2006). The use of more recent data captures the technological and driver behavioral changes in the past decade including the recent proliferation of mobile devices and the associated distracted driving problems.

METHODOLOGY

Site Selection
The first RLC installed in Missouri was in the city of Arnold in 2005, and many municipalities followed suit. In building a data sample, a master list of locations with RLC across the state was first developed. From the list, facilities were randomly selected and validated to obtain a consistent sample. The sampling criteria consisted of four leg intersections, urban locations, no influence from other facilities, and crash data availability. A total of 24 intersections were selected for this study. The HSM recommends a sample of 20-40 sites for safety evaluations (AASHTO 2010). Additionally, 35 comparable intersections with no RLC treatment were also selected to estimate crashes by type (right angle and rear end). The periods of analysis consisted of two years before and two years after RLC implementation. The crash data was collected from the Missouri State Highway Patrol (MSHP) database.

Data Collection
The data collection included intersection geometry, signal control operation, traffic volume, surrounding features, and crash data. The data was collected using tools such aerial photographs, Missouri traffic volume database, and the MSHP crash records database. The geometry required for the analysis was the number of left/right turn lanes and the length of pedestrian crossings. The traffic volume was the annual average daily traffic (AADT) for every year of analysis. The AADT was collected for each leg of the intersection for each year of analysis. Since pedestrian volume counts were not available, estimates of crossing volumes were determined based on the general level of pedestrian activity provided by the HSM (AASHTO 2010). Pedestrian accessibility, businesses, public transportation, population density, and other factors are used to determine pedestrian activity. The signal control operations were collected for left turn signal phasing type (permissive, protective/ permissive, and protected) and right turn on red restriction. It was important to identify educational facilities, bus stops, and alcohol sale establishments in the area (within 1,000 feet of the center of the intersection), since they significantly influence crashes (Harwood et al. 2008; AASHTO 2010). These facilities were located using address coordinates in combination with aerial imaging and navigation (Google Earth). The crash data was collected using the functional area of the intersections as illustrated in Figure A1 for the before and after periods. All crashes that occurred in the shaded functional area shown in Figure A1 were included. The functional area of an intersection was determined on case by case basis because each intersections have different geometric and operational features that may prolong queues up to different distances from the intersection.

Safety Evaluation
Crashes are random events that fluctuate over time at any given site. In previous safety evaluation practice, crash frequency (crashes/year) over a short period of time was used to quantify the frequency of crashes at roadway facilities. Although this is a fair estimate, it is not completely accurate. As illustrated in Figure A2, short term average crashes may not accurately describe expected average crash frequency. Short-term crash rates may differ
significantly from the long term estimates. This difference is magnified in locations in which a small number of crashes are observed, so variations in crash frequency represent an even larger fluctuation in relation to the expected crash frequency. Therefore, it would be difficult to identify high, average, or low crash frequencies at a site using short term crash rates (AASHTO 2010).

In the case of treatments such as RLCs, it is difficult to determine if changes in crash frequency are due to changes in site conditions or natural fluctuations. There is a tendency, called regression to the mean (RTM), which dictates that a period with comparatively high crash frequency will likely be followed by a comparatively low crash frequency or vice versa (low crash frequency followed by a high frequency period) (Hauer 1996). Since sites are many times selected for treatments based on short term trends in the observed data, RTM bias is introduced—selection bias. The effect of this bias is significant while evaluating treatment effectiveness. When using conventional before and after studies to evaluate safety treatments, the perceived effectiveness is an overestimate of the actual treatment effectiveness. Figure A3 illustrates graphically the regression to the mean effect and the difference between actual and perceived effectiveness.

Treated sites that were selected for improvement due to an unusually high number of red-light running violations and crashes suffer from a selection bias that can result in high RTM in safety effectiveness evaluations. The Empirical Bayes method, as applied in this study, accounts for RTM and provides unbiased estimates.

**Empirical Bayes for Safety Effectiveness** The main purpose of the Empirical Bayes (EB) method is to determine an unbiased expected crash frequency in the after period had the treatment not been implemented (Hauer 1997). The predicted crashes are obtained using the prediction methodology of the HSM (AASHTO 2010) using Safety Performance Functions (SPF), Crash Modification Factors (CMF), Calibration factors (C), and crash type distribution (D) by facility and severity type. All these functions and factors account for local site characteristics, refining the prediction of crashes. The crash type distribution for angle, rear end, and other crashes was determined using the 35 comparable sites. Additional crash data was collected for these sites, and crashes were classified according to type (angle, rear end, and other) to determine their incidence over the total. Since the HSM prediction models were developed by Harwood et al. (2007) with data form other states (Minnesota and North Carolina), the use of calibration factors for Missouri was required. The calibration factors for the state of Missouri were taken from Sun et al. (2013). To obtain calibration factors, the observed crashes in Missouri were compared with the predicted crashes from the model—calibration factor is the ratio of observed over predicted crashes. The SPF and CMFs for four leg signalized urban intersections from the HSM were considered (AASTHO 2010). Equation 1 shows the general form of the prediction methodology. The base model SPF has an additional parameter called overdispersion (k) which forms the basis for the application of the Empirical Bayes method.

\[ N_{pred} = D_i \times C_j \times N_{spf} \times (CMF_1 \times CMF_2 \times ... \times CMF_z) \tag{1} \]

Where,

- \( N_{pred} = \) predicted crash frequency (crashes/year);
- \( D_i = \) crash type distribution (i = all, right angle, and rear end crashes);
- \( C_j = \) calibration factor according to local conditions for facility j;
\[ N_{spf} = \text{predicted crash frequency for site type SPF (crashes/year)} \]

\[ CMF_z = \text{crash modification factor specific to a site type characteristic } z. \]

The expected crash frequency \( N_{exp,b} \) in Equation 2 is then calculated as the weighted average \( (w) \) of the observed crashes \( (N_{obs,b}) \) and the predicted crash frequency in the before period \( (N_{pred,b}) \) from Equation 1. The weight \( (w) \) is determined using the overdispersion parameter \( (k) \) of the base SPF model.

\[
N_{exp,b} = w \times N_{pred,b} + (1 - w) \times N_{obs,b}
\]

Where,

\[
w = \frac{1}{1 + k \times N_{pred,b}}
\]

The adjustment factor \( (r) \) is introduced to account for variations between before and after periods. These variations include the durations of periods and traffic volume. Therefore, the factor is the ratio of the predicted crashes in the after period \( (N_{pred,a}) \) over predicted crashes in the before period \( (N_{pred,b}) \). Since the before and after period were of the same duration, they cancelled each other out in the equation. Thus, the duration is not included in Equation 4.

\[
r = \frac{N_{pred,a}}{N_{pred,b}}
\]

Using Equation 5, the expected crashes in the after period \( (N_{exp,a}) \) are then calculated by multiplying the adjustment factor \( (r) \) to the expected crashes in the before period \( (N_{exp,b}) \).

\[
N_{exp,a} = r \times N_{exp,b}
\]

The expected crashes in the after period \( (N_{exp,a}) \) is then compared with the actual observed crash frequency in the after period \( (N_{obs,a}) \). Equation 6 shows the comparison designated as \( OR' \).

\[
OR' = \frac{N_{obs,a}}{N_{exp,a}}
\]

Since \( OR' \) is potentially biased, it is adjusted using Equation 7 to remove bias and account for regression to the mean using the variance of the expected crashes in the after period.

\[
OR = \frac{OR'}{1 + \frac{Var[N_{exp,a}]}{[N_{exp,a}]^2}}
\]
Where,

\[ \text{Var}\left[N_{\text{exp},a}\right] = \left[(r)^2 \times N_{\text{exp},b} \times (1 - w)\right] \]

Eq. (8)

The comparison (unbiased OR) of expected and observed crash frequency for the after period forms the basis for deriving the safety effectiveness, as shown in Equation 9. The safety effectiveness is the measure of the treatment effectiveness at a site or group of sites after implementation. When crash frequency decreases after a treatment, the safety effectiveness is positive. When crash frequency increases, the safety effectiveness is negative.

\[ \text{Safety Effectiveness} (\%) = 100 \times (1 - \text{OR}) \]

Eq. (9)

**Empirical Bayes for Crash Cost Benefit**  The change in crash costs over all treated facilities in a jurisdiction for specific crash types was estimated. Based on the method used for the safety effectiveness described previously, the Empirical Bayes method measures the difference between net crash costs expected without treatment and observed with treatment in the after period. The cost modification factor (\(\theta_{\text{cost}}\)) is a measure quantifying the change in crash cost with the treatment (Council 2005, 2005a):

\[ \theta_{\text{cost}} = \frac{\Lambda_{\text{cost},a}}{\Pi_{\text{cost},a}} \left\{ 1 + \frac{\text{Var}\left(\frac{\Lambda_{\text{cost},a}}{\Pi_{\text{cost},a}}\right)}{\frac{\text{Var}\left(\frac{\Pi_{\text{cost},a}}{\Pi_{\text{cost},a}}\right)}{\Pi_{\text{cost},a}}} \right\} \]

Eq. (10)

\[ \text{Var}\left(\theta_{\text{cost}}\right) = \text{Var}\left(\frac{\Lambda_{\text{cost},a}}{\Pi_{\text{cost},a}}\right) \left\{ 1 + \frac{\Pi_{\text{cost},a}^2}{\text{Var}\left(\frac{\Pi_{\text{cost},a}}{\Pi_{\text{cost},a}}\right)} \right\} \]

Eq. (11)

Where,

\(\theta_{\text{cost}}\) = cost modification factor;

\(\text{Var}\left(\theta_{\text{cost}}\right)\) = variance of crash modification factor;

\(\Lambda_{\text{cost},a}\) = cost of crashes at treated sites in the after period;

\(\Pi_{\text{cost},a}\) = expected cost of crashes in the after period over all treated sites had there been no RLC (after correcting for regression to the mean).

Additionally, the change in crash cost (\(\Phi_{\text{cost}}\)) and variance can be estimated in dollar costs:

\[ \Phi_{\text{cost}} = \Pi_{\text{cost},a} - \Lambda_{\text{cost},a} \]

Eq. (12)

\[ \text{Var}\left(\Phi_{\text{cost}}\right) = \text{Var}\left(\Pi_{\text{cost},a}\right) + \text{Var}\left(\Lambda_{\text{cost},a}\right) \]

Eq. (13)
RESULTS

The results section contains the details of the data collected, safety effectiveness, and crash cost benefit. Table 1 contains the data in which automated enforcement was implemented. The traffic volumes for the major road ranged from 13,000 to 60,000 (vehicles/day) and the minor road between 2,000 and 33,000 (vehicles/day) during the before period. The characteristics of turning lanes on approaching legs are listed, including the left and right turn lanes. Two types of signal control for left turns exist—permissive/protective and protected only. Pedestrian movements were not considered in previous research. In this study, five levels of pedestrian volume were considered as shown in Table 1. The maximum number of lanes pedestrians must cross to complete their movements was also considered. Several bus stops were common around the intersections, and in some cases, there were up to 8 stops. Site 11 was the only intersection without any bus stops. Alcohol sale establishments were also common in the surrounding areas of the intersections. Site 9 was the only location without an alcohol sale establishment in the area.

The crash data for the before and after periods is shown in Figures 1 to 3. Total, angle, and rear end crashes are shown individually. Figures 1 and 2 show that 11 and 16 sites experienced a reduction in observed crashes for total and angle crashes, respectively. On the other hand, there was an increase of rear end crashes at 15 sites as shown in Figure 3. The changes in crashes between before and after periods were not large in magnitude.

It was important to determine the distribution of crashes (i.e., $D$ in Eq. 1) at non-treated facilities to accurately estimate the effect of the treatment by crash type. Therefore, an additional 35 non-treated comparison sites were used to determine crash distribution by type (e.g., angle, read end). Angle crash distribution refers to right angle crashes or collisions between vehicles in converging directions (front end and lateral crashes). Also, the distribution of type of crashes was further identified by the severity categories of total (TOT), fatal and injury (FI), and property damage only (PDO). The results are shown in Table A1.

The safety effectiveness results across all sites are shown in Table 2. The implementation of RLC in Missouri resulted in a reduction in FI crashes by 7.4%, increase in PDO crashes by 3.8%, and increase in TOT crashes by 1.6%. Additionally, right angle crashes were reduced across all severities, including 14.5% for FI. Rear end crashes increased by 16.5% overall but decreased by 10.9% for FI crashes. These results are in agreement with previous studies (Høye 2013).

The economic benefit of RLC was calculated using aggregated crash costs by crash types and severity levels. It involved placing a monetary value on crashes, including material and life losses. An adaptation of the Empirical Bayes Method was used for the economic estimates. The method accounts for regression to the mean (Council 2005, 2005a). The analysis performed focused on crashes at urban intersections with speed limits equal to or less than 45 mph. Although there are crash costs for every individual KABCO severity scale (K=fatal; A, B, C=injury levels; O=no injury), fatal and injury crash costs were aggregated for this analysis as per common practice. This was done to limit the potential bias from fatal crashes which have large values but very few samples. The crash cost used were $64,468 for angle FI crashes, $44,687 for rear end FI crashes, $91,917 for all FI crashes, $8,673 for angle PDO crashes, $11,463 for rear end PDO crashes, and $7,068 for all PDO crashes (Council et al. 2005b). All crash values are in 2001 dollars. An adaptation of the Empirical Bayes Method was used for the economic estimates (Council 2005, 2005a). The Empirical Bayes estimates of crash cost benefit results are presented in Table 3. RLC in
Missouri showed a positive net economic benefit of $35,269 per site per year in 2001 dollars (approximately $47,000 in 2015 dollars). It translated into an overall 5.0% economic crash benefit. The results are similar to the estimates from previous research (Council 2005, 2005a).

CONCLUSIONS
RLC programs have been controversial over the years. RLC effectiveness has been questioned on different accounts such as research methodology, political pressure, revenues, and statutory authority. Despite the controversies, RLC have been found to improve safety but exhibit certain trade-offs. The results of this study, using unbiased statistical methods, are in line with previous research. The Missouri results found a decrease in right angle crashes by 11.6% and an increase in rear end crashes by 16.5%. For fatal and injury crashes (FI), there was a reduction in both right angle and rear end crashes of 14.5% and 10.9%, respectively. Property Damage Only (PDO) crashes were reduced by 11.2% for angle crashes, but there was an increase of 23.1% in rear end crashes. The results from the crash economic evaluation showed a net economic benefit of $35,269 per site per year in 2001 dollars (approximately $47,000 in 2015 dollars). It translated into a 5.0% overall economic crash cost benefit. At the disaggregate level, 11 sites experienced an overall crash reduction, and 16 sites experienced reductions in right angle crashes. On the other hand, there was an increase of rear end crashes at 15 sites. The main controlling factors in the database were the major road AADT, speed limit, and left turn signal control.

Effective automated enforcement could be accomplished with the application of transportation safety research. The candidate intersections should be evaluated by considering geometric and operational features. The HSM methodology and the application of rigorous statistical methods such as Empirical Bayes provide accurate estimates accounting for regression to the mean bias. Right angle and rear end crashes are two primary crash types of interest. The distribution of these types of crashes could be analyzed to identify facilities with abnormally high crash frequencies. It is important to consider measures of exposure, including speed limits and traffic volumes by movements (left/right turns and through movements).

The integration of automated enforcement should be closely related to local signal design, safety strategies, legislation, and driver behavior. RLC technology has developed into its own industry, a provider of a service rather than a provider of safety. Thus a community would need to consider how RLC could fit into an overall traffic safety program. State legislatures could adopt guidelines promoted by federal agencies and uniform law committees to develop state statutes that would balance procedural safeguards with safety. The involvement of different stakeholders could contribute to the effective selection of sites and implementation of RLCs. As shown by Missouri data, judicious deployment of RLC will help to reduce opposition and increase traffic safety at suitable signalized intersections.
# TABLES

**Table 1** Site data characteristics

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<td>23,221</td>
<td>18,860</td>
<td>4</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>24</td>
<td>2/24/2008</td>
<td>15,782</td>
<td>16,909</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Notes: ^1 Locations are not identified for due to data confidentiality (listed from 1 to 24); ^2 Average AADT during before enforcement; ^3 Establishments within 1,000 ft. from the center of intersection; ^4 Pedestrian volume 1 (3,200 ped/day), 2 (1,500 ped/day), 3 (700 ped/day), 4 (240 ped/day), and 5 (50 ped/day) (13); ^5 Presence of educational establishment Y = yes or N = no.

**Table 2** Aggregated RLC safety effectiveness results

<table>
<thead>
<tr>
<th>Type</th>
<th>Severity</th>
<th>TOT</th>
<th>FI[^1]</th>
<th>PDQ[^2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>All crashes</td>
<td>-1.6% (3.9%, 0.6847[^3])</td>
<td>7.4% (7.3%, 0.3073)</td>
<td>-3.8% (4.5%, 0.4037)</td>
<td></td>
</tr>
<tr>
<td>Angle crashes</td>
<td>11.6% (6.6%, 0.0817)</td>
<td>14.5% (11.4%, 0.2034)</td>
<td>11.2% (7.9%, 0.1550)</td>
<td></td>
</tr>
<tr>
<td>Rear end crashes</td>
<td>-16.5% (6.3%, 0.0088)</td>
<td>10.9% (8.5%, 0.1997)</td>
<td>-23.1% (7.5%, 0.0019)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: ^1 Fatal and Injury; ^2 Property Damage Only; ^3 The results are safety effect. % (std. error %, p-value), and negative values represent increase in crashes.
Table 3 Economic effects

<table>
<thead>
<tr>
<th>Empirical Bayes Estimates</th>
<th>Crash Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right Angle</td>
</tr>
<tr>
<td>Crash cost without RLC</td>
<td>$8,220,077</td>
</tr>
<tr>
<td>Crash cost after RLC</td>
<td>$7,128,809</td>
</tr>
<tr>
<td>Dollar crash cost benefit, all treated facilities</td>
<td>$1,091,268</td>
</tr>
<tr>
<td><strong>Dollar crash cost benefit</strong></td>
<td><strong>$22,735</strong></td>
</tr>
<tr>
<td><strong>by treated facility per year</strong></td>
<td><strong>($3,374)^1</strong></td>
</tr>
<tr>
<td><strong>% Crash cost benefit</strong></td>
<td><strong>12.3%</strong></td>
</tr>
<tr>
<td></td>
<td><strong>(1.8%)^2</strong></td>
</tr>
</tbody>
</table>

Notes:  
1. Crash cost ($St. error) in 2001 dollar costs;  
2. Crash cost benefit% (St. error%), all significant at the 95% confidence; Negative values indicate increase in costs.
Figure 1 Before and after total crashes

Figure 2 Before and after angle crashes

Figure 3 Before and after rear end crashes
APPENDIX A

Table A1 Crashes by type and severity distribution

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>TOT</th>
<th>FI</th>
<th>PDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rear end</td>
<td>62.60%</td>
<td>56.00%</td>
<td>64.80%</td>
</tr>
<tr>
<td>Angle</td>
<td>33.40%</td>
<td>40.10%</td>
<td>30.90%</td>
</tr>
<tr>
<td>Other</td>
<td>4.00%</td>
<td>3.90%</td>
<td>4.30%</td>
</tr>
</tbody>
</table>

Figure A1 Functional area of an intersection (AASHTO 2010)

Figure A2 Expected and short term crash frequency (AASHTO 2010)

Figure A3 Regression to the mean bias (AASHTO 2010)

REFERENCES


Pulugurtha SS and Otturu R. Effectiveness of red light running camera enforcement program in reducing crashes: evaluation using “before the installation”, “after the installation”, and “after the termination” data. *Accident Analysis and Prevention Journal*. 2014;64:9-17.


Srinivasan R, Carter D, and Bauer KM. *How to Choose Between Calibrating SPF*s from the HSM and Developing Jurisdiction-Specific SPF*s*. Project TPF-5(255). The University of North Carolina, Highway Safety Research Center, MRIGlobal, FHWA; 2013.