AN EMPIRICAL BAYES ANALYSIS OF PHOTOGRAPHIC TRAFFIC ENFORCEMENT SYSTEMS IN TEXAS

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Prepared for the

Traffic Operations Division
Texas Department of Transportation
Austin, Texas 78701-2473

August 2012

Executive Summary

In Texas, there were over 11,600 crashes in 2011 associated with Red-Light Related (RLR) violations. To improve intersection safety related to RLR violations, automated photographic traffic signal enforcement systems, also known as red-light running camera (RLC), have been installed at signalized intersections. In 2011, 50 communities reported operating RLC systems at 398 intersections.

The primary objective of this research was to evaluate the safety effectiveness of RLC systems using the before-after study with the Empirical Bayesian (EB) method in Texas. A before-after study using a naïve, comparison group (CG), or EB method can be used to evaluate the safety effectiveness of RLC systems. However, naïve and CG methods suffer from the important limitation of regression-to-mean (RTM) bias. The EB method was used in this study to address the RTM bias during the evaluation of treatments. Using the EB method allowed TTI to estimate safety benefits at treated sites based upon reference sites with similar traits and without RLC treatments. Using the EB method, this research results indicated significant decrease in all type and right-angle RLR crashes by 20% and 24%, respectively, while a significant increase in rear-end RLR crashes by 37%. This result is consistent with the findings from the naïve and CG methods. Thus, irrespective of the method used, the RLC systems have shown to reduce all type and RA crashes related to RLR violations, while an increase in RE crashes.

The secondary objective of this research was to analyze the criteria used for selecting the intersections for RLC treatment placement. In terms of site selection criteria, results suggested that if intersections experienced less than two RLR crashes per year or one RLR crash per 10,000 vehicles per year are treated then one can expect an increase in all type and RA RLR crashes. If the intersections have four or more RLR crashes per year or two RLR crashes per 10,000 vehicles per year, then the treatment will significantly decreases all type and RA crashes.

The traffic volume during the before study period was also considered as another site selection criterion. The results showed that there is no specific trend in safety with the change in traffic volume and thus it is recommended not to consider the traffic volume as a sole site selection criterion.

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INTRODUCTION

Intersections deserve special attention because they provide an important role in safety and operation of highways. According to the National Highway Traffic Safety Administration (NHTSA), approximately 733,000 people were injured at more than 2.3 million reported intersection-related crashes in 2008. It was estimated that 165,000 people were injured by red-light running (RLR) at signalized intersections. In Texas, there were over 11,600 crashes in 2011 associated with RLR violations (*1*). To improve intersection safety related to RLR violations, automated photographic traffic signal enforcement systems, also known as red-light running camera (RLC) systems, have been installed at signalized intersections.

RLC systems are one of several countermeasures used for reducing violations and crashes related to red light running. The automated enforcement systems provide recorded images of offending vehicle (*2*). Advantages of red light cameras include traffic enforcement 24 hours a day resulting in a deterrent effect on violations at intersections.

There has been an increase in the installation of RLC systems at signal control intersections between 2009 and 2011. In 2009, 41 communities operated RLC systems at 362 intersections. In 2011, RLC systems were operated at 398 intersections in 50 communities. Table 1 lists communities that had operated or have been operating RLC systems in Texas between 2009 and 2011.

This study evaluates the effectiveness of RLC systems on intersection safety. A before-after study using a naïve, comparison group (CG), or Empirical Bayesian (EB) method can be used to evaluate the safety effectiveness of RLC systems. However, naïve and CG methods suffer from the limitation of regression-to-mean (RTM) bias. This bias exists due to the methods' prediction concerning the expected number of target crashes from the treatment site based upon before-period crash numbers only. RTM phenomenon suggests that there is a possible tendency for a fluctuating characteristic of the treatment site to return to a typical value in the period after an extraordinary value has been observed (*3*). The EB method can be used to address the RTM bias during the evaluation of treatments. The EB method estimates safety benefits at treated sites based upon reference sites with similar traits and where RLC systems were not installed.

Table 1 Communities and Intersections with RLC Systems in Texas, 2009 to 2011

Community	Number of Intersections with RLC Systems			Community	Number of Intersections with RLC Systems		
	2011	2010	2009		2011	2010	2009
Amarillo	5	5	5	Arlington	17	14	14
Austin	9	--	9	Balch Springs	3	--	--
Balcones Heights	10	9	--	Baytown	9	6	8
Bedford	6	6	6	Burleson	5	5	5
Cedar Hill	5	4	5	Cleveland	3	3	--
College Station	--	--	9	Conroe	7	7	--
Coppell	3	3	3	Corpus Christi	13	13	13
Dallas	54	48	43	Denton	6	--	4
Diboll	3	2	2	Duncanville	8	8	8
El Paso	17	14	14	Farmers Branch	7	7	7
Fort Worth	31	24	17	Frisco	2	--	2
Garland	11	11	20	Grand Prairie	15	13	11
Haltom City	6	--	2	Houston	--	66	66
Humble	6	6	9	Hurst	5	4	1
Hutto	--	--	1	Irving	9	9	6
Jersey Village	11	9	9	Killeen	7	7	5
Lake Jackson	2	4	4	League City	3	3	--
Little Elm	3	3	--	Longview	8	8	--
Lufkin	10	9	9	Magnolia	1	--	--
Marshall	5	5	5	McKinney	1	--	1
Mesquite	4	4	1	North Richland Hills	7	7	7
Plano	16	14	14	Port Lavaca	5	--	--
Richardson	6	--	6	Richland Hills	3	3	1
Roanoke	2	2	2	Rowlett	4	4	4
South Lake	6	6	--	Sugar Land	8	8	1
Terrell	3	3	3	University Park	2	--	--
Willis	6	3	--	--	--	--	--
Total							
Communities	*50*	*42*	*41*	*Intersections*	*398*	*389*	*362*

Source: Texas Department of Transportation RLC Annual Data Reports (*4*)

Objectives & Scope

This report provides TxDOT with the results of an EB before-after study conducted to analyze the effectiveness that RLC systems have on reducing motor vehicle crashes at signal controlled intersections. Secondly, Texas Transportation Institute (TTI) researchers analyzed criteria for selecting intersections for RLC treatments. Intersections for RLC treatments are generally selected based upon high crash frequency, RLR violations, traffic volumes, and/or crash rates. However, it is not always true that these higher values correspond to greater number of RLR crashes (*5*). In addition, the researchers of this study could not find any research that documented the site selection criteria. In order to identify appropriate and effective criteria for site selection, a statistical analysis was performed to evaluate the effectiveness of RLC systems when site selection criteria are categorized by the RLR crash frequency (crashes per year), average daily traffic (ADT), and RLR crash rates (crashes per 10,000 vehicles per year).

Outline

This report is organized as follows:

Section I provides an evaluation of effectiveness of RLC systems on intersection safety using the EB methodology. The section presents a review of literature on the effectiveness of RLC systems and provides the methodology related to EB analysis. It also includes the data description and the procedure used for collecting the data. This section ends with providing the results on the evaluation.

Section II evaluates different site selection criteria for RLC system installation. This section includes the background, description of various criteria, and the analysis results.

Section III presents the comparison of results with different before-after study methods. A brief background about the before-after methods is provided followed by the comparative results. The last section documents the main findings of this research along with the recommendations and directions for future research.

SECTION I

EVALUATION OF EFFECTIVENESS OF RED-LIGHT RUNNING CAMERA SYSTEMS USING EMPIRICAL BAYESIAN METHOD

Purpose

The purpose of this section is to provide TxDOT with the evaluation of RLC systems using the EB before-after analysis. The EB method is considered to be superior to the other methods because it accounts for the regression-to-the-mean bias while evaluating the treatments.

Background

Ng et al. (*6*) reported results of their evaluation that was conducted at 42 camera-equipped and non-camera intersections in Singapore. The non-treated intersections used for comparison each had similar configuration to that of the treated intersections. The study results indicated a 7% reduction in all crash types and an 8% reduction in RA crashes after RLC systems were used. Winn (*7*) evaluated the effectiveness of RLC systems by considering six treatment sites and six non-treatment sites in Glasgow, Scotland. Crash data were collected three years before treatment and three years after treatment periods. The study findings indicated that there was a 62% reduction in injury crashes associated with active RLC treatments. In Texas, Walden (*8*) used a naïve before-after study to analyze the effectiveness of RLCs at 56 intersections, and concluded that there was a 30% decrease in all type crashes and a 43% decrease in RA crashes. RE RLR crashes were increased by 5%. Although all the above studies concluded that RLC systems are effective in reducing crash frequency, they did not consider the "spillover" effect and RTM bias in their analyses.

There are some studies that controlled the spillover effect and the RTM bias. Retting and Kyrychenko (*9*) analyzed the RLC systems by considering 29 months of before and after crash data from approximately 125 intersections (including 11 intersections with RLCs) in the City of Oxnard, California. For comparison, the researchers selected three similarly sized cities that did not implement RLCs. These comparison cities were located more than 100 miles from Oxnard to control the spillover effect (i.e. the change in driver's behavior at the intersections without RLC but are nearby the intersections with RLC systems). The study results indicated that all type and RA crashes at the signalized intersections within the treated city were significantly reduced by 7% and 32%. Though not significant, the study found that RE crashes increased by 3%. Similarly, Hu et al. (*10*) evaluated the city-wide effects of red-light camera enforcement on per capita fatal crash rates. Poisson regression analysis was used to model fatal crash rates among 14 cities with RLC systems and 48 cities without the system during the same period. The average annual rates of fatal RLR crashes were decreased by 35% for cities with treated intersections and 14% for cities without treatments. Crash reductions found in Retting and Kyrychenko (*9*) and Hu et al. (*10*) are not just due to RLC installations but also resulted from city-wide effects (*11*).

Walden et al. (*12*) evaluated RLC effectiveness with the CG method at 296 intersections in 39 communities in Texas, and concluded that all type and RA crashes decreased by 26% and 19%, respectively, while RE crashes increased by 44%. Washington and Shin (*11*) analyzed crashes at 10 intersections in Phoenix and 14 intersections in Scottsdale equipped with RLC systems. Based on the CG method and using Phoenix data, the researchers found that angle and left-turn (LT) crashes decreased by 42% and 10% but RE crashes increased by 51%. Using Scottsdale data and the EB method, the authors found that angle and LT crashes decreased by 20% and 45% at the treated intersections while RE crashes increased by 41%. The overall conclusions suggest that RLCs installation had a positive influence in reducing angle and LT crashes and a negative influence in reducing RE crashes.

Hallmark et al. (*13*) performed a Bayesian before and after analysis to evaluate the safety effect of RLC systems at four intersections in the City of Davenport, Iowa. The authors found that the total crashes per quarter decreased by 20% at RLC sites while an increase in crashes by almost 7% occurred at non-treated sites. Persaud et al. (*14*) evaluated the effects of RLC treatments occurred at 132 intersections in seven jurisdictions across the United States using the EB method. For individual jurisdictions, the study results suggested that RA crashes decreased from 14% to 40% at six jurisdictions and increased by less than 1% at one jurisdiction. The RE crashes increased from 7% to 38% at all jurisdictions. For all jurisdictions together, RA crashes were decreased by 25% and RE crashes were increased by 15%.

Methodology

As discussed earlier, the EB method is useful to adjust for the regression-to-the-mean bias. The key element in EB method is to predict what would have been the expected frequency of target crashes in the after period for each treated site, had the treatment not been applied. The EB method is advanced compared to other methods in that it predicts the expected number of target crashes of a site based on two pieces of information: (a) actual number of crashes at treated site during the before period, and (b) the information about the safety of reference sites with similar geometric characteristics. The expected crash frequency ($E[k|K]$) at a treated site is a result from the combination of the predicted crash count ($E[k]$) based on the reference sites with similar traits and the crash history (K) of that site. The expected crash frequency and its variance are shown in Eq. (1) and Eq. (2).

$$E[k|K] = w \cdot E[k] + (1 - w) \cdot K \tag{1}$$

$$V[k|K] = (1 - w) \cdot E[k|K] \tag{2}$$

where w is a weight between 0 and 1 and it is calculated as:

$$w = \frac{1}{1+\frac{V[k]}{E[k]}} \tag{3}$$

The parameter $E[k]$ is estimated from the safety performance functions (SPFs) developed using a negative binomial regression (also known as, Poisson-gamma) model under the assumption that the covariates in SPFs represent the main safety traits of the reference sites (*11*). The procedure for using the before-after study with the EB method is described below:

Step 1. Develop SPFs

Using crash, traffic, and geometric data from the reference sites, develop SPFs using the negative binomial regression models for all type, RA, and RE RLR crashes. The negative binomial regression model is the most common type of model used by transportation safety analysts for modeling traffic crashes. This model is preferred over other mixed-Poisson models since the gamma distribution is the conjugate of the Poisson distribution. The negative binomial regression model has the following model structure: the number of crashes 'Y_{it}' for a particular i^{th} site and time period t when conditional on its mean μ_{it} is Poisson distributed and independent over all sites and time periods.

$$Y_{it}|\mu_{it} \sim Po(\mu_{it}) \quad \text{i} = 1, 2, \ldots, i \text{ and t} = 1, 2, \ldots, t \tag{4}$$

The mean of the Poisson is structured as:

$$\mu_{it} = f(X;\beta)\exp(e_{it}) \tag{5}$$

where:

$f(.)$ is a function of the covariates (X);

β is a vector of unknown coefficients; and

e_{it} is the model error independent of all the covariates.

Although different functional forms were tried, the best fit functional forms used for each crash type in this study are as follows:

$$\boldsymbol{E[k]_{all\,type} = e^{\beta_0} \cdot \mathrm{N} \cdot \left(\frac{ADT_{min}}{ADT_{maj}+ADT_{min}}\right)^{\beta_1}} \tag{6}$$

$$E[k]_{RA} = e^{\beta_0} \cdot \mathrm{N} \cdot \left(\frac{ADT_{min}}{ADT_{maj}+ADT_{min}}\right)^{\beta_1} \tag{7}$$

$$E[k]_{RE} = e^{\beta_0} \cdot \mathrm{N} \cdot (ADT_{maj} + ADT_{min})^{\beta_1} \tag{8}$$

Where:

N is the number of years of crash data; and

β_i is a vector of unknown coefficients (to be estimated) (i = 0,1).

Step 2. Predict the expected number of crashes (π) and calculate the observed number of crashes (λ)

Based on Eq. (1), predict the expected number of crashes at particular i^{th} site with the equation as follows:

$$\hat{\pi}_i = E[\hat{k}_i|K_i] = \hat{w}_i \cdot E[\hat{k}_i] + (1 - \hat{w}_i) \cdot K_i \tag{9}$$

The $\hat{w}$ in Eq. (9) can be calculated as:

$$\hat{w}_i = \frac{1}{1+\alpha \cdot E[\hat{k}_i]} \tag{10}$$

Where α is the over-dispersion parameter of a negative binomial regression model. The expected number of after-period crashes and their variances for a group of sites had the treatment not been implemented at the treated sites is given as:

$$\hat{\pi} = \sum_{i=1}^{n} \hat{\pi}_i \tag{11}$$

n represents the total number of sites in the treatment group, and $\hat{\pi}$ is the expected after-period crashes at all treated sites had there been no treatment. This step is not required when the safety effect is assessed at each community level.

For a treated site, the crashes in the after-period are influenced by the implementation of the treatment. The safety effectiveness of a treatment is known by comparing the actual crashes with the treatment to the expected crashes without the treatment. The number of after-period crashes for a group of treated sites is given as:

$$\hat{\lambda} = \sum_{i=1}^{n} L_i \tag{12}$$

Where L_i is the crash frequency during the after period at site i. The estimate of λ is equal to the sum of the observed number of crashes at all treated sites during the after study period. This step is not required when the safety effect is assessed at each community level.

Step 3. Estimate $Var[\hat{\lambda}]$ and $Var[\hat{\pi}]$

Based on the assumption of a Poisson distribution, the estimate of variance of $\hat{\lambda}$ is assumed to be equal to L. The estimate of variance of $\hat{\pi}$ can be calculated from the equation as follows:

$$Var[\hat{\lambda}_i] = L_i \tag{13}$$

$$Var[\hat{\lambda}] = \sum_{i=1}^{n} Var[\hat{\lambda}_i] \tag{14}$$

$$Var[\hat{\pi}_i] = (1-\hat{w}_i)\cdot E\left[\hat{k}_i\middle|K_i\right] = (1-\hat{w}_i)\cdot\hat{\pi}_i \tag{15}$$

$$Var[\hat{\pi}] = \sum_{i=1}^{n} Var[\hat{\pi}_i] \tag{16}$$

Step 4. Estimate $\boldsymbol{\hat{\delta}}$ and $\boldsymbol{\hat{\theta}}$

The 'change in the safety (δ)' and 'index of effectiveness (θ)' are defined as the difference and the ratio of what safety is with the treatment to what it would have been without the treatment respectively. These parameters give the overall safety effect of the RLC treatment and are given by:

$$\boldsymbol{\hat{\delta} = \hat{\pi} - \hat{\lambda}} \tag{17}$$

$$\hat{\theta} = \frac{\left(\frac{\hat{\lambda}}{\hat{\pi}}\right)}{\left(1+\frac{Var(\hat{\pi})}{\hat{\pi}^2}\right)} \tag{18}$$

If $\hat{\delta}$ is greater than zero and $\hat{\theta}$ is less than one, then the treatment has a positive safety effect. In addition, the percent decrease in the number of target crashes due to the treatment is calculated as $100\left(1-\hat{\theta}\right)\%$.

Step 5. Estimate $\boldsymbol{Var[\hat{\delta}]}$ and $\boldsymbol{Var[\hat{\theta}]}$

The estimated variance and standard error of the estimated safety-effectiveness are given by:

$$Var\left[\hat{\delta}\right] = \hat{\pi} + \hat{\lambda} \tag{19}$$

$$Var\left[\hat{\theta}\right] = \frac{\hat{\theta}^2\cdot\left[\frac{Var(\hat{\lambda})}{\hat{\lambda}^2}+\frac{Var(\hat{\pi})}{\hat{\pi}^2}\right]}{\left[1+\frac{Var(\hat{\pi})}{\hat{\pi}^2}\right]} \tag{20}$$

$$s.e[\hat{\theta}] = \sqrt{Var[\hat{\theta}]} \tag{21}$$

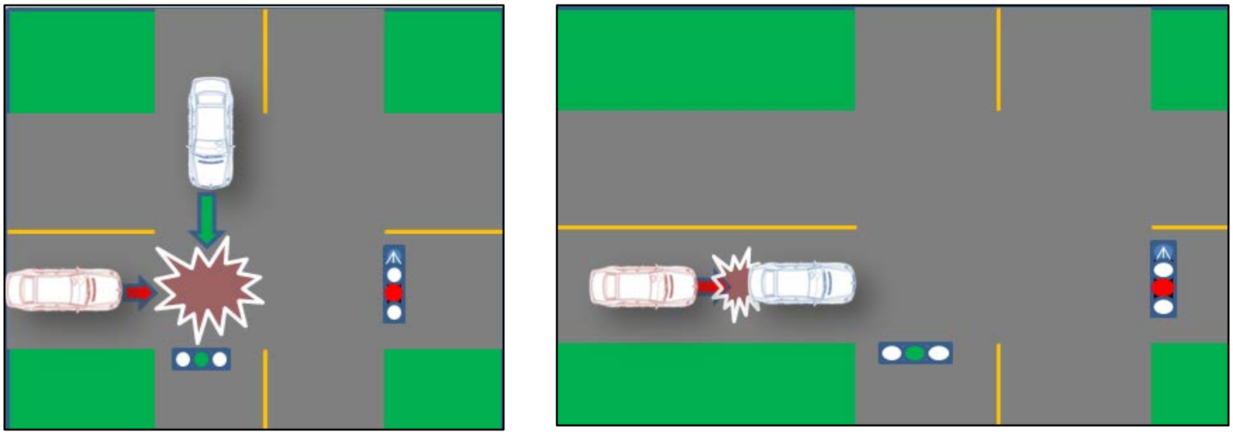
The 95% confidence interval for $\hat{\theta}$ is calculated as $\hat{\theta} \pm 1.96 s.e\left[\hat{\theta}\right]$. If the confidence interval contains the value one, then no significant effect has been observed at the 5% level.

Data Collection

Crash information originated from electronic copies of stored crash records maintained in the Texas Department of Transportation (TxDOT) Crash Records Information System (CRIS) database. Individual crash records were remotely accessed electronically by interfacing with CRIS and searching the database using crash identification numbers assigned to each crash record. From 32 communities in Texas, the researchers collected crash data at 245 intersections with RLC systems during the study period varying from one to four years for before (a total of

516 intersection years) and after camera installation (a total of 663 intersection years). More detailed information about the treatment intersections is provided in APPENDIX 1.

The target (RLR) crashes are defined as those types of crashes that are likely influenced by RLCs. RLR crashes should include those crash events taking place inside the intersection where one vehicle disregards the red signal, plus any intersection-related RE crash event occurring as a consequence of heavy braking in anticipation of a yellow signal turning to red while the units are traveling in the same approach direction (see Figure 1). Although some crashes occurred due to signal violations, they were not counted towards the target crashes when they occurred under the following conditions: 1) driving under the influence, 2) adverse weather condition, such as icing on roadways, 3) cut-in front of traffic from a side lane, or 4) related to emergency vehicles.



(a) Right-Angle (RA) Crash (b) Rear-End (RE) Crash

Figure 1 RA and RE Collision Type at an Intersection

Table 2 summarizes the number of treatment intersections in each community and provides the total frequency by all type, RA, and RE RLR crashes.

Table 2 RLR Crashes at RLC Intersections in 32 Communities

Community	No. of Intersections with RLCs	RLR Crashes (Before)			RLR Crashes (After)		
		All	RA	RE	All	RA	RE
Amarillo	5	37	37	0	22	21	1
Arlington	14	88	79	5	78	78	0
Austin	7	102	98	0	81	78	1
Austin	5	77	73	0	62	59	1
Baytown	6	50	47	1	29	27	0
Bedford	2	4	4	0	3	3	0
Burleson	5	39	28	8	30	17	11

Community	No. of Intersections with RLCs	RLR Crashes (Before)			RLR Crashes (After)		
		All	RA	RE	All	RA	RE
Cedar Hill	4	28	28	0	21	18	3
College Station	3	5	2	2	3	2	1
Coppell	2	10	9	0	9	6	2
Corpus Christi	12	35	28	5	52	29	21
Dallas	36	404	376	10	351	320	12
Diboll	2	2	1	1	15	2	12
Duncanville	4	44	42	2	17	17	0
El Paso	18	142	130	12	144	89	50
Farmers Branch	7	22	19	3	24	17	5
Fort Worth	14	62	60	1	38	35	2
Garland (Dallas)	3	16	16	0	15	14	1
Grand Prairie	7	22	21	1	19	14	5
Haltom City	2	15	15	0	13	11	2
Houston	46	1,097	1,083	9	1,123	1,075	34
Humble (Harris)	1	19	15	4	21	10	10
Irving	1	4	4	0	3	2	1
Jersey Village	4	73	55	18	50	34	16
Killeen	2	13	11	1	10	5	5
Lufkin	5	45	28	15	56	33	19
Mesquite	2	2	2	0	5	4	0
North Richland Hills	6	30	26	3	14	9	4
Plano	13	206	192	9	205	178	24
Richardson	3	39	35	4	43	29	12
Roanoke	2	8	7	0	10	8	2
Sugar Land	1	37	34	2	28	23	3
Terrell	1	4	4	0	3	1	2
Grand Total	245	2,781	2,609	116	2,597	2,268	262

The next step in the EB analysis is selecting a set of reference sites that are similar to treated sites but minus the RLC treatment. The reference sites were selected after a careful examination of the geometric characteristics of the treated sites. This is important because the reference groups being compared must be similar as possible to the before conditions of treated sites. The reference intersections were selected in such a way that they were located 2 miles away from the closest treatment intersection in order to minimize the spillover effect. An illustration regarding the selection of reference sites is given in Figure 2. Figure 2 represents the location of RLC treatment and reference intersections in Dallas, Texas. Since the results greatly depend on the accuracy of the safety performance function (SPF) for reference sites that matches the characteristics of the treated sites, it is important to select a reasonable number of reference sites.

It is considered desirable to have at least 25 sites for developing a reliable SPF. In this study, 66 reference intersections were selected and crash and traffic data at these intersections were collected for the period from 2007 to 2010. Detailed information about the reference intersections used in this study is provided in APPENDIX 2.

Figure 2 RLCs and Reference Intersections in Dallas, Texas

Table 3 provides the summary statistics of the variables collected at the intersections in the treatment and reference groups. The TxDOT state databases did not include all variables that describe road-related factors known to be associated with crash frequency. To overcome these limitations, the database was enhanced using data from other sources. Aerial photography was used as a source of enhanced data. The aerial photographs were obtained from Google Earth and the road-level photographs were obtained from its companion tool, Street View. Google Earth is software available from Google ©. A complete discussion of the data collection activities and procedures is provided in APPENDIX 3.

Table 3 shows that there were 2,781 and 2,597 reported all type RLR crashes during the before and after study periods. Of the crashes reported during the before study period, 2,609 were RA and 116 were RE RLR crashes. In the after study period, 2,268 were RA and 262 were RE RLR crashes. At the reference intersections, 432 all type, 229 RA and 106 RE RLR crashes were reported.

Table 3 Summary Statistics of Treatment and Reference Intersection Groups

Intersection Type	Variable			Min	Max	Mean	Std. dev	Sum
Treatment	RLR Crashes	Before	All Type	0	162	11	17	2,781
			RA	0	161	11	16	2,609
			RE	0	11	0.5	1.1	116
		After	All Type	0	187	10.6	18.2	2,597
			RA	0	185	9.3	17.8	2,268
			RE	0	13	1.1	2	262
			ADTmaj*	1,300	158,000	31,212	17,647	--
			ADTmin*	950	52,000	15,998	9,067	--
Reference	RLR Crashes		All Type	0	23	6.5	5.8	432
			RA	0	20	3.4	4.4	229
			RE	0	8	1.6	1.6	106
	Major		ADT	5,750	64,914	23,884	9,780	--
			One way[1]	0	1	0.02	--	--
			LT bay[2]	0	2	1.89	--	--
			RT bay[2]	0	2	0.77	--	--
			RT Channelization[2]	0	2	0.45	--	--
			Median Presence[2]	0	2	1.15	--	--
			Protected LT Signal[3]	0	1	0.30	--	--
			Yellow Interval (second)	4.0	4.7	4.06	--	--
			All Red (second)	1.0	2.6	1.67	--	--
		Thru Lane	Dir 1	0	3	2.26	--	--
			Dir 2	1	3	2.30	--	--
		Lane width (ft)	Dir 1	9	15	11.14	--	--
			Dir 2	9	16	11.14	--	--
		Speed Limit (mph)	Dir 1	30	55	39.85	--	--
			Dir 2	30	55	39.62	--	--
	Minor		ADT	2,080	29,885	15,629	7,901	--
			One way[1]	0	1	0.02	--	--
			LT bay[2]	0	2	1.89	--	--
			RT bay[2]	0	2	0.86	--	--
			RT Channelization[2]	0	2	0.59	--	--

Intersection Type	Variable		Min	Max	Mean	Std. dev	Sum
	Median Presence[2]		0	2	1.29	--	--
	Protected LT Signal[3]		0	1	0.33	--	--
	Yellow Interval (second)		3.0	5	4.01	--	--
	All Red (second)		1.0	2.6	1.71	--	--
	Thru Lane	Dir 1	0	4	2.29	--	--
		Dir 2	1	3	2.33	--	--
	Lane width (ft)	Dir 1	9	13	11.24	--	--
		Dir 2	10	20	11.33	--	--
	Speed Limit (mph)	Dir 1	30	50	37.88	--	--
		Dir 2	20	50	37.73	--	--

NOTE: * ADT$_{\text{maj}}$ and ADT$_{\text{min}}$ are the ADT for major and minor roadways at intersections; [1] 0 = two ways, 1 = one way; [2] 0 = no bay, lane, or median, 1 = bay, lane(s), or median in one direction only, 2 = bay, lane(s), or median in both directions; [3] 1 = protected-only left-turn operation, 0 = permissive or protected-permissive.

Safety Evaluation Results

This section of the report provides the consumer with the evaluation results of RLCs effectiveness at the intersections using the EB method. Table 4 summarizes the estimation results for all type, RA, and RE RLR crashes. The coefficients summarized in Table 4 were combined with Eqs (6) to (8) to obtain the crash mean for each crash type. The variables that have an absolute t-statistic value greater than 2.0 were only included in the final model. The t-statistics indicate a test of the hypothesis that the coefficient value is equal to 0.0. Those t-statistics with an absolute value that is larger than 2.0 indicate that the hypothesis can be rejected with the probability of error in this conclusion being less than 0.05. In general, the trend of each variable is logical and intuitive. Particularly, the estimation results suggest that with the increase in total traffic flow, the RE crashes increase at the intersection. At the same time, as the proportion of minor approach volume increases, all type and RA RLR crashes increase.

Table 4 Estimates SPFs for Reference Intersections

Variable	All Type RLR Crashes	RA RLR Crashes	RE RLR Crashes
Constant (β_0)	1.4256 (0.379)	1.5697 (0.638)	-11.3326 (3.387)
$AADT_{maj} + AADT_{\min}$ (β_1)	--	--	0.9848 (0.319)
$\frac{AADT_{\min}}{AADT_{maj} + AADT_{\min}}$ (β_1)	0.978 (0.371)	1.8295 (0.645)	--
Dispersion parameter (α)	0.7274 (0.171)	1.3907 (0.343)	0.3844 (0.213)
Log-likelihood	-191.4	-150.8	-108.9
AIC	388.8	307.6	223.9
BIC	395.3	314.1	230.5

NOTE: the values in parentheses represent standard errors.

Table 5 summarizes the change in the safety (δ) due to the installation of RLCs by community and crash type. If δ is greater than one, it implies that the treatment is effective for crash reduction at a community. Out of 32 communities, δ is greater than one at 18 communities for all type RLR crashes and at 20 communities for RA RLR crashes. For RE RLR crash type, only five communities have δ greater than one. Table 5 also summarizes the index of effectiveness by community and crash type. Twenty-eight communities show reductions in all type and RA RLR crashes after RLC installation. For RE RLR crashes, 18 communities show crash reduction at the treatment intersections.

Table 5 Safety Effects by Community

Community	$\hat{\delta}$			$\hat{\theta}$		
	All	RA	RE	All	RA	RE
Amarillo	5.1 (5.20)	4.9 (5.08)	0.4 (1.19)	0.65 (0.23)	0.64 (0.23)	0.38 (0.43)
Arlington	10.2 (8.75)	5.2 (8.45)	3.9 (1.96)	0.74 (0.16)	0.84 (0.19)	0.02 (0.05)
Austin	12.8 (13.2)	11 (12.9)	0.3 (1.52)	0.85 (0.12)	0.86 (0.12)	0.54 (0.46)
Baytown	7.3 (6.02)	6.2 (5.76)	1.6 (1.26)	0.63 (0.20)	0.65 (0.21)	0.04 (0.11)
Bedford	0.9 (1.97)	0.5 (1.85)	0.6 (0.79)	0.47 (0.36)	0.55 (0.41)	0.10 (0.26)
Burleson	0.4 (5.51)	0.8 (4.21)	-1.8 (3.03)	0.92 (0.29)	0.85 (0.34)	1.28 (0.64)
Cedar Hill	3.5 (4.17)	3.5 (3.93)	-0.2 (1.33)	0.62 (0.26)	0.58 (0.26)	0.91 (0.77)
College Station	1.9 (2.81)	0.1 (2.02)	0.9 (1.70)	0.52 (0.31)	0.69 (0.47)	0.42 (0.38)
Coppell	1.3 (2.70)	1.4 (2.31)	-0.1 (1.10)	0.60 (0.36)	0.49 (0.34)	0.88 (0.87)
Corpus Christi	1.1 (6.30)	3.5 (5.17)	-3.4 (3.25)	0.90 (0.27)	0.72 (0.26)	1.68 (0.80)
Dallas	33.7 (19.1)	33.9 (18.3)	1 (3.51)	0.82 (0.08)	0.81 (0.08)	0.75 (0.36)
Diboll	-4.1 (2.42)	-0.5 (0.91)	-3.4 (2.14)	4.07 (2.26)	2.14 (1.79)	4.86 (2.78)
Duncanville	9.2 (4.20)	8.2 (4.08)	1.1 (1.06)	0.29 (0.15)	0.31 (0.16)	0.06 (0.16)
El Paso	-0.4 (10.1)	14.7 (8.90)	-12. (4.75)	0.98 (0.18)	0.67 (0.14)	2.95 (1.17)
Farmers Branch	1.4 (4.00)	1.8 (3.54)	0.4 (1.80)	0.76 (0.33)	0.67 (0.33)	0.59 (0.46)
Fort Worth	12.6 (7.65)	12.7 (7.46)	0.8 (1.68)	0.62 (0.16)	0.61 (0.16)	0.41 (0.35)
Garland	-0.2 (4.04)	-0.5 (3.93)	0.8 (1.12)	0.93 (0.39)	0.97 (0.42)	0.17 (0.26)
Grand Prairie	2.5 (4.37)	3.4 (4.00)	-0.3 (1.92)	0.71 (0.29)	0.6 (0.27)	0.88 (0.60)
Haltom City	-1.1 (3.44)	-1.3 (3.11)	-0.5 (1.24)	1.08 (0.50)	1.16 (0.57)	1.32 (1.13)
Houston	101. (26.9)	109. (26.6)	-4.5 (3.89)	0.75 (0.05)	0.73 (0.05)	1.56 (0.69)
Humble	-0.5 (3.67)	1.9 (2.93)	-2.6 (2.01)	0.98 (0.43)	0.56 (0.32)	3.74 (2.21)
Irving	0.6 (1.61)	0.4 (1.33)	0.1 (0.86)	0.48 (0.42)	0.44 (0.43)	0.57 (0.76)
Jersey Village	4.4 (7.37)	5 (6.24)	-3 (3.60)	0.82 (0.21)	0.74 (0.22)	1.47 (0.62)
Killeen	-0.1 (3.14)	0.9 (2.42)	-0.8 (2.04)	0.90 (0.45)	0.63 (0.40)	1.12 (0.72)
Lufkin	-0.4 (6.08)	-0.2 (4.67)	-1.9 (3.28)	0.97 (0.29)	0.95 (0.35)	1.29 (0.59)
Mesquite	-1.4 (1.88)	-1.6 (1.55)	0.5 (0.68)	1.64 (1.04)	2.99 (1.97)	0.14 (0.35)
North Richland Hills	8.8 (4.29)	6.8 (3.62)	1.2 (1.96)	0.33 (0.16)	0.29 (0.17)	0.43 (0.34)
Plano	21.4 (11.8)	23.1 (11.1)	-2.9 (3.50)	0.72 (0.12)	0.67 (0.12)	1.40 (0.64)
Richardson	0.7 (4.71)	2.8 (4.15)	-1.3 (2.17)	0.87 (0.33)	0.66 (0.28)	1.38 (0.84)
Roanoke	-1.8 (2.86)	-2.2 (2.40)	-0.5 (1.21)	1.32 (0.68)	1.79 (1.01)	1.53 (1.30)
Sugar Land	1.2 (4.45)	1.4 (4.08)	-0.1 (1.36)	0.84 (0.31)	0.80 (0.32)	0.91 (0.81)
Terrell	0.1 (1.77)	0.7 (1.29)	-0.4 (1.24)	0.70 (0.53)	0.30 (0.34)	1.31 (1.11)

NOTE: the values in parentheses represent standard errors.

Table 6 presents the average safety effect of the RLC enforcement systems at 32 communities in Texas. This table shows that there are about 933 crashes reported annually during the after study period. The analysis results suggest that if the treatment had not been installed, the expected number of the crashes per year would have been 1,166 crashes annually during the after study period. Thus, there is a positive safety effect and one can expect to see about 233 less crashes per year with the implementation of RLC systems. The average safety effect of the systems is estimated to be a decrease in all type RLR crashes by 20%. The standard deviation of this estimate of average safety effect is 3%. At a 95% confidence interval, this result is statistically significant and one may expect a decrease in the crashes from 13% to 27%.

Table 6 also shows that, for RA RLR crashes, about 812 crashes were reported annually, and one would expect 1,070 crashes had the treatment not been installed. Thus, a reduction of about 258 crashes per year is expected with the treatment. The average safety effect of the red light camera enforcement on RA crashes shows that, at the 5% level, there is a significant decrease in RA crashes by 24%.

Contrary to all type and RA crashes, an increase in RE crashes after the implementation of RLCs is observed. Overall, there were about 95 RE crashes reported annually, and one would expect about 68 crashes had there been no treatment. Thus, 26 more RE crashes occurred annually at the treatment intersections since RLC installation. The average safety effect of RLCs systems on RE crashes is estimated to be an increase in crashes by 37%. This result is significant at 95% confidence level. Even though there is a significant increase in RLR RE crashes, the frequency and severity of these crash events are much rarer that other crash types at signal controlled intersections. When comparing safety benefits readers should recognize the in its proper context.

Table 6 Average Safety Effects of All Treatment Intersections

	$\hat{\lambda}$	$\hat{\pi}$	$\hat{\delta}$	$\sigma[\hat{\delta}]$	$\hat{\theta}$	$\sigma[\hat{\theta}]$
All RLR Crashes	932.8	1165.642	232.8	44.82	0.8	0.03
RA RLR Crashes	812.4	1069.993	257.6	42.46	0.76	0.03
RE RLR Crashes	94.8	68.39224	-26.4	11.62	1.37	0.19

SECTION II

EVALUATION OF SITE SELECTION CRITERIA OF RED-LIGHT RUNNING CAMERA SYSTEMS

Purpose

The purpose of this section is to provide TxDOT with the evaluation of criteria for selecting sites for RLC treatment. This section provides information about the safety effectiveness of RLC treatment when the intersections are selected based on different criteria.

Background

According to Chapter 707 of the Texas Transportation Code, local jurisdictions have the authority to install RLC systems at their intersections. From the past few years, RLC systems have been installed and operated by local jurisdictions in Texas. In 2011, RLC systems were operated at 398 intersections in 50 communities. Recently, published Highway Safety Manual (HSM) and other studies have documented consistent results concerning the effectiveness of RLC systems on intersection safety (*8*, *9*, *11*, *12*, *14*). The majority conclude that the RLC systems reduced most all crash types especially right-angle crashes related to red-light violations. However, the same majority of studies indicate increases in RE crashes.

Washington and Shin (*11*) recommended that treatment intersections be selected based on high crash or RLR crash history and represented by city-wide coverage. Hallmark et al. (*15*) stated that the treatment intersections be selected based on crash rates, intersection configuration and where no future intersection improvements were planned. However, none of the studies mentioned about the exact number of crashes where RLCs are warranted.

For the installation of RLC systems, intersections are generally selected based on the high crash frequency, red light running violations, traffic volumes, or crash rates. However, it is not always true that the selection of treatment sites based on higher values will improve intersection safety. Improper selection of sites may often lead to increased number of crashes.

Methodology

TTI researchers evaluated the safety effect evaluations at the intersection groups categorized by the following criteria for site selection: 1) RLR crash frequency, 2) ADTs from all approaches, and 3) crash rates (RLR crashes per 10,000 vehicles per year). Categorization was based upon data collected during the before study period. These evaluations provided the information on the criteria needed for site selection for RLC installation.

For criterion based on RLR crash frequency, 245 intersections with RLC systems were divided into three groups; 1) less than two crashes per year; 2) greater than or equal to two and less than four crashes per year; and 3) greater than or equal to four crashes per year. Relating to the criterion based on average ADT from all approaches, the intersections were divided into: 1) less than 15,000 vehicles per day; 2) greater than or equal to 15,000 and less than 25,000 vehicles per day; and 3) greater than 25,000 vehicles per day. For the last criterion based on RLR crash rates, the intersections were grouped into 1) less than one crash per 10,000 vehicles per year, 2) greater than or equal to one and less than two crashes per 10,000 vehicles per year, and 3) greater than two crashes per 10,000 vehicles per year. Table 7 shows the three site selection criteria and the total number of intersections in each group.

Table 7 Number of Intersections Categorized by Different Site Selection Criteria

Criteria		Value		
RLR Crash Frequency (Crashes/year)	Category	**< 2**	**2-4**[1]	**≥ 4**
	No. of Intersections	70	61	114
Average ADT (Vehicles/day)	Category	**< 15,000**	**15,000-25,000**	**≥ 25,000**
	No. of Intersections	56	89	100
RLR Crash Rate (Crashes/10,000 vehicles/year)	Category	**<1**	**1-2**	**≥ 2**
	No. of Intersections	95	72	78

NOTE:[1] Range is listed as x-y with x being inclusive and y being exclusive.

Site Selection Criteria Analysis Results

Results suggest that if intersections experience less than two crashes per year in the before period and they are selected for the treatment, then there will be an expected increase of 49% in all crash types and a 28% increase in RA RLR crashes by installing RLC enforcement systems. In other words, if intersections experiencing less than two crashes are selected and treated, then a counter-productive result may be observed. If the intersections has greater than or equal to two but less than four crashes per year, one can expect a decrease in all crash types by 18% and RA crashes by 29%, respectively. If the intersection has four or more crashes per year, then all crash types decrease by 23% and RA crashes decrease by 29%. In terms of the change in safety benefit (δ), there were reductions of about 205 all type and 260 RA RLR crashes at 114 intersections. Thus, if the intersections with four or more RLR crashes are selected for treatment then there is a reduction of about two crashes per intersection.

The average traffic volume (average of ADT_{maj} and ADT_{min}) at an intersection during the before study period was also evaluated as a selection criterion. In the first group, intersections less than 15,000 vehicles per day, there was a significant decrease in all crash types by 29% and RA RLR crashes decreased by 27% after the intersections were treated with RLC systems. The second group of intersections showed that all type crashes decreased by 7% and RA crashes decreased by 11%. These included intersections with greater than or equal to 15,000 and less than 25,000 vehicles per day. The third group (25,000 vehicles or greater), showed significant decreases in all crash types by 18% and RA crash reductions at 22%. There appeared to be no trends in the safety effectiveness of RLC systems with the change in ADT even though a clear safety benefit was always present.

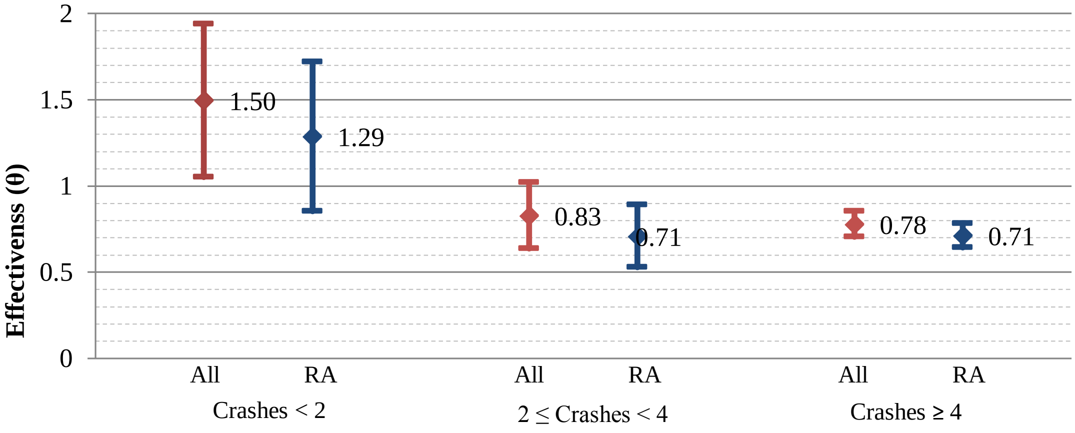
The final criterion considered for site selection was RLR crash rate (i.e. number of RLR crashes per 10,000 vehicles per year). If intersections with crash rate less than one were selected for RLC installation, then all type crashes and RA crashes increased by 13% and 11% respectively. When the intersections having crash rate greater than or equal to one but less than two were selected, all type crashes and RA crashes decreased by 22% and 14% respectively. The third group of intersections with crash rates greater than or equal to two, showed that both all type crashes and RA crashes significantly decreased by 29% and 27%, respectively. This reduction is approximately equal to a decrease of three all type crashes and two RA crashes per intersection after the treatment. Table 8 summarizes the safety effectiveness by different site selection criteria.

Table 8 Safety Effects by Site Selection Criteria

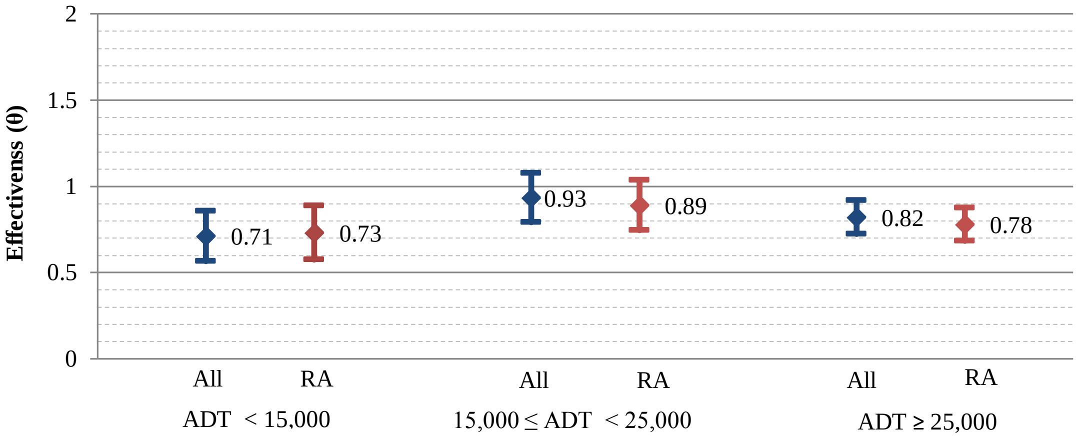
Criteria	Variable		Value		
RLR Crashes (Crashes/year)	All	Category	**< 2**	**2-4**	**≥ 4**
		θ	1.49 (0.22)*	0.82 (0.09)	0.77 (0.03)*
		δ	-32	23	205
		Changes per Int.[1]	-0.5	0.4	1.8
	RA	θ	1.28 (0.22)	0.71 (0.09)*	0.71 (0.03)*
		δ	-17	37	260
		Changes per Int.[1]	-0.2	0.6	2.3
Traffic Volume (Vehicles/day)		Category	**< 15,000**	**15,000-25,000**	**≥ 25,000**
	All	θ	0.71 (0.07)*	0.93 (0.07)	0.82 (0.04)*
		δ	58	20	105
		Changes per Int.[1]	1.0	0.2	1.0
	RA	θ	0.73 (0.07)*	0.89 (0.07)	0.78 (0.04)*
		δ	48	30	119
		Changes per Int.[1]	0.9	0.3	1.2
RLR Crash Rate (Crashes/year/ 10,000 vehicles)		Category	**<1**	**1-2**	**≥ 2**
	All	θ	1.13 (0.14)	0.78 (0.07)*	0.71 (0.03)*
		δ	-16	48	245
		Changes per Int.[1]	-0.2	0.7	3.1
	RA	θ	1.11 (0.14)	0.86 (0.08)	0.73 (0.04)*
		δ	-12	28	186
		Changes per Int.[1]	-0.1	0.4	2.4

NOTE:[1] change in the number of crashes per intersection- negative values represent increase in crashes after the treatment; the values in parentheses represent standard errors; * significant at 5% level.

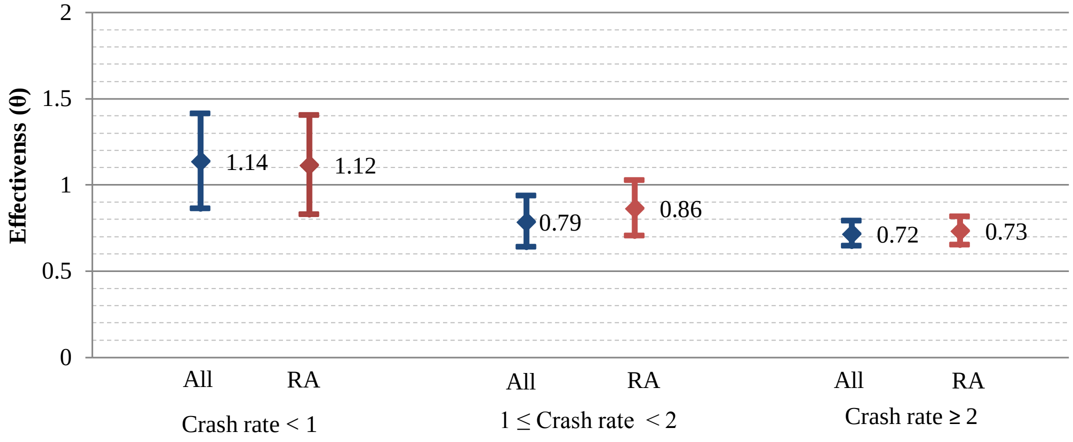
Figure 3 shows the effectiveness indices ($\hat{\theta}$) and their 95% confidence intervals based on different site selection criteria. If $\hat{\theta}$ is less than one and its interval does not include one, then the treatment has a significant positive effect on intersection safety. If $\hat{\theta}$ is greater than one and its interval does not include one, a significant negative effect is experienced with the RLC treatment. Regardless of $\hat{\theta}$ value, if an interval includes one, then the result is not significant at a 5% level. Figure 3 shows that if crash frequency and crash rate were used as site selection criteria, then with the increase in crash frequency or rate, the value of $\hat{\theta}$ decreases. It is also interesting to note that the interval becomes narrower as the crashes or crash rate increase. However, when traffic volume is used as a site selection criterion, there is no specific trend observed in the effectiveness index ($\hat{\theta}$) with the change in traffic volume.



(a) Number of RLR Crashes



(b) ADT



(c) RLR Crash Rate

Figure 3 95% CI for Index of effectiveness by different site selection criteria

SECTION III

COMPARISON OF RESULTS FROM DIFFERENT BEFORE-AFTER STUDY METHODS

Purpose

The purpose of this section is to provide TxDOT with the comparison of the results of RLC systems evaluated by different before-after study methods.

Background

In the before-after studies, the safety effectiveness of a treatment is determined by the difference in the expected number of crashes occurring before the treatment and the actual number of crashes occurring after the treatment. Since there are many factors other than a treatment affecting safety, different methods are proposed depending on how they account for these factors in the analysis. The three types of before-after study methods that are generally used include: simple (or naïve) before-after study, comparison group method, and the empirical Bayes (EB) method.

The simple before-after study assumes that the number of crashes that occurred before improvement is a good estimate of what would have occurred during the after period without improvement. In reality, however, since many things can change from the before to after period, it cannot distinguish between the effect of the treatment and the effect of other external causal factors. It also suffers from other important problems such as regression-to-the-mean, crash migration, and maturation. Because of these factors, the results from this simple approach are often biased and tend to overestimate the true effectiveness of a countermeasure.

The comparison group method uses a group of comparison sites selected as being similar enough to the treated sites in traffic volume and geographic characteristics. Two assumptions underlying this approach are that the factors that affected safety have changed in the same way from before the improvement to after the improvement for both the treatment and the comparison groups, and that the changes in the various factors influence the safety of the treatment and the comparison groups in the same manner. The results from this approach are considered more accurate and reliable than a simple before-after study because it can account for the external causal factors and maturation problems. This method is still subject to the regression-to-the-mean bias because it predicts the expected number of target crashes of a site based on the before-period crash number only.

The EB method is useful to adjust for the regression-to-the-mean bias. The key element in EB method is to predict what would have been the expected frequency of target crashes in the after period for each treated site, had the treatment not been applied. The EB method is more advanced than other methods because it predicts the expected number of target crashes of a site based on two pieces of information: (a) actual number of crashes at treated site during the before period, and (b) the information about the safety of reference sites with similar geometric characteristics.

Comparison Results

Walden (*8*) conducted the evaluations of RLC systems in Texas using a naïve before-after study method. In a subsequent study, Walden et al. (*12*) used the comparison group method to evaluate the safety benefit of RLC systems in Texas. This study evaluated the safety effectiveness of RLC systems using the EB before-after study method. Figure 4 shows the comparison results of the naïve, CG and EB methods.

In general, irrespective of the method used, all type and RA crashes related to RLR violations were significantly decreased after the RLC installation, while installation resulted in an increase in RE crashes. For all type RLR crashes, naïve, CG and EB method showed a decrease of 30%, 26%, and 20% respectively after RLC systems installation. For RA RLR crashes, depending on the analysis method, a decrease of about 19% to 43% is observed. All three methods supported the belief that the RLC systems will have a negative safety influence on RE RLR crashes. Naïve, CG and EB method showed an increase in RE crashes of 5%, 44%, and 37% respectively after RLC systems installation.

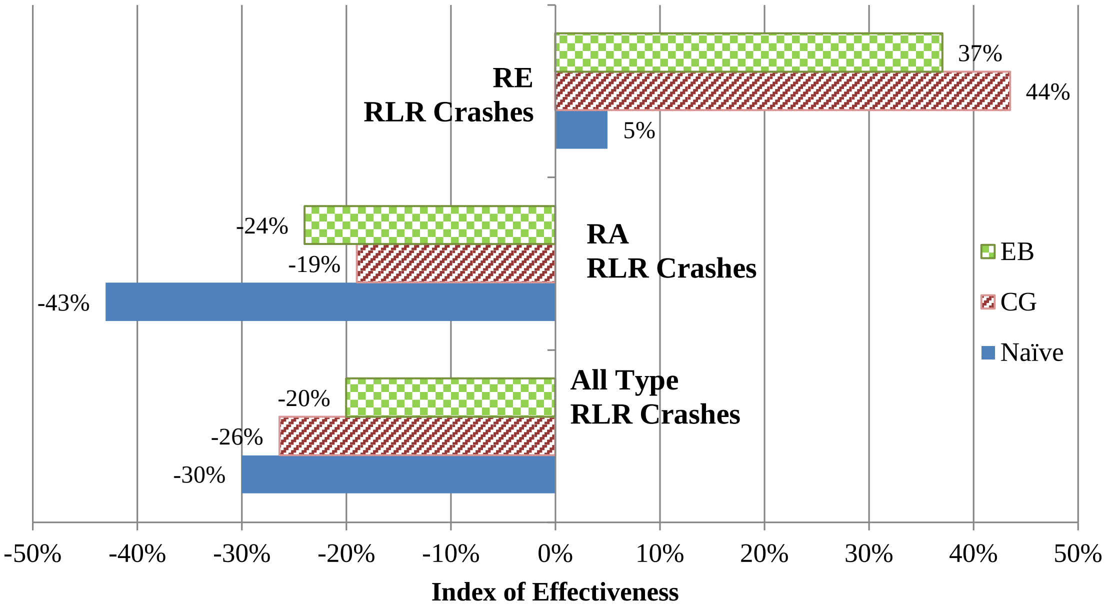


Figure 4 Effectiveness of RLC Systems by Analysis Methods and Crash types
(Source: Walden (*8*) for the naïve method and Walden et al. (*12*) for the CG method)

CONCLUSIONS & RECOMMENDATIONS

This study evaluated the safety effectiveness of RLC systems using the data collected at 245 intersections in 32 communities in Texas. Using the naïve before-after method, Walden (*8*) concluded that the RLC systems have a positive impact on intersection safety. Recently, Walden et al. (*12*) evaluated safety effectiveness of RLC systems using a before-after study with a comparison group method and indicated a significant decrease in all type RLR crashes by 26.4%. However, the results in both studies are subject to possible RTM bias because these two methods predict the expected number of target crashes of a site based on the before-period crash frequency only. This study made use of the EB method to control for the RTM bias and concluded that the RLC treatment played a positive role in reducing all type and RA RLR crashes at the signalized intersections and a negative impact on RE RLR crashes. Results of this study indicated significant decrease in all type and RA RLR crashes by 20% and 24%, respectively, while a significant increase in RE RLR crashes by 37%. Although the EB method provides precise estimates, this method cannot be easily applied to all RLC research due to the requirement of needing large amount of data.

The results of this study were consistent with the previous studies. Interestingly, the Highway Safety Manual (HSM) (*16*) has a Crash Modification Factor (CMF) for RLC installation of 0.74 for RA crashes and a CMF of 1.18 for RE crashes. This basically means that RLCs would typically be expected to reduce RA crashes by 26% and increase RE crashes by 18%. Finding in the CG and EB results are consistent with the estimated safety benefits for RLC as indicated in the HSM. This paper also provided evaluation related to site selection criteria for the implementation of RLC systems, since there are no specific guidelines on when the implementation of RLC systems is warranted. Results suggest that RLC systems have a significant and positive impact when the intersections with greater than or equal to four crashes per year or a crash rate of two (crashes per 10,000 vehicles per year) are selected for the treatment. It is expected that each treated intersection will have a reduction of about two or more RLR crashes per year after the RLC installation. If the intersections with less than two RLR crashes per year or a crash rate of less than one are selected then a negative safety impact should be expected after the treatment.

This study also considered ADT as one of the site selection criteria. The study results showed that there is no specific trend in safety with the change in traffic volume. Thus, it is recommended not to solely consider ADT as the only site selection criteria. According to the research by Walden et al. (*12*), more RLR violations occurred during morning and afternoon peak hours (8-10 AM and 4-6 PM) when RLCs were not installed. With RLCs, more violations occurred between 12 to 3 PM. Additional research is needed to determine if traffic violations can be used as one of the sources for site selection criteria.

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APPENDIX 1

Crash and Traffic Data Collected at Treatment Intersections

City	Intersection		ADT		Period(year)		RLR Crashes (Before)			RLR Crashes (After)		
	Major	Minor	Major	Minor	Before	After	All	RA	RE	All	RA	RE
Amarillo	Coulter	Elmhurst	31,448	2,000	2	2	1	1	0	0	0	0
Amarillo	Coulter	IH 40	28,194	18,235	2	2	2	2	0	3	3	0
Amarillo	Ross	IH 40 SR	16,995	13,735	2	2	1	1	0	3	2	1
Amarillo	US 60	SE 11th	11,318	1,144	2	2	15	15	0	12	12	0
Amarillo	US 60	SE 3rd	11,322	6,912	2	2	18	18	0	4	4	0
Arlington	FM 157	Spur 303	53,964	31,413	2	2	12	10	2	21	21	0
Arlington	Little Rd	W Poly Webb Rd	18,838	5,544	2	2	5	5	0	1	1	0
Arlington	Matlock Rd	Arbrook Blvd	45,311	20,942	2	2	4	4	0	3	3	0
Arlington	S Cooper St	SE Green Oaks Blvd	40,531	17,139	2	2	12	11	0	7	7	0
Arlington	Spur 303	S Collins St	34,772	25,822	2	2	9	8	0	3	3	0
Arlington	Collins	E Sublett	20,835	17,864	2	3	1	1	0	4	4	0
Arlington	Cooper	W Rd to Six Flags	36,982	13,535	2	2	0	0	0	1	1	0
Arlington	FM 157	Spur 303	50,172	30,491	2	3	12	10	2	21	21	0
Arlington	FM 157	SW Green Oaks	39,512	17,329	2	3	12	11	0	7	7	0
Arlington	FM 157	W Park Row	51,521	14,972	2	2	3	3	0	1	1	0
Arlington	Matlock	Arbrook	42,749	18,582	2	3	4	4	0	3	3	0
Arlington	Spur 303	S Collins	32,930	25,945	2	2	9	8	0	3	3	0
Arlington	Tx 180	Collins	28,181	19,234	2	2	3	2	1	0	0	0
Arlington	Tx 180	Cooper	36,982	15,423	1	2	2	2	0	3	3	0
Austin	IH 35	11th St	23,728	23,862	2	2	30	29	0	27	25	0
Austin	IH 35	15th St	29,092	14,288	2	2	9	8	0	15	15	0

City	Intersection		ADT		Period(year)		RLR Crashes (Before)			RLR Crashes (After)		
	Major	Minor	Major	Minor	Before	After	All	RA	RE	All	RA	RE
Austin	IH 35	MLK, Jr.	30,056	12,543	1	1	6	6	0	6	6	0
Austin	Loop 1	Howard Ln	20,380	7,351	1	2	6	5	0	1	1	0
Austin	S Pleasant Valley	E Riverside	19,598	17,248	2	2	18	17	0	15	15	0
Austin	SL 360	SL 343	21,500	15,225	1	1	19	19	0	13	13	0
Austin	US 290	Loop 1	21,662	7,674	2	2	14	14	0	4	3	1
Austin	IH 35 North Frontage	E 11th ST	11,931	11,863	2	2	30	29	0	27	25	0
Austin	IH 35 South Frontage	E 15th ST	29,092	14,288	2	2	9	8	0	15	15	0
Austin	Loop 1 NB	Howard Ln	20,380	7,351	2	1	6	5	0	1	1	0
Austin	S. Pleasant Valley Rd.	E. Riverside Dr	19,598	17,248	2	2	18	17	0	15	15	0
Austin	US 290 EB SFR	Loop 1 SB WFR	21,662	7,674	2	2	14	14	0	4	3	1
Baytown	BS 146	SH 146	56,130	34,800	2	2	10	10	0	7	7	0
Baytown	BS 146	Wyoming	1,300	950	2	2	11	11	0	5	5	0
Baytown	Garth	IH 10	72,070	13,312	2	2	18	16	1	7	6	0
Baytown	Garth	SH 146	24,550	13,431	2	2	5	5	0	3	3	0
Baytown	W Baker	Garth	15,686	8,914	3	2	4	3	0	7	6	0
Baytown	W Baker	Spur 330	28,180	4,111	2	2	2	2	0	0	0	0
Bedford	Harwood	Brown	32,407	20,972	2	2	0	0	0	2	2	0
Bedford	SH 183	Bedford	16,451	11,904	2	2	4	4	0	1	1	0
Burleson	SH 174	Elk	56,050	4,610	2	2	6	4	1	3	0	3
Burleson	SH 174	FM 731	49,680	21,340	2	2	13	5	6	9	5	3
Burleson	SH 174	Gardens	56,930	12,740	2	2	1	0	1	4	1	3
Burleson	SH 174	Newton	55,010	6,280	2	2	7	7	0	1	0	1
Burleson	SH 174	Spur 50	52,810	17,060	2	2	12	12	0	13	11	1
Cedar Hill	E Belt Line	Clark	16,270	12,350	3	3	9	9	0	5	4	1
Cedar Hill	E Belt Line	Hwy 67	28,000	6,800	2	3	14	14	0	11	11	0

City	Intersection		ADT		Period(year)		RLR Crashes (Before)			RLR Crashes (After)		
	Major	Minor	Major	Minor	Before	After	All	RA	RE	All	RA	RE
Cedar Hill	E Belt Line	Joe Wilson	20,000	8,070	2	3	5	5	0	4	3	1
Cedar Hill	E Belt Line	Waterford Oaks	18,290	1,470	2	3	0	0	0	1	0	1
College Station	Sh 6 BS	FM 2347	48,000	31,000	1	1	2	1	0	2	1	1
College Station	Sh 6 BS	FM 2818	25,000	24,000	1	1	2	0	2	1	1	0
College Station	Sh 6 BS	Holleman	44,000	12,240	1	1	1	1	0	0	0	0
Coppell	Beltine	MacArthur	27,462	11,601	2	3	6	5	0	7	5	1
Coppell	Denton Tap	Sandy Lake	17,777	10,591	2	3	4	4	0	2	1	1
Corpus Christi	Ayers	Baldwin	21,572	10,204	2	3	3	3	0	2	2	0
Corpus Christi	Ayers	Gollihar	29,920	11,512	2	3	3	3	0	5	4	1
Corpus Christi	Baldwin	Greenwood	14,998	9,403	1	1	1	1	0	3	3	0
Corpus Christi	Everhart	Holly	21,789	18,033	2	3	4	4	0	6	4	0
Corpus Christi	Greenwood	Gollihar	9,403	7,972	2	3	0	0	0	0	0	0
Corpus Christi	Holly	Weber	24,360	16,904	2	3	7	4	2	14	6	8
Corpus Christi	McArdle	Airline	23,698	12,862	2	3	2	2	0	8	3	5
Corpus Christi	Ocean	Airline	9,489	7,045	1	1	2	0	2	0	0	0
Corpus Christi	Ocean	Doddridge	14,617	8,442	2	3	9	9	0	4	3	1
Corpus Christi	Staples	Kostoryz	22,164	12,909	1	1	2	1	0	0	0	0
Corpus Christi	Staples	Williams	24,577	8,761	2	3	1	0	1	9	3	6
Corpus Christi	Yorktown	Cimarron	10,659	8,926	1	3	1	1	0	1	1	0
Dallas	Abrams	Forest	36,776	23,167	1	3	3	3	0	11	11	0
Dallas	Alpha	Dallas Pkwy	23,728	21,626	2	3	33	33	0	20	19	0
Dallas	Banner	Coit	54,373	7,102	2	3	5	5	0	2	2	0
Dallas	Beckley	Colorado	25,847	16,947	2	3	6	6	0	3	3	0
Dallas	Bruton	2nd	15,258	15,228	2	3	8	8	0	7	6	0
Dallas	Bruton	Loop 12	35,982	24,170	2	3	18	18	0	7	6	0

City	Intersection		ADT		Period(year)		RLR Crashes (Before)			RLR Crashes (After)		
	Major	Minor	Major	Minor	Before	After	All	RA	RE	All	RA	RE
Dallas	Camp Wisdom	US 67	23,265	9,567	1	1	1	1	0	1	0	1
Dallas	Camp Wisdom	Westmoreland	25,172	17,191	2	3	2	2	0	3	3	0
Dallas	Central Expry	Commerce	8,985	6,487	2	3	24	24	0	4	4	0
Dallas	Cockrell Hill	SH 180	30,226	11,931	2	3	5	5	0	7	5	0
Dallas	Dallas North Tollway	Keller Springs	33,516	17,802	2	2	3	3	0	14	13	0
Dallas	Dallas North Tollway	Loop 12	49,759	7,737	2	3	4	4	0	5	5	0
Dallas	Ferguson	Gus Thomasson	22,938	16,208	2	3	8	8	0	3	3	0
Dallas	Ferguson	Peavy	20,890	6,814	2	2	8	8	0	8	8	0
Dallas	Forest	Inwood	37,008	22,471	2	3	2	2	0	4	4	0
Dallas	Forest	Plano	52,003	31,978	2	2	14	14	0	6	5	1
Dallas	Forest	Schroeder	53,842	4,509	2	2	3	3	0	3	1	1
Dallas	Frankford	SH 289	55,772	29,614	1	3	0	0	0	1	1	0
Dallas	Greenville	Mockingbird	46,272	22,287	2	3	1	1	0	2	1	0
Dallas	Hampton	Wheatland	22,251	14,870	2	3	8	7	1	7	7	0
Dallas	IH 635	SH 289	33,076	18,605	2	3	3	3	0	9	8	1
Dallas	IH 635	Skillman	14,517	6,046	2	1	18	16	0	22	21	0
Dallas	Jefferson	Tyler	17,802	7,400	2	3	19	19	0	15	15	0
Dallas	Lemmon	Loop 12	41,626	5,055	2	3	2	2	0	17	17	0
Dallas	Lemmon	Mockingbird	25,016	25,009	2	3	8	7	0	3	2	1
Dallas	Lemmon	Oak Lawn	47,358	30,282	2	3	15	10	0	5	5	0
Dallas	Lombardy	Webb Chappel	27,585	18,308	2	2	2	2	0	2	1	0
Dallas	Loop 12	John West	45,626	10,996	2	3	10	7	3	8	5	2
Dallas	Miller	Plano	30,964	29,026	2	3	12	9	2	13	10	1
Dallas	SH 342	Loop 12	28,797	20,018	2	3	9	7	1	12	10	2
Dallas	Spur 348	Loop 12	41,854	25,321	2	3	29	24	2	33	29	1

City	Intersection		ADT		Period(year)		RLR Crashes (Before)			RLR Crashes (After)		
	Major	Minor	Major	Minor	Before	After	All	RA	RE	All	RA	RE
Dallas	Alpha Rd	Dallas Pkwy	23,728	21,626	2	2	33	33	0	20	19	0
Dallas	Coit Rd	IH 635	46,363	30,282	2	2	31	30	1	28	28	0
Dallas	Jefferson Blvd	Tyler St	14,517	6,046	2	2	19	19	0	15	15	0
Dallas	Lemmon Ave	Oak Lawn Ave	47,358	30,282	2	2	15	10	0	5	5	0
Dallas	US 75	Lovers Ln	29,716	14,994	2	1	23	23	0	26	23	1
Diboll	US 59	FM 1818	29,000	3,200	2	3	1	0	1	5	1	4
Diboll	US 59	Lumberjack	29,000	2,500	2	3	1	1	0	10	1	8
Duncanville	S Cedar Ridge	W Wheatland	18,082	14,259	3	4	5	5	0	2	2	0
Duncanville	S Cockrell Hill	E Wheatland	22,256	18,855	3	4	16	16	0	8	8	0
Duncanville	S Cockrell Hill	US 67	23,048	11,551	3	4	15	15	0	2	2	0
Duncanville	US 67	E Danieldale	15,781	12,343	3	4	8	6	2	5	5	0
El Paso	Gateway	Kenworth	14,545	7,127	3	4	2	1	1	2	2	0
El Paso	Gateway	Zaragoza	39,354	22,091	3	4	12	10	2	8	3	5
El Paso	Gateway North	Woodrow	30,225	15,013	2	4	0	0	0	4	4	0
El Paso	Joe Battle	Montwood	57,263	31,217	2	2	1	1	0	8	5	3
El Paso	Joe Battle	Rojas	37,430	34,994	2	2	13	13	0	11	10	1
El Paso	McCombs	Sun Valley	17,311	4,316	3	4	7	7	0	1	1	0
El Paso	Mesa	Resler	27,533	26,189	3	4	17	15	2	16	8	8
El Paso	Missouri	Campbell	22,770	7,387	3	4	13	12	1	18	12	4
El Paso	Montana	Airway	32,071	2,774	2	2	5	5	0	8	4	3
El Paso	Montana	Hawkins	47,973	16,068	3	4	6	5	1	6	4	2
El Paso	Redd	Resler	20,145	18,691	2	2	0	0	0	0	0	0
El Paso	Sunland Park	Mesa Hills	32,040	27,190	3	4	5	5	0	4	1	3
El Paso	Woodrow Bean	Rushing	23,710	21,637	3	4	1	1	0	1	1	0
El Paso	Gateway Blvd	Zaragoza Rd	39,354	22,091	3	2	12	10	2	8	3	5

City	Intersection		ADT		Period(year)		RLR Crashes (Before)			RLR Crashes (After)		
	Major	Minor	Major	Minor	Before	After	All	RA	RE	All	RA	RE
El Paso	Joe Ballte Blvd	Rojas Dr	37,430	34,994	2	3	13	13	0	11	10	1
El Paso	Mesa St	Resler Dr	27,533	26,189	3	3	17	15	2	16	8	8
El Paso	Missouri Ave	Campbell St	22,770	7,387	3	2	13	12	1	18	12	4
El Paso	Sunland Park Dr	Mesa Hills Dr	34,330	12,761	3	3	5	5	0	4	1	3
Farmers Branch	Josey	Valwood	11,649	7,553	3	4	3	3	0	1	1	0
Farmers Branch	Marsh	Valley View	17,124	4,609	2	3	6	6	0	5	3	2
Farmers Branch	Midway	Alpha	22,524	6,419	3	4	5	4	1	7	4	2
Farmers Branch	Spring Valley	Inwood	145,513	7,649	1	2	0	0	0	3	3	0
Farmers Branch	Valley View	Luna	9,645	8,226	2	3	2	2	0	2	2	0
Farmers Branch	Valley View	Webb Chapel	10,665	7,913	3	4	6	4	2	4	2	1
Farmers Branch	Webb Chapel	Valwood	8,241	4,003	3	4	0	0	0	2	2	0
Fort Worth	8th Ave	Elizabeth	10,462	10,436	2	2	6	6	0	4	4	0
Fort Worth	Alta Mere	Calmont	17,417	11,354	1	1	4	4	0	3	3	0
Fort Worth	Beach	Scott	11,597	10,928	2	1	3	3	0	2	2	0
Fort Worth	Bryant Irvin	W Vickery	11,824	11,595	2	2	4	4	0	4	3	0
Fort Worth	E Lancaster	Riverside	8,240	6,903	2	2	14	14	0	4	4	0
Fort Worth	E. Rosedale	S. Handley	8,425	7,800	1	1	4	4	0	2	2	0
Fort Worth	Lancaster	Sandy	7,801	7,105	1	2	0	0	0	0	0	0
Fort Worth	Long	Deen	13,454	12,899	2	2	5	4	0	2	2	0
Fort Worth	McCart	Westcreek	18,685	16,790	2	2	7	6	1	5	4	1
Fort Worth	NW 25th St	Clinton	3,367	2,296	2	2	1	1	0	2	2	0
Fort Worth	S Hulen	Bellaire	16,824	15,739	2	2	1	1	0	1	1	0
Fort Worth	S Hulen	Overton Ridge	21,898	19,219	2	2	1	1	0	2	1	1
Fort Worth	Western Center	Beach	32,749	26,353	2	2	10	10	0	6	6	0
Fort Worth	Western Center	North Frwy	14,459	13,590	1	1	2	2	0	1	1	0

City	Intersection		ADT		Period(year)		RLR Crashes (Before)			RLR Crashes (After)		
	Major	Minor	Major	Minor	Before	After	All	RA	RE	All	RA	RE
Garland (Dallas)	Beltline	Shiloh	22,280	19,960	3	4	10	10	0	9	8	1
Garland (Dallas)	Broadway	IH 30	41,679	19,351	1	1	3	3	0	4	4	0
Garland (Dallas)	First St	Ave B	50,455	12,704	1	1	3	3	0	2	2	0
Grand Prairie	Beltline	Lone Star Pkwy	45,158	5,817	2	3	1	1	0	3	1	2
Grand Prairie	Beltline	Tarrant	24,839	6,171	2	2	3	2	1	4	3	1
Grand Prairie	Carrier Pkwy	Roy Orr	19,798	18,047	2	3	2	2	0	0	0	0
Grand Prairie	Jefferson	Carrier Pkwy	23,570	16,038	2	3	6	6	0	4	3	1
Grand Prairie	Pioneer Pkwy	Carrier Pkwy	31,203	25,275	2	2	5	5	0	5	4	1
Grand Prairie	S Carrier Pkwy	IH 20	41,185	10,108	2	2	2	2	0	3	3	0
Grand Prairie	SH 360	Carrier	28,183	15,327	2	3	3	3	0	0	0	0
Haltom City	Haltom Rd	SL 820	39,000	12,442	1	2	0	0	0	1	1	0
Haltom City	SH 377	IH 820	11,821	4,045	2	2	15	15	0	12	10	2
Houston	Antoine	US 290	25,511	21,226	2	3	10	10	0	26	26	0
Houston	Bay Area	El Camino Real	31,346	31,045	3	4	12	10	1	22	20	2
Houston	Bellaire	Wilcrest	44,681	17,775	3	4	22	22	0	20	15	4
Houston	Bissonnet	Beltway 8 South	52,251	36,701	3	4	123	123	0	159	155	2
Houston	Brazos	Elgin	13,551	11,461	3	4	5	5	0	9	8	0
Houston	Chartes	St Joseph Pkwy	17,701	13,650	2	3	4	4	0	6	6	0
Houston	Chimney Rock	US 59 South	35,871	26,791	2	4	0	0	0	19	18	0
Houston	El Dorado	IH 45	31,161	12,101	2	3	17	17	0	9	8	1
Houston	Elgin	Milam	14,726	6,440	3	4	11	11	0	6	6	0
Houston	Fairbanks N Houston	US 290	30,775	29,961	2	3	30	30	0	4	4	0
Houston	FM 1960	SH 249	57,001	13,894	4	4	162	161	1	187	185	1
Houston	FM 2351	IH 45 South	26,846	24,851	2	3	4	3	1	3	2	1
Houston	Greens	IH 45 North	27,821	27,071	2	3	4	4	0	11	11	0

City	Intersection		ADT		Period(year)		RLR Crashes (Before)			RLR Crashes (After)		
	Major	Minor	Major	Minor	Before	After	All	RA	RE	All	RA	RE
Houston	Hillcroft	Harwin	50,106	19,176	3	4	10	10	0	12	12	0
Houston	Hillcroft	US 59 South	51,506	11,041	3	4	65	65	0	38	38	0
Houston	Hollister	US 290	52,411	18,866	2	3	36	36	0	26	26	0
Houston	IH 10	Market	24,901	13,456	2	3	1	1	0	3	3	0
Houston	IH 10	Normandy	24,459	21,786	2	3	7	7	0	7	6	1
Houston	IH 10	Uvalde	25,401	19,461	3	4	10	10	0	7	7	0
Houston	IH 45	South Wayside	23,601	17,801	1	3	1	1	0	7	6	1
Houston	IH 45	Woodridge	22,651	21,401	2	3	12	12	0	9	9	0
Houston	IH 45 North	West Rankin	39,796	24,801	2	3	8	8	0	21	20	0
Houston	John F Kennedy	Greens	51,606	12,746	4	4	15	14	1	42	41	1
Houston	Pease	La Branch	7,201	5,151	3	4	20	20	0	10	10	0
Houston	Post Oak	IH 610	39,552	26,386	2	3	5	5	0	2	2	0
Houston	Richmond	Dunvale	36,316	18,170	3	4	23	22	0	20	19	1
Houston	Richmond	Hillcroft	34,046	22,766	3	4	12	12	0	16	16	0
Houston	S Gessner	Beechnut	41,981	30,235	3	4	44	44	0	48	43	1
Houston	Scott	IH 610	20,346	10,031	2	3	7	7	0	12	12	0
Houston	SH 3	IH 45	12,701	10,401	2	3	16	16	0	10	9	1
Houston	South Beltway 8	SH 35	34,336	29,664	2	3	2	2	0	6	6	0
Houston	Stella Link	South IH 610 West	22,671	18,751	2	3	2	2	0	4	4	0
Houston	Travis	Webster	12,461	7,891	3	4	37	36	1	19	19	0
Houston	US 290	Mangum	22,126	19,801	2	3	1	1	0	3	3	0
Houston	US 59	Beechnut	38,566	18,801	2	3	18	18	0	13	13	0
Houston	US 59	Bellaire	35,381	19,101	2	3	59	56	1	38	36	2
Houston	US 59	Fondren	33,341	12,101	2	3	15	14	1	19	17	2
Houston	US 59	Fountainview	18,786	8,101	3	4	26	25	1	33	28	5

City	Intersection		ADT		Period(year)		RLR Crashes (Before)			RLR Crashes (After)		
	Major	Minor	Major	Minor	Before	After	All	RA	RE	All	RA	RE
Houston	US 59	Wilcrest	40,816	27,626	2	3	0	0	0	0	0	0
Houston	US 90 A	IH 610	40,993	38,576	2	3	25	25	0	63	60	3
Houston	West Beltway 8	Beechnut	49,901	21,841	3	4	35	34	1	34	33	1
Houston	West Beltway 8	Bellaire	50,451	20,601	2	3	26	26	0	28	24	2
Houston	West Beltway 8	Westpark	29,501	22,801	2	3	73	73	0	35	35	0
Houston	West IH 610	San Felipe	35,031	32,556	2	3	26	26	0	12	12	0
Houston	Westheimer	IH 610	39,521	34,061	2	3	7	7	0	10	8	2
Houston	Westpark	US 59 South	40,531	31,921	3	4	49	48	0	35	34	0
Humble (Harris)	FM 1960	SH 59	24,871	23,530	2	3	19	15	4	21	10	10
Irving	Belt Line	Pioneer	34,800	14,100	2	3	4	4	0	3	2	1
Jersey Village	US 290	FM 529	27,000	27,000	2	2	5	4	1	7	2	5
Jersey Village	US 290	Jones	27,000	27,000	3	2	22	20	2	22	17	5
Jersey Village	US 290	Sam Houston Pkwy	24,000	24,000	2	2	34	23	11	10	8	2
Jersey Village	US 290	Senate	24,000	24,000	2	2	12	8	4	11	7	4
Killeen	US 190	FM 3470	72,000	29,000	2	2	5	4	0	1	0	1
Killeen	US 190	SH 195	158,000	52,000	2	2	8	7	1	9	5	4
Lufkin	Loop 287	FM 1271	38,000	8,800	2	3	11	7	4	12	7	5
Lufkin	US 59	FM 58	22,000	14,900	2	3	11	7	3	7	7	0
Lufkin	US 59	FM 819	50,000	2,100	2	3	12	7	5	24	9	13
Lufkin	US 59	Loop 287	44,000	2,000	2	3	1	1	0	2	2	0
Lufkin	US 59	US 69	12,000	7,400	2	3	10	6	3	11	8	1
Mesquite	Bryan-Beltline	Grubb	28,000	3,500	2	2	1	1	0	2	1	0
Mesquite	N Galloway	Grubb	20,000	3,500	2	2	1	1	0	3	3	0
North Richland Hills	FM 1938	Harwood	41,428	5,137	2	3	4	4	0	2	1	1
North Richland Hills	FM 1938	Lola	41,428	5,518	2	3	5	4	1	2	0	1

City	Intersection		ADT		Period(year)		RLR Crashes (Before)			RLR Crashes (After)		
	Major	Minor	Major	Minor	Before	After	All	RA	RE	All	RA	RE
North Richland Hills	FM 1938	Maplewood	47,208	5,074	2	3	8	7	1	1	1	0
North Richland Hills	NE Loop 820	Rufe Snow	32,828	9,152	1	2	3	2	1	1	1	0
North Richland Hills	Rufe Snow	Dick Lewis	68,375	6,625	2	3	8	7	0	6	6	0
North Richland Hills	Rufe Snow	Mid Cities	32,084	21,294	2	3	2	2	0	2	0	2
Plano	15th	Independence	24,024	20,432	3	4	11	10	1	7	6	1
Plano	Coit	Park	44,002	32,573	2	3	11	10	1	18	8	9
Plano	Coit	West Spring Creek	36,546	13,962	2	3	8	8	0	11	10	0
Plano	Custer	SH 121	20,997	15,091	2	3	1	1	0	4	3	1
Plano	Jupiter	East Plano Pkwy	40,895	19,649	2	3	8	7	1	10	9	1
Plano	Legacy	Dallas Pkwy	33,216	8,980	3	4	60	58	1	82	80	1
Plano	Park	Ventura	35,044	4,118	3	4	17	15	1	13	11	2
Plano	Preston	West Plano Pkwy	61,549	14,904	2	3	12	12	0	18	16	2
Plano	Preston	West Spring Creek	48,108	27,340	2	3	18	12	3	13	7	6
Plano	SH 121	Dallas Pkwy	17,858	7,188	2	3	17	17	0	8	8	0
Plano	West Parker	Dallas Pkwy	23,916	11,762	2	3	13	13	0	8	8	0
Plano	West Plano Pkwy	Dallas Pkwy	16,316	13,468	2	3	13	12	1	6	6	0
Plano	West Spring Creek	Custer	26,237	14,419	3	4	17	17	0	7	6	1
Richardson	Centennial	Greenville	34,500	15,400	3	4	19	19	0	19	13	6
Richardson	Coit	Campbell	46,100	41,600	3	4	14	11	3	14	9	3
Richardson	Plano	Arapaho	32,300	31,200	3	4	6	5	1	10	7	3
Roanoke	SH 114	North Oak	7,300	1,000	1	2	1	0	0	0	0	0
Roanoke	SH 114	US 377	35,000	12,900	2	2	7	7	0	10	8	2
Sugar Land	US 59	SH 6	51,000	29,000	2	3	37	34	2	28	23	3
Terrell	US 80	FM 148	47,900	21,200	2	2	4	4	0	3	1	2

APPENDIX 2

Crash, Traffic, and Geometric Data Collected at Reference Intersections

City	Intersection		RLR Crashes			MAJOR						MINOR					
	Major	Minor	RA	RE	All	ADT	PRO LT	Yellow Int.	All Red	lane wid.	spd lmt	ADT	PRO LT	Yellow Int.	All Red	lane wid.	spd lmt
Arlington	Arbrook Blvd	New York Ave	1	0	4	17,238	0	4	2	12	40	5,966	0	4	2	12	40
Arlington	Bowen Rd	Pleasant Ridge Rd	3	1	7	20,266	0	4	2	13	40	11,937	0	4	2	11.5	38
Arlington	Cooper St	Sublett Rd	0	2	2	40,820	0	5	3	11	45	17,712	0	4	3	12.5	40
Arlington	Division St	Bowen Rd	2	0	6	20,122	0	4	2	11	40	8,348	0	4	2	9.9	35
Arlington	Mayfield Rd	New York Ave	4	3	7	19,973	0	4	3	12	40	16,189	0	4	2	12	40
Arlington	N Fielder Rd	Randol Mill Rd	1	0	5	32,253	1	4	2	11	40	20,821	0	4	2	11.5	40
Arlington	NE Green Oaks Blvd	N Collins St	0	1	1	27,508	1	5	2	12	55	23,437	1	5	2	11.1	45
Arlington	New York Ave	E Bardin Rd	0	1	1	17,677	0	4	2	12	40	6,462	1	4	2	10.6	40
Arlington	Park Row Dr	Bowen RArbrook Blvdd	0	0	0	24,768	0	4	2	11	35	13,998	0	4	2	10.2	40
Arlington	S Collins St	Arbrook Blvd	0	3	3	28,014	0	5	2	12	45	14,039	0	4	2	11.5	40
Arlington	S Cooper St	W Arbrook Blvd	0	0	0	64,914	1	4	3	11	40	18,437	0	4	3	12.5	40
Arlington	Spur 303	S Bowen Rd	0	0	0	31,869	1	5	2	11	45	24,768	1	4	3	11.5	35
Arlington	Spur 303	S Fielder Rd	1	0	1	31,869	0	5	2	11	45	7,873	1	4	3	12	40
Arlington	Spur 303	W Green Oaks Blvd	4	2	8	29,377	1	5	2	12	45	27,788	1	5	2	11	45
Arlington	W Lamar Blvd	N Fielder Rd	1	0	2	23,034	0	4	2	11	40	15,081	0	4	2	10.5	40
Austin	1st St	Oltorf St	0	1	2	25,310	0	4	1	11	35	2,080	0	4	1	11	35
Austin	1st St	Slaughter Ln	2	3	10	42,672	0	5	2	11	45	7,379	0	5	2	11.5	35
Austin	Anderson Ln	Burnet Rd	0	0	0	29,680	1	4	1	12	40	27,830	0	4	1	10	35
Austin	Congress Ave	Stassney Ln	1	2	4	25,000	1	4	1	13	45	21,820	1	4	1	11	45
Austin	E 51st St	Springdale Rd	9	0	10	13,600	1	4	1	10	30	7,960	1	4	1	11	35
Austin	E MLK Jr. Blvd	Springdale Rd	0	0	1	19,600	0	4	2	12	45	13,600	0	4	2	10.5	35
Austin	Escarpment	Slaughter Ln	2	2	7	27,310	1	4	2	12	50	12,820	0	4	2	13	40

City	Intersection		RLR Crashes			MAJOR						MINOR					
	Major	Minor	RA	RE	All	ADT	PRO LT	Yellow Int.	All Red	lane wid.	spd lmt	ADT	PRO LT	Yellow Int.	All Red	lane wid.	spd lmt
	Blvd																
Austin	Manchaca Rd	William Canon Dr	7	3	13	30,390	1	4	1	11	40	29,000	0	4	1	10.5	35
Austin	Metric Blvd	Braker Ln	0	1	5	26,890	0	4	2	11	45	26,780	0	4	2	12	40
Austin	Metric Blvd	Kramer Ln	6	0	7	16,340	0	4	1	12	35	12,130	1	4	1	11	40
Austin	Metric Blvd	Rundberg Ln	1	2	3	11,080	0	4	1	10	35	5,610	0	4	1	12.5	35
Austin	N Lamar Blvd	Braker Ln	7	5	15	25,700	1	4	2	10	45	24,590	1	4	2	12	45
Austin	N Lamar Blvd	E Koeing Ln	4	2	6	28,043	0	4	1	10	40	25,334	0	4	1	11.5	35
Austin	N Lamar Blvd	Rundberg Ln	12	4	19	39,100	1	4	1	12	45	27,250	1	4	1	10.5	35
Austin	N Lamar Blvd	W 38th St	9	1	12	30,163	0	4	1	11	40	29,885	0	4	1	10.5	30
Austin	S 1st St	W William Cannon Dr	5	2	9	36,443	1	4	1	11	40	22,043	1	4	1	10.5	35
Austin	S Congress Ave	US 290 EB Frontage	16	2	23	32,274	0	4	2	12	45	21,827	1	4	2	6	50
Dallas	Corinth St	Morrell Ave	2	0	3	11,150	0	4	2	11	35	5,340	1	4	2	16.5	30
Dallas	Hampton Rd	Ledbetter Dr	4	5	17	24,600	0	4	1	9.5	40	22,000	0	5	2	10	45
Dallas	Harry Hines Rd	Royal Ln	0	3	3	26,690	1	4	2	12	35	22,000	1	5	2	11.7	40
Dallas	Hillcrest Rd	Royal Ln	6	1	8	23,720	0	4	2	10	35	17,160	0	4	2	9.5	35
Dallas	Irving Blvd	Sylvan Ave	2	0	2	15,970	0	4	2	10	40	6,580	1	4	2	12	28
Dallas	Kiest Blvd	Duncanville Rd	17	0	19	12,660	0	5	2	11	45	9,730	0	5	2	11	45
Dallas	Kiest Blvd	Illinois Ave	2	3	6	13,570	0	5	2	12	40	6,360	0	4	2	12	35
Dallas	Ledbetter Dr	Westmoreland Rd	5	1	10	18,490	0	4	1	10	35	14,500	0	5	2	11.1	45
Dallas	Military Pkwy	Hatcher St	4	1	6	15,500	0	4	2	11	30	11,210	0	4	2	10	30
Dallas	Northwest Hwy	Lake Highlands Dr	0	0	0	27,340	0	4	2	11	40	13,150	0	4	2	10.5	35
Dallas	Royal Ln	Marsh Ln	3	4	7	23,660	0	5	2	11	35	17,380	0	5	2	10.5	35
Dallas	Singleton Blvd	Hampton Rd	4	2	8	30,550	0	4	2	13	40	15,920	0	4	2	10.5	30
Dallas	Skillman St	Richmond Ave	6	0	7	12,750	0	4	1	10	35	6,110	0	4	1	10	30
Dallas	Webb Chapel Rd	Forest Ln	5	3	9	27,180	1	4	3	12	18	24,920	1	4	3	10.5	35

City	Intersection		RLR Crashes			MAJOR						MINOR					
	Major	Minor	RA	RE	All	ADT	PRO LT	Yellow Int.	All Red	lane wid.	spd lmt	ADT	PRO LT	Yellow Int.	All Red	lane wid.	spd lmt
El Paso	Alameda Ave	Clark Dr	0	0	0	14,342	1	4	2	15	40	3,396	1	4	2	13	30
El Paso	Alameda Ave	Delta Dr	0	0	0	14,891	0	4	2	12	40	14,179	1	4	2	12.5	40
El Paso	Edgemere Blvd	Saul Kleinfeld Dr	2	3	6	15,502	0	4	2	13	40	11,992	0	4	2	12	40
El Paso	Fort Blvd	Copia St	0	0	0	5,750	0	4	1	13	30	2,740	0	4	1	12.5	30
El Paso	Gateway N Blvd	Dyer St	0	0	0	19,233	0	4	1	12	40	4,585	0	4	1	10.5	45
El Paso	Gateway N Blvd	Montana Ave	20	0	20	22,965	1	4	2	6	40	21,293	0	4	2	13	35
El Paso	Mesa St	Doniphan Dr	0	3	3	28,559	0	5	2	13	35	16,341	1	4	2	11.5	35
El Paso	Zaragoza Rd	FM 76	0	1	1	25,053	1	4	2	12	40	24,748	1	4	2	11	35
Fort Worth	E Rosedale St	Miller Ave	1	3	5	12,140	0	4	2	15	40	11,610	0	4	3	9.9	40
Fort Worth	E Seminary Dr	Campus Dr	4	2	7	13,100	0	4	3	11	30	8,410	0	4	2	10.2	40
Fort Worth	Lancaster Ave	Oakland Blvd	10	4	16	19,170	1	4	2	11	40	11,610	1	4	3	12	40
Fort Worth	McCart Ave	Seminary Dr	0	3	5	16,330	0	4	2	11	35	14,140	0	4	2	11	35
Fort Worth	Miller Ave	E Berry St	0	3	5	13,710	1	4	2	11	40	13,630	1	4	2	12.5	35
Fort Worth	Mitchell Blvd	Berry St	9	0	11	11,020	0	4	1	10	35	6,040	0	3	1	10.5	40
Fort Worth	Sylvania Ave	Yucca Ave	6	1	7	13,060	0	4	2	11	35	4,870	0	4	2	11	35
Plano	Custer Rd	Hedgcoxe Rd	0	0	0	25,047	0	5	1	12	45	15,953	0	4	1	11.5	43
Plano	McDermott Rd	Coit Rd	2	1	4	26,697	0	4	1	11	40	24,442	0	4	1	11.5	45
Plano	Park Blvd	Custer Rd	13	4	19	31,061	0	4	1	10	40	28,897	0	4	1	10.5	40
Plano	Parker Rd	Custer Rd	3	4	9	36,465	0	4	1	11	40	27,278	0	4	1	11	40
Plano	Spring Creek Pkwy	Alma Dr	1	8	16	39,133	0	4	1	11	40	22,190	0	4	1	10.5	38

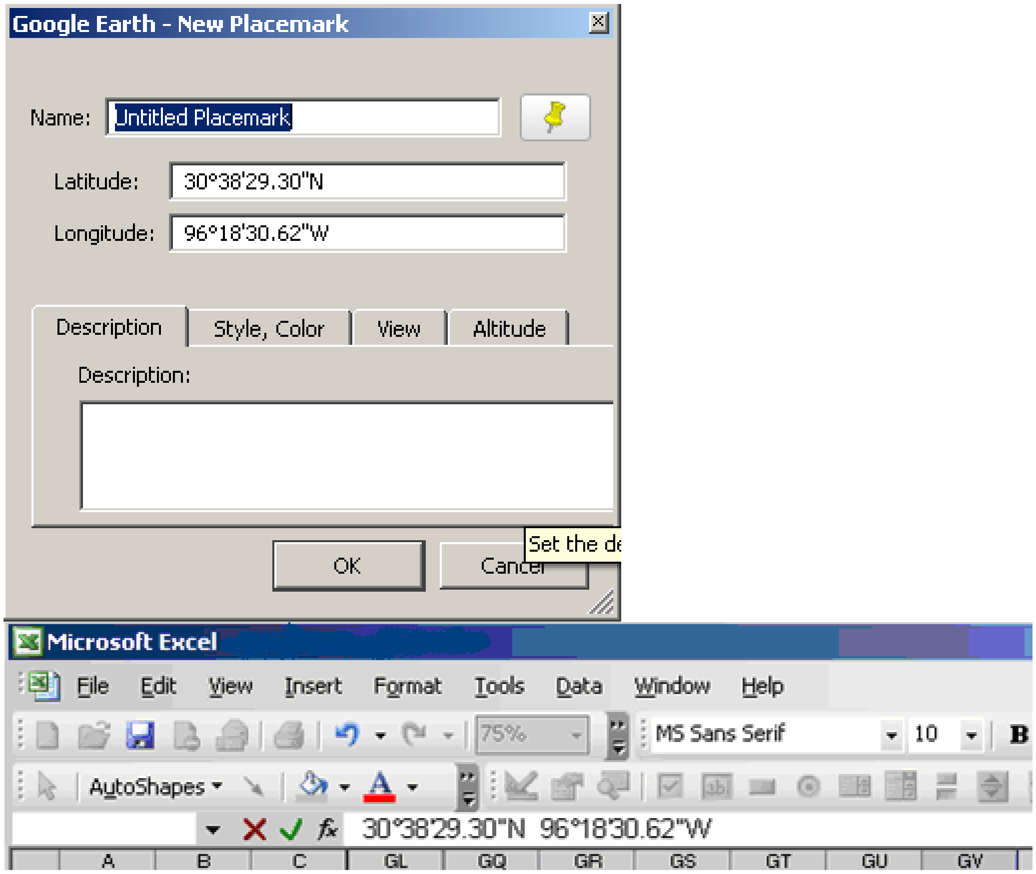
APPENDIX 3

Data Collection Manual

This document describes procedures for extracting geometric data at intersections.

site_type: Indicate whether the intersection is three-legged or four-legged. Codes: 3 = if 3-legged, 4 = if 4-legged.

lat_lon_coord: Geocoordinates of the center of the intersection. Use the Placemark feature in Google Earth (click Add, Placemark; or cntl+shift+P; or yellow push pin on toolbar). Use the mouse to put the tip of the push pin on the center of the intersection. Then, select the latitude information from the window shown in Figure A. In Excel, put the cursor in the cell of interest and paste the data in the spreadsheet. Next, select the longitude from the window and paste it in as shown. Press "enter" in Excel. Be sure there is a blank space between the two entries.



Name: Untitled Placemark

Latitude: 30°38'29.30"N

Longitude: 96°18'30.62"W

Description:

30°38'29.30"N 96°18'30.62"W

Figure A. Extraction and Entry of Latitude and Longitude.

one_way: Indicate whether the approach is one-way or two-way. Street View may be needed to make the determination. Codes: 1 = if one-way, 0 = if two-way.

th_lanes: Number of lanes (shared or exclusive) serving *through* traffic in both travel directions. This variable includes only lanes that go completely through the intersection and are aligned. Count these lanes along the stop line on both approaches to the intersection. **th_lanes_dir1=** lanes in direction 1, **th_lanes_dir2=** lanes in direction 2. ***Be consistent with the direction*** *(see Figure B). For example, the ways of West to East and North to South are Direction 1 at major and minor roadways. East to West and South to North are Direction 2.*

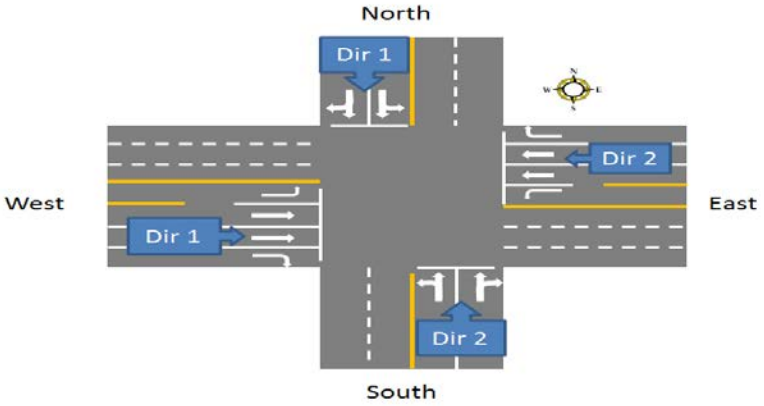


Figure B. Identification of Directions 1 and 2 at Typical Intersection.

lane_wid (feet): Average lane width for the traveled way excluding the exclusive-left and right turn lanes. This width is determined by first measuring the surface_width, by only including the through lanes. Then, this width is divided by the number of through lanes represented in the measurement. In the spreadsheet, enter this value as an equation. For example: enter as "=24/2". **lane_wid_dir1=** lane width in direction 1, **lane_wid_dir2=** lane width in direction 2.

lt_bay: Indicate whether one/both directions have a left-turn bay or exclusive left-turn lane(s). Codes: 0 = no bay or lane, 1 = bay or lane(s) in one direction only, 2 = bay or lane(s) in both directions.

A turn bay is developed by a taper, represents a short lane (or lanes) added to the cross section just before the intersection, ends at the intersection, and is for the exclusive use of the turn movement (often indicated by an arrow marking).

Sometimes, a turn lane is *not* developed by a taper. Rather, it is the extension of a lane through the upstream intersection, ends at the intersection, and is for the exclusive use of the turn movement (often indicated by an arrow marking).

rt_bay: Indicate whether the approach has a right-turn bay or an exclusive right-turn lane. See lt_bay for guidance in determining bay or lane presence. Codes: 0 = no bay or lane, 1 = bay or lane(s) in one direction only, 2 = bay or lane(s) in both directions.

rt_chan: Indicate whether the approach has right turn channelization**.** Right-turn channelization serves the purpose of facilitating right turn movement by providing drivers with a clearly-marked path. Channelization is delineated with raised curb or white pavement markings. Right-turn channelization can be provided with or without a speed-change lane (note: a decelerating speed-change lane at an intersection is called a right-turn bay). Codes: 0 = no bay or lane, 1 = channelization in one direction only, 2 = channelization in both directions.

med_pres: Indicate whether a median is present**.** A median can be a concrete barrier or a raised curb. Codes: 0 = no median, 1 = median in one direction only, 2 = median in both directions.

prot_lt: Presence of protected-only left-turn operation on the approach. Codes: 1 = protected-only left-turn operation, 0 = permissive or protected-permissive. Street View will be needed to make the determination of left-turn protection. To determine if a protected-only left-turn operation is provided an approach, the following conditions must be satisfied:

1. The intersection is signal controlled,
2. A left-turn movement exists, and
3. One of the following cases exists:
   a) The approach has a left-turn bay (or lane) with **one** lane for left turns and a three- or four section head is provided for the sole use of the left-turn movement without a sign “LEFT TURN YIELD ON GREEN; or
   b) The approach has a left-turn bay (or lane) with **two or more** lanes serving left turns;

spd_lmt: Enter the posted speed limit on each approach in both directions. Street View will be needed to make the determination of speed limit. **spd_lmt_dir1=** speed limit in direction 1, **spd_lmt_dir2=** speed limit in direction 2.