EVALUATION OF AUTOMATED TRAFFIC ENFORCEMENT SYSTEMS IN TEXAS

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Executive Summary

Red-light running violations are a primary cause of crashes that take place at intersections. In 2009, 696 people were killed in motor vehicle crashes that occurred within Texas intersections, and these crashes accounted for 23% of all motor vehicle fatalities that year. Sadly, intersection crash deaths accounted for 4.6 billion dollars in economic loss for Texas motorists in 2009.

The objective of this technical memorandum is to provide the Texas Department of Transportation (TxDOT) with the results of a before-after analysis conducted to determine how effective automated traffic enforcement systems are in reducing the frequency of motor vehicle crashes at signal-controlled intersections. Secondly, researchers sought to measure changes in driver behavior regarding red light running occurrences after automated traffic enforcement systems were removed from treated intersections.

Researchers compared two groups—intersections with no systems installed at all, and those with a system installed. Crash frequency counts from signal controlled intersections were combined within each community to determine the effectiveness of the automated traffic enforcement systems on crashes. All communities were combined in order to develop a statewide estimate of effectiveness.

Out of 39 total communities evaluated, 22 experienced reductions in red-light related rear end (RLR RE) crashes at treated intersections during system use. This represents an overall reduction in RLR RE crashes for 56% of the communities. Thirty-three communities experienced reductions in red light related right angle (RLR RA) crashes, which represents an overall reduction in crashes for 85% of the communities. When all RLR crashes types were considered, 35 communities experienced crash reductions at treated intersections. This represents an overall reduction in all RLR crash types for 90% of the communities with intersections using the camera systems.

When considering the overall safety effect for treated intersections statewide, there was a significant decrease in all RLR crashes types by 26.4% when the cameras are installed and in use. The average safety benefits for all Texas intersections that use automated traffic enforcement systems should be to expect red-light related crash reductions from 19% to 34%. Finally, there was clear evidence that showed reductions in RLR violations while the treatments cameras were active and increases in RLR violations when the treatments cameras were removed.

Disclaimer

The conclusions expressed in this document are those of the authors and do not represent those of the state of Texas, TxDOT or any political subdivision of the state or federal government.

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Introduction

Evaluation of Photographic Traffic Signal Enforcement Systems in Texas: A Before-After Study

Background

In 2009, the Texas Department of Motor Vehicles (TxDMV) reported approximately 21.5 million registered vehicles in Texas (*1*). The Texas Department of Transportation (TxDOT) Crash Records Information System (CRIS) identified 2,793 fatal motor vehicle crashes, which resulted in 3,089 deaths (*2*). This equates to 1 traffic related death for every 6,960 registered vehicles in Texas and 1 person killed every 2 hours and 50 minutes (*2*). Additionally, 1 in every 92 registered vehicles was involved in a crash that included some claim of injury. In fact, CRIS identified 59,164 injury related crashes in Texas for 2009, and from these events, 80,640 persons were seriously injured (*2*).

Unfortunately, intersection collisions are common occurrences, and red light running violations account for many of these crashes. In 2009, 696 people were killed in motor vehicle crashes that occurred within intersections in Texas (*2*). Sadly, these crashes accounted for 23% of all motor vehicle fatalities for that year. A listing of crash fatalities, serious body injury, and intersection crash fatalities in Texas for the past 5 years is provided in Table 1.

TABLE 1 Casualties, Serious Body Injury, and Intersection Crash Deaths 2005–2009

	2005	2006	2007	2008	2009
Deaths	3,558	3,521	3,463	3,477	3,089
Serious Injury	91,754	89,194	89,160	84,946	80,640
Intersection Deaths	768	786	837	832	696

While Texas has experienced a decline in the number of fatal crashes over the past five years, the economic impact that these preventable events cause is alarming. According to National Safety Council projections, the average cost for Texas crash deaths reached $20.3 billion in 2009, an average of $6.6 million for each traffic-related crash death. Using the same National Safety Council figures, intersection crash deaths accounted for $4.6 billion in economic loss for Texans in 2009 (*3*). Consequently, reducing red-light running violations and the crashes associated with them plays a significant role in terms of social and fiscal harm.

Objective

This technical memorandum provides TxDOT with the results of a before-after analysis conducted to determine how effective automated traffic enforcement systems are in

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reducing the frequency of motor vehicle crashes at signal controlled intersections in Texas. Secondly, Texas Transportation Institute (TTI) researchers measured changes in driver behavior regarding red light running occurrences after removal of automated traffic enforcement systems. This technical memorandum addresses the following actions.

1. Perform a statistical analysis to evaluate the effectiveness that automated traffic enforcement systems have on signal controlled intersection crashes at the state and community level.

2. Perform a statistical analysis to evaluate the effectiveness that automated traffic enforcement systems have on right angle and rear end crash types at the state and community level.

3. Perform a statistical analysis to evaluate changes in red light running violations among drivers after removal of automated traffic enforcement systems in College Station, Texas.

Section I of the technical memorandum addresses the evaluation of safety benefits that automated traffic enforcement systems have on signal controlled intersection crashes. Section I also addresses the influence that automated traffic enforcement systems have on different crash types on different roadway systems.

Section II addresses driver behavior changes toward running red signals post removal of automated traffic enforcement systems in one community. TTI researchers also explored red-light running (RLR) experiences that exist after the automated traffic enforcement system had been removed.

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Section I

Evaluation of Photographic Traffic Signal Enforcement Systems on Crash Frequencies

Purpose

The purpose of this section is to provide TxDOT with a sense of the magnitude of intersection crashes and the types of crashes that are occurring at signal controlled intersections monitored with automated traffic enforcement systems. This section will define the nature and characteristics of signal controlled intersection crashes as much as possible, so that specific conclusions regarding the effectiveness that automated traffic enforcement systems have on crash frequencies and types of collisions can be better understood.

Data Collection and Experimental Design

Crash information used for this section of the technical memorandum originated from electronic copies of stored crash records maintained in the TxDOT Crash Records Information System database. The individual crash data was remotely accessed electronically by interfacing with CRIS and searching the database using crash identification numbers assigned to each crash record. Each community that reported automated traffic enforcement activity to TxDOT was named, and researchers obtained and analyzed crash records for the identified signal-controlled intersection locations.

Crashes were categorized into three types: right-angle (RA), rear-end (RE), and other crash type (OT). Crashes were also separated into red-light related (RLR) and not red-light related (NLR) categories. Table 2 summarizes the average crashes per year in the period before and after installation of the automated traffic enforcement systems.

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TABLE 2 Average Crash Types per Year by Community

Community	RLR (Before)			RLR (After)			NLR (Before)			NLR (After)		
	RA	RE	OT	RA	RE	OT	RA	RE	OT	RA	RE	OT
Amarillo	18.5	0.0	0.0	5.3	0.3	0.0	1.5	2.0	4.0	1.5	0.3	2.0
Arlington	36.5	1.5	1.0	18.3	0.3	0.3	28.0	31.5	11.0	20.0	29.0	10.0
Austin	64.0	0.0	2.5	19.5	0.3	0.5	12.5	15.0	5.5	3.0	5.0	7.0
Baytown	23.0	0.5	0.8	6.8	0.0	0.5	6.5	21.2	10.3	4.8	11.5	5.3
Bedford	10.5	0.5	0.0	4.3	0.0	0.3	2.0	10.5	2.0	1.3	6.3	1.8
Burleson	14.0	4.0	1.5	4.3	2.8	0.5	3.5	41.0	5.5	1.3	9.8	2.3
Cedar Hill	12.5	0.0	0.0	4.5	0.8	0.0	22.2	18.8	7.8	15.3	9.5	5.3
College Station	9.0	4.0	1.0	0.8	0.8	0.0	32.5	31.5	3.5	4.5	6.5	1.3
Coppell	5.5	0.5	0.5	1.6	0.9	0.3	15.5	3.0	5.5	8.1	5.3	4.9
Corpus Christi	15.5	3.5	1.5	9.7	7.0	0.7	32.0	27.5	8.5	27.0	57.0	9.3
Dallas	200.0	10.5	6.5	123.0	5.7	7.3	104.5	69.0	38.0	96.7	77.7	51.0
Denton	10.7	1.3	0.3	10.3	1.0	0.0	5.5	4.8	4.8	5.3	7.7	2.7
Diboll	0.5	0.5	0.0	0.7	4.0	0.3	1.5	9.5	1.0	0.0	7.7	0.7
Duncanville	14.0	0.7	0.0	5.7	0.0	0.0	10.0	6.3	5.7	12.3	7.7	6.3
El Paso	28.8	2.3	0.3	19.0	10.7	1.0	19.8	60.8	30.3	13.3	65.0	34.0
Farmers Branch	7.7	1.0	0.0	5.7	1.7	0.7	9.5	9.0	4.0	10.3	8.3	2.7
Fort Worth	43.5	1.5	0.5	13.3	1.0	0.3	12.5	31.5	13.0	9.7	21.0	8.0
Garland (Dallas)	27.3	2.0	1.3	14.7	2.0	0.3	22.3	12.7	4.7	31.0	18.7	5.7
Grand Prairie	10.5	0.5	0.0	4.7	1.7	0.0	6.5	9.5	7.0	8.0	12.3	3.3
Haltom City	7.5	0.0	0.0	3.7	0.7	0.0	1.0	9.0	4.0	1.0	4.7	1.7
Houston	451.4	3.8	2.0	465.3	18.2	6.7	66.2	93.1	130.5	74.3	145.3	162.5
Humble (Harris)	19.0	12.5	0.0	13.0	16.0	0.5	3.5	32.5	9.5	8.0	30.5	10.5
Hutto	0.0	4.0	0.0	1.0	0.5	0.0	2.0	4.0	1.0	0.5	3.0	0.0
Irving	21.0	0.0	0.0	19.0	2.0	0.5	3.5	4.0	2.0	1.5	8.0	5.5
Jersey Village	24.2	8.7	0.0	17.0	8.0	0.0	2.3	21.8	61.2	3.0	26.5	60.0
Killeen	12.0	1.5	1.0	6.0	4.5	0.5	7.5	27.0	25.0	9.0	39.0	21.0
Lake Jackson	1.0	1.0	0.0	7.0	4.0	0.5	1.5	14.5	5.0	0.0	12.5	4.5
Lufkin	22.3	9.7	1.5	19.0	16.0	3.0	4.8	35.3	13.8	6.0	59.5	17.0
Marshall	12.5	1.5	0.0	10.0	7.0	1.0	11.0	16.0	7.0	27.5	28.0	11.5
McKinney	1.5	0.0	0.0	0.5	0.0	0.0	2.0	0.0	0.0	2.0	0.5	0.0
Mesquite	1.0	0.0	0.0	2.0	0.0	0.5	1.0	0.5	1.0	1.0	1.0	0.5
North Richland Hills	17.0	2.5	1.0	6.0	4.5	0.5	6.5	18.0	5.5	6.0	20.5	3.0
Plano	79.3	4.0	2.2	114.5	16.5	1.5	48.0	29.5	24.2	50.0	69.5	55.0
Richardson	17.2	2.8	0.0	33.0	14.0	2.0	18.2	13.8	7.5	65.0	43.0	23.0
Richland Hills	1.5	0.0	0.0	1.0	1.0	0.0	0.5	0.5	0.5	6.0	0.0	0.0
Roanoke	3.5	0.0	1.0	8.0	2.0	0.0	8.0	19.0	2.0	16.0	30.0	8.0
Rowlett	4.5	0.0	0.0	5.0	2.0	0.0	6.0	6.7	1.0	24.0	22.0	4.0
Sugar Land	17.0	1.0	0.5	23.0	3.0	2.0	1.0	10.0	7.5	4.0	45.0	21.0
Terrell	4.0	0.0	0.0	4.0	2.0	0.0	0.5	2.5	1.0	2.0	15.0	3.0
Total	1269.4	87.8	27	1029.8	162.4	32.1	543.3	772.9	481.3	580.1	969.6	575

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A before-after approach was used to evaluate the safety effectiveness of the automated traffic enforcement systems. To overcome some of the issues with a simple before-after study, a comparison group method was used. TTI researchers used a comparison group that had influencing factors similar to that of the treated group. Two assumptions underlying this approach are (*4*):

1. Factors that affect safety have changed in the same way from before the improvement to after the improvement for both treatment and comparison groups.

2. Changes in the various factors influencing safety of the treatment and the comparison groups are comparatively similar.

The results from this approach are considered more accurate and robust than the simple before-after methods because it accounts for external causal factors and maturation concerns that may be encountered.[4] While this type of approach improves upon the weakness of simple before-after study method by carefully selecting comparison groups, it is still subject to the regression-to-the-mean (RTM) bias. This is due to the methods prediction concerning the expected number of target crashes from the treatment site based upon before-period crash numbers only. RTM means 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 (*5*). In this study, the crashes in the comparison group are from the same intersection as that of the treated group, so the effect of RTM is minimal.

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Methodology

Crash frequency counts from the signal controlled intersections were combined within each community to determine the effectiveness that the automated traffic enforcement systems had on crashes within each jurisdiction. All communities were combined in order to develop a statewide estimate of effectiveness.

Step 1. Define the Target Crashes

Target (or RLR) crashes are defined as those types of crashes that are likely influenced by the automated traffic enforcement systems. RLR crashes include those crash events taking place inside the signal controlled 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.

Step 2. Define the Comparison Group

The comparison group represents those crashes that are not associated with red signal violations. Crash reports analyzed as part of this investigation indicated other crash causes useful in explaining factors, other than the automated enforcement system, that have influenced the safety of an intersection. Each of the following incidents describes crashes that are not associated with red signal violations, even though the crash may still have occurred in the intersection.

- Collisions occurring during a lane change not related to a red light.
- Vehicles slowing down due to congestion.

- Vehicle turning into or out of a public/private drive.
- Unprotected permissive left turns.
- Cases where the light turns from red to green, the following vehicle accelerates faster than the lead, and the lead unit is struck from the rear.

Step 3. Predict the Expected Number of Crashes and Variances for the After Period

Predicting expected crashes and variances in the after period is necessary in order to account for influences that affect safety other than the treatment itself. Since other factors may cause an effect, predicting after-period crash frequency and variances that are either not measured or produce an influence on safety, the factors must be considered. The expected number of after-period crashes and their variances for site *i* (note: site *i* represents a group of intersections in a community) had the treatment not been implemented at the treated site is given as (*4*):

$$\hat{\pi} = \hat{r}_T K \text{ and } V\hat{A}R(\hat{\pi}) = \hat{\pi}^2 \left(1/K + V\hat{A}R\{\hat{r}_T\}/r_T{}^2\right)$$

$$\text{with, } \hat{r}_T = (N/M)/(1+1/M) \text{ and } V\hat{A}R\{\hat{r}_T\}/r_T{}^2 \cong 1/M + 1/N$$

where,

K = Total crash counts during the before period in treated group.
M = Total crash counts during the before period in comparison group.
N = Total crash counts during the after period in comparison group.

(note: site represents a group of intersections in a community)

If there were no crashes (zero) recorded in a community, then an adjustment factor of 0.5 crashes was evenly made for each of all crash types (e.g., RE, RA, and OT crashes for RLR and NLR) within the community.

Step 4. Compute the Sum of the Predicted Crashes over All Treated Sites and Its Variance

It is widely recognized that the safety effect of a treatment varies from one site to another. Thus, instead of a single site, the average safety effect of the treatment for a group of sites must be calculated. To account for this, 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:

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$$\hat{\pi} = \sum_{i=1}^{N} \hat{\pi}_i \text{ and } Var(\hat{\pi}) = \sum_{i=1}^{N} Var(\hat{\pi}_i)$$

where,

N= Total number of sites in the treatment group.

$\hat{\pi}$ = 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.

Step 5. Compute the Sum of the Actual Crashes over All Treated Sites

For a treated site, 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 actual number of after-period crashes for a group of treated sites is given as:

$$\hat{\lambda} = \sum_{i=1}^{N} L_i$$

where,

L_i = Total crash counts during the after period at site *i*.

This step is not required when the safety effect is assessed at each community level.

Step 6. Compute the Unbiased Estimate of Safety-Effectiveness of the Treatment and Its Variance

The 'index of effectiveness (θ)' is defined as the ratio of what safety was with the treatment to what it would have been without the treatment.

The parameter $\hat{\theta}$ gives the overall safety effect of the treatment and is given by:

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

The percent change in the number of target crashes due to the treatment is calculated by $100(1-\hat{\theta})$ %. If $\hat{\theta}$ is less than 1, then the treatment has a positive safety effect. The estimated variance and standard error of the estimated safety effectiveness are given by:

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$$Var(\hat{\theta}) = \hat{\theta}^2 \frac{\left(1/L + Var(\hat{\pi})/\hat{\pi}^2\right)}{\left(1 + Var(\hat{\pi})/\hat{\pi}^2\right)^2}$$

$$s.e.(\hat{\theta}) = \sqrt{Var(\hat{\theta})}$$

The approximate 95% confidence interval for θ is given by adding and subtracting $1.96 s.e.(\hat{\theta})$ from $\hat{\theta}$. If the confidence interval contains the value 1, then no significant effect has been observed.

Results

Safety Effects

Out of 39 total communities evaluated, 22 experienced reductions in RLR RE crashes at treated intersections. This represents an overall reduction in RLR RE crashes for 56% of the 22 different communities using automated enforcement cameras. Thirty-three communities experienced reductions in RLR RA crashes at treated intersections. This represents an overall reduction in RLR RA crashes of 85% for the 39 different communities using automated enforcement cameras. When all RLR crash types were considered, 35 communities experienced crash reductions at treated intersections. This represents an overall reduction in all RLR crash types for 90% of the communities that use automated traffic enforcement systems. Table 3 summarizes the safety effects and changes in crashes by community.

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TABLE 3 Safety Effect by Community

Community	Index of Effectiveness			Change in Crashes[1]		
	θ			(1-θ)%		
	RE	RA	All[2]	RE	RA	All[2]
Amarillo	1.48	0.20	0.46	48%	-80%	-54%
Arlington	0.11	0.65	0.55	-89%	-35%	-45%
Austin	1.39	0.96	0.62	39%	-4%	-38%
Baytown	0.44	0.33	0.49	-56%	-67%	-51%
Bedford	0.40	0.41	0.54	-60%	-59%	-46%
Burleson	2.15	0.51	1.29	115%	-49%	29%
Cedar Hill	1.61	0.46	0.62	61%	-54%	-38%
College Station	0.65	0.45	0.51	-35%	-55%	-49%
Coppell	0.39	0.43	0.46	-61%	-57%	-54%
Corpus Christi	0.75	0.67	0.58	-25%	-33%	-42%
Dallas	0.43	0.65	0.58	-57%	-35%	-42%
Denton	0.27	0.81	0.78	-73%	-19%	-22%
Diboll	3.39	1.56	3.54	239%	56%	254%
Duncanville	0.19	0.29	0.29	-81%	-71%	-71%
El Paso	2.98	0.89	0.92	198%	-11%	-8%
Farmers Branch	0.90	0.56	0.84	-10%	-44%	-16%
Fort Worth	0.59	0.35	0.45	-41%	-65%	-55%

Garland (Dallas)	0.45	0.36	0.38	-55%	-64%	-62%
Grand Prairie	0.89	0.30	0.50	-11%	-70%	-50%
Haltom City	1.44	0.31	0.88	44%	-69%	-12%
Houston	2.40	0.90	0.81	140%	-10%	-19%
Humble (Harris)	1.23	0.26	0.83	23%	-74%	-17%
Hutto	0.11	2.39	0.51	-89%	139%	-49%
Irving	0.97	1.36	0.59	-3%	36%	-41%
Jersey Village	0.66	0.43	0.70	-34%	-57%	-30%
Killeen	1.25	0.36	0.60	25%	-64%	-40%
Lake Jackson	2.31	7.20	4.63	131%	620%	363%
Lufkin	0.88	0.58	0.71	-12%	-42%	-29%
Marshall	1.61	0.29	0.60	61%	-71%	-40%
McKinney	0.25	0.19	0.16	-75%	-81%	-84%
Mesquite	0.29	1.00	1.25	-71%	0%	25%
North Richland Hills	1.11	0.32	0.51	11%	-68%	-49%
Plano	1.39	1.34	0.89	39%	34%	-11%
Richardson	1.18	0.50	0.70	18%	-50%	-30%
Richland Hills	2.00	0.04	0.22	100%	-96%	-78%
Roanoke	1.09	0.87	0.97	9%	-13%	-3%
Rowlett	0.57	0.23	0.35	-43%	-77%	-65%
Sugar Land	0.35	0.29	0.38	-65%	-71%	-62%
Terrell	0.38	0.20	0.24	-62%	-80%	-76%

[1] A negative value represents a decrease, while a positive value represents an increase in crashes.
[2] All=RE+RA+OT.

The average safety effect for camera monitored signal controlled intersections in Texas shows an overall decrease in all RLR type crashes by 26.4%. The standard deviation of this estimated average safety effect is 4%. Measuring the safety effect at a 95% confidence level, the result is highly significant and represents an average decrease in all crashes from 19% to 34%.

Investigation of the results in Table 3 shows that automated traffic enforcement systems had highly (or significantly) adverse safety effects on all crash types in the communities of Diboll and Lake Jackson. However, this result is attributed to very few reported crashes in the 'before' period. As such, the increase in the crash frequency in these two communities for the after period may not be due to the installation of automated enforcement systems, but instead, may have occurred by chance. Further investigation of the safety effect by removing these two communities (Diboll and Lake Jackson) revealed that the estimated reduction in RLR crashes was 27.5% (see Table 5).

Crash Type Differences

It is important to understand the average safety effects that automated traffic enforcement systems have on different crash types. A review of the literature suggests that automated traffic enforcement systems mostly influence RE and RA crashes. The RE crashes increased by 43.6%, and RA crashes decreased by 19% statewide. Statistically, these changes are significant at a 95% confidence level. Table 4 summarizes the average safety

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effects of the treatments. However, further analysis of RE crashes without considering Diboll and Lake Jackson (low crash frequency communities) resulted in RE crashes becoming insignificant (i.e., only significant at 92.5% confidence level). Table 5 summarizes the average safety effect of the treatment, less the communities of Diboll and Lake Jackson.

TABLE 4 Average Safety Effect of Automated Traffic Enforcement Systems

Measure	Description	Rear end crashes	Right angle crashes	All crashes
$\hat{\lambda}$	Number of crashes observed during the after period[1]	169.4	1031.3	1224.3
$\hat{\pi}$	Expected number of crashes during after period had red light cameras not been installed	115.9	1262.5	1658.8
$Var(\hat{\pi})$	Variance of $\hat{\pi}$	245.95	13689.72	6727.85
$\hat{\theta}$	Unbiased estimate of index of effectiveness	1.44	0.81	0.74
$\sigma(\hat{\theta})$	Standard error of $\hat{\theta}$	0.22	0.08	0.04
$100(\hat{\theta}-1)$	Percent increase in the number of crashes	43.56%	-19.01%	-26.38%
$(\theta_{lower}, \theta_{upper})$	95% confidence interval for θ	(1.01, 1.86)	(0.65, 0.96)	(0.65, 0.81)
Significance	Statistical significance level	95.23%	98.45%	99.99%

[1] Adjusted crashes when zero crashes were recorded in a community.

TABLE 5 Average Safety Effect of Automated Traffic Enforcement Systems without Diboll and Lake Jackson Communities

Measure	RE crashes without Diboll and Lake Jackson	All crashes without Diboll and Lake Jackson
$\hat{\lambda}$	161.4	1207.8
$\hat{\pi}$	114.7	1656.7
$Var(\hat{\pi})$	244.90	15781.9
$\hat{\theta}$	1.38	0.72
$\sigma(\hat{\theta})$	0.21	0.06
$100(\hat{\theta}-1)$	38.14%	-27.51%
$(\theta_{lower}, \theta_{upper})$	(0.96, 1.80)	(0.61, 0.83)
Significance	92.49%	99.99%

Although the average safety effect is known, it is important to understand how variable the effect of the automated traffic enforcement system is when applied to different sites and on different occasions (*4*). This is essential for two reasons:

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1. One may wish to know the chance that the treatment will reduce safety.

2. To determine in what circumstances a treatment is more effective and in what circumstances a reduction in safety may occur.

The variability of the safety effect of the treatment can be estimated by approximating the distribution of θ's by a gamma distribution. The mean of the distribution can be estimated by the average value of θ from Table 3. The variance can be estimated by computing the sample variance of θ, and subtracting the average of the variances of θ estimated for each community.

This study's finding suggests that in about half of the treatment sites, automated traffic enforcement systems would produce a decrease in RLR RE crashes, while increasing RLR RE crashes in about half of the others. At the same time, approximately three-fourths of the treatment site intersections would generate positive safety benefits by decreasing RLR RA crashes. Figure 1 illustrates the cumulative probability of the safety benefits for RLR RE and RLR RA crashes.

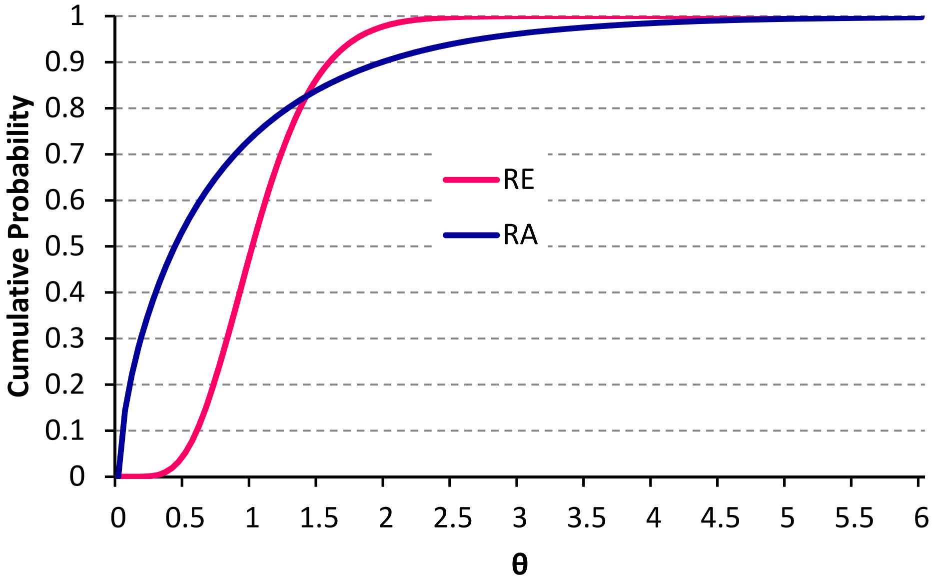

FIGURE 1 The distribution of θs for RLR crashes after treatment installation.

Conclusions

The findings of this investigation provide strong evidence that automated traffic enforcement systems are effective safety countermeasures that aid in reducing RLR crashes at signalized intersections. The before-after analysis showed that the average safety effect of automated traffic enforcement systems decreases all types of RLR crashes by an estimated 26.4% (95% confidence level). Further analysis showed that by removing two communities with a low crash frequency, additional safety benefits were observed with crashes decreasing 27.5% after the automated traffic enforcement systems were installed and operational.

When evaluating RLR RE crashes, the study results did show an increase in these types of collisions by 43.6%, respectively. However, when RLR RE crashes are compared to the number of RLR RA crashes, there is a very large difference in frequency count. While there is a high percentage of change in the number of RLR RE crashes from before to after time periods, the relative few RLR RE events that occurred are minor when compared to the overall number of RLR RA crashes. The more dangerous and prevalent RLR RA collisions showed a decrease of 19%. Interestingly, when all RLR crashes were considered, there was a positive safety benefit experienced, with all RLR crash types *decreasing* while automated traffic enforcement systems were in use.

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Section II

Effect of Red-Light-Running Camera Removal on Violations at Intersections in College Station

Introduction

Reducing red-light-running violations at intersections plays a significant role in terms of traffic safety and social costs. Recognizing the characteristics of RLR violations and implementing traffic safety countermeasures aimed at reducing RLR violations has and will continue to be a key issue in improving intersection safety.

Implementation of traffic safety countermeasures that address RLR violations at signal-controlled intersections is based on the identification of certain human factors and roadway characteristics. Bonneson and Zimmerman's (2004) prediction model best quantifies the effect of various intersection features related to RLR violation frequency. The prediction model consists of appraising approach traffic flow rates, signal cycle lengths, yellow signal interval durations, 85th percentile speeds, clearance path lengths, heavy-vehicle use percentage, volume-to-capacity ratios, and presence of back plates on signal lights. Each element, when addressed, provides some safety benefit toward reducing RLR violations at signalized intersections (*6*).

Retting et al. analyzed the frequency of RLR violations at signalized intersections and determined that busy locations that experienced 30,000 vehicles per day had RLR violations occurring every 12 minutes and every 5 minutes during morning peak hours. Intersections with lower traffic volumes, approximately 14,000 vehicles per day, had RLR violations occurring at 1.3 per hour and 3.4 per hour in the evening peak. Retting's work concluded that there was a positive correlation in the number of RLR violations and high traffic volumes (*7*).

Fleck and Smith, Retting et al., and Wahl et al. suggest that automated traffic enforcement is more effective and provides a specific deterrent effect on RLR violations (*8,9,10*). Wahl et al. found that RLR violations significantly decrease with the installation of automated traffic enforcement systems. Initially, non-treated intersections experienced a rate of 2,428 violations per week. After treatments were installed and became active, the number decreased to 534 violations per week. After 8 months, the average number of violations decreased to 356 (*10*).

Additional evidence suggests RLR violations are reduced at signalized intersections that are not treated with cameras. Chen et al. discovered that automated traffic enforcement systems changed driver behavior regarding RLR violations regardless of the presence of a treatment camera. RLR violations declined by 70% at non-camera enforced intersections one month after the introduction of automated enforcement systems at other intersections. In the immediate six months after treatments became active, a 38% reduction occurred (*11*). Chen's results demonstrate how automated traffic enforcement systems provide a strong "halo effect" for those intersections that do not have treatment cameras in place

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and operational. However, caution should be taken when considering the positive “halo effect” since evidence suggests that results are variable and time sensitive.

Purpose

The purpose of this section is to provide the results of an analysis to determine changes in driver behavior toward red light running after automated traffic enforcement systems were removed from treated intersections in the City of College Station, Texas. The intent was to determine any difference in RLR violation frequencies compared with violations rates before the removal of the treatments at the intersections. TTI researchers also wanted to determine if RLR violation rates within 24 hour time frames and RLR violation rates at peak traffic times during weekdays and weekends were affected.

Methodology

Data Collection and Experimental Design

Prior to data collection and analyses, TTI researchers determined if any significant modification had been made that might adversely affect the outcome of the assessment. Geometric roadway design, traffic signalization, changes in yellow signal timing, all-red phasing, traffic volume, and posted speed limits were assessed for changes. There were no distinctive changes found at the intersections that could affect RLR violations other than a slight reduction in traffic volumes. TTI researchers discovered that traffic volume decreased by 6% to 11% at each intersection between 2008 and 2009 and that overall traffic volume decreased between 2007 and 2009 at all intersections. Table 6 provides the yellow interval durations, all-red intervals, speed limits, and traffic volume characteristics for the four intersections.

TABLE 6 Driving Environment Characteristics at Selected Intersections

Intersection	Yellow Interval Durations	All-Red Interval Duration (s)	Speed Limit (mph)	Traffic Volume (veh)*		
				2007	2008	2009
W/B HARVEY RD @ G. BUSH EAST	4.0	1.0	40	21,000	17,800	16,700
N/B WELLBORN RD @ G. BUSH DR	4.0	1.0	40	25,000	23,000	21,000
E/B HARVEY RD @ MUNSON AVE	4.0	1.0	40	19,400	18,400	16,400
N/B TEXAS AVE @ WALTON AVE	4.0	1.0	40	40,000	42,000	38,000

*Annual Average Daily Traffic (AADT) source: TxDOT Traffic Maps

In November 2009, the City of College Station deactivated the automated traffic enforcement systems from all treated intersections within the city. Prominent news coverage in both print and television markets was circulated throughout the community notifying resident drivers of the camera deactivation.

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TTI research staff made use of the technology infrastructure that was still in place using the in-ground sensors at previously treated intersections. Video cameras were installed upon mast arms of the intersection signal light poles. The video cameras were tied into traffic signals using roadway sensors and signal timing present at the intersections. Upon the signal light changing from yellow to red, the videotape would trigger on, and violations were captured in 10 to 15 second video clips. Sensor readings verified and captured violations. Each violation was reviewed by TTI researchers to ensure robustness of the data being used for the analysis.

RLR violation data were collected at four intersections during eight periods within three years. TTI researchers chose one week (i.e., a period) intervals as a minimum unit for RLR violation data collection and analysis. The one week intervals reflect normal traffic patterns in College Station.

The RLR violation data for the periods before the automated traffic enforcement system was removed were collected in 2008 and 2009. RLR violations that occurred in the after period (2010) were accessed through web interface with the permission of the City of College Station. The dates for interval periods in 2008, 2009, and 2010 are provided in Table 7.

Data were categorized using the following characteristics:

1) Violation time and day.
2) Vehicle speed approaching the intersection.
3) Time-in-Red A (i.e., the time after a signal turning to red when a vehicle enters an intersection).
4) Time-in-Red B (i.e., the time after a signal turning to red when exiting the intersection).

TABLE 7 Data Collection Periods

Period	2008		2009		2010	
	From (mm/dd)	To (mm/dd)	From (mm/dd)	To (mm/dd)	From (mm/dd)	To (mm/dd)
1	04/14	04/20	04/13	04/19	04/12	04/18
2	04/21	04/27	04/20	04/26	04/19	04/25
3	04/28	05/04	04/27	05/03	04/26	05/02
4	05/05	05/11	05/04	05/10	05/03	05/09
5	05/12	05/18	05/11	05/17	05/10	05/16
6	05/19	05/25	05/18	05/24	05/17	05/23
7	05/26	06/01	05/25	05/31	05/24	05/30
8	06/02	06/08	06/01	06/07	05/31	06/06

The Wilcoxon Matched-Pairs Signed Ranks Test and interrupted time series analysis were used to measure significant differences in the number of RLR violations before and after the removal of automated traffic enforcement system treatments. More descriptive information concerning the use of these methods is explained within the body of the results.

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Results

Percentage of Change: RLR Violations

RLR violation data used in the analysis were collected from automated traffic enforcement systems operating in 2008 and 2009. The 2008 and 2009 RLR violation data were termed as the “before” data set. RLR violation data used in the analysis collected in 2010 were termed as the “after” data set. RLR violations decreased for three of the four intersections between 2008 and 2009 while the treatments were active. As expected there were fewer RLR violations that occurred in the second year than in the first year. First year intersections totaled 2,445 RLR violations, while second year intersections RLR violations decreased to 1,738.

Comparison of RLR violations between the first and second year periods (with treatments) and the third year periods (without treatment), revealed that RLR violations increased in all periods except for one. A total of 4,756 RLR violations occurred at four intersections during eight periods in 2010 after treatment removal. When comparing the number of RLR violations in the first year (with treatment) against violations in the third year (no treatment), RLR violations increased by a factor of two. When comparing RLR violations in the second year (with treatment) against violations in the third year (no treatment), RLR violations increased to a factor of three. Based on the results from the changes of RLR violations between the years with and without the camera treatments, there was significant evidence that showed RLR violations dramatically increased after the treatment was removed. Equally important is that while treatment intersections that had automated traffic enforcement systems were in operation, RLR violation rates were reduced, meaning that there was less chance for collisions to occur. Table 8 summarizes an overview of RLR violation changes for 2008 through 2010.

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TABLE 8 RLR Violations and Percentage Comparisons

Period	W/B HARVEY RD @ G. BUSH EAST						N/B WELLBORN RD @ G. BUSH DR					
	No of Violations			% Change			No of Violations			% Change		
	2008	2009	2010	2008 VS 2009	2008 VS 2010	2009 VS 2010	2008	2009	2010	2008 VS 2009	2008 VS 2010	2009 VS 2010
1	112	72	160	-36%	43%	122%	42	42	142	0%	238%	238%
2	110	60	198	-45%	80%	230%	33	31	133	-6%	303%	329%
3	114	71	183	-38%	61%	158%	43	50	151	16%	251%	202%
4	98	65	171	-34%	74%	163%	31	44	147	42%	374%	234%
5	54	62	190	15%	252%	206%	35	34	137	-3%	291%	303%
6	79	47	173	-41%	119%	268%	35	35	102	0%	191%	191%
7	69	37	180	-46%	161%	386%	42	38	88	-10%	110%	132%
8	64	56	144	-13%	125%	157%	35	31	102	-11%	191%	229%
Total	700	470	1399	-33%	100%	198%	296	305	1002	3%	239%	229%

Period	E/B HARVEY RD @ MUNSON AVE						N/B TEXAS AVE @ WALTON AVE					
	No of Violations			% Change			No of Violations			% Change		
	2008	2009	2010	2008 VS 2009	2008 VS 2010	2009 VS 2010	2008	2009	2010	2008 VS 2009	2008 VS 2010	2009 VS 2010
1	84	60	121	-29%	44%	102%	96	60	193	-38%	101%	222%
2	96	56	127	-42%	32%	127%	64	61	192	-5%	200%	215%
3	110	50	131	-55%	19%	162%	97	70	198	-28%	104%	183%
4	108	40	103	-63%	-5%	158%	150	66	191	-56%	27%	189%
5	92	79	132	-14%	43%	67%	78	90	181	15%	132%	101%
6	88	57	101	-35%	15%	77%	74	58	143	-22%	93%	147%
7	68	60	105	-12%	54%	75%	80	55	171	-31%	114%	211%
8	85	50	97	-41%	14%	94%	79	51	169	-35%	114%	231%
Total	731	452	917	-38%	25%	103%	718	511	1438	-29%	100%	181%

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Distribution of RLR Violations by Time and Days

During weekends in the years with treatment, more RLR violations occurred between 1 PM and 4 PM. However, when the treatments were not present, weekend RLR violations were evenly distributed between 8 AM and 7 PM. During weekdays in the years with treatment, more RLR violations occurred between 12 PM and 3 PM. The trend regarding frequency differences in RLR violations by time is comparatively different between treatment and non-treatment periods. During the weekdays in the year without the treatment, more violations occurred between 8 AM and 10 AM and 4 PM and 6 PM. These results, as well as those in the Bonneson and Zimmerman study (*6*), show a strong relationship between RLR violations and traffic volumes. However, while the treatment cameras were operational, RLR violations were more likely to occur during the afternoon hours before the afternoon peak. The frequencies of RLR violations that occurred during eight periods in each year of 2008, 2009, and 2010 are distributed by time, weekday, and weekend in Table 9.

TABLE 9 Frequency Distribution of RLR Violations by Time

Time (hh:mm:ss)		2008			2009			2010		
From	To	Weekday	Weekend	Total	Weekday	Weekend	Total	Weekday	Weekend	Total
00:00:01	01:00:00	19	11	30	32	15	47	67	44	111
1:00:01	02:00:00	9	18	27	19	11	30	40	41	81
2:00:01	03:00:00	16	8	24	19	12	31	41	45	85
3:00:01	04:00:00	7	7	14	8	6	14	15	23	38
4:00:01	05:00:00	5	3	8	5	3	8	15	13	28
5:00:01	06:00:00	11	4	15	11	4	15	35	7	42
6:00:01	07:00:00	23	3	26	29	3	32	76	16	92
7:00:01	08:00:00	56	12	68	27	9	36	176	42	218
8:00:01	09:00:00	88	35	123	40	28	68	215	70	285
9:00:01	10:00:00	89	34	123	56	28	84	210	70	280
10:00:01	11:00:00	102	40	142	61	27	88	138	84	222
11:00:01	12:00:00	95	45	140	64	31	95	172	63	235
12:00:01	13:00:00	129	56	185	86	30	116	190	70	260
13:00:01	14:00:00	121	71	192	100	51	151	176	77	253
14:00:01	15:00:00	154	72	226	92	48	140	211	68	279
15:00:01	16:00:00	123	63	186	59	51	110	207	78	285
16:00:01	17:00:00	87	58	145	74	39	113	285	70	355
17:00:01	18:00:00	103	51	154	73	34	107	277	75	352
18:00:01	19:00:00	110	41	151	92	39	131	195	81	276
19:00:01	20:00:00	122	36	158	67	36	103	173	61	234
20:00:01	21:00:00	82	29	111	53	18	71	167	67	234
21:00:01	22:00:00	61	25	86	55	18	73	156	53	209
22:00:01	23:00:00	37	17	54	32	12	44	107	58	165
23:00:01	24:00:00	38	19	57	25	6	31	86	50	136
Total		1,687	758	2,445	1,179	559	1,738	3,430	1,326	4,756

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Distributions of RLR Violation by Time-in-Red and Approaching Speeds

Among the 4,756 violations that occurred after the treatment was removed in 2010, over 2,500 RLR violations (52%) occurred within one second after the yellow signal turned to red. Approximately 4,000 RLR violations (84%) occurred within five seconds of the signal turning to red. Figure 2 represents the distribution of RLR violations according to the time-in-red and approaching speeds.

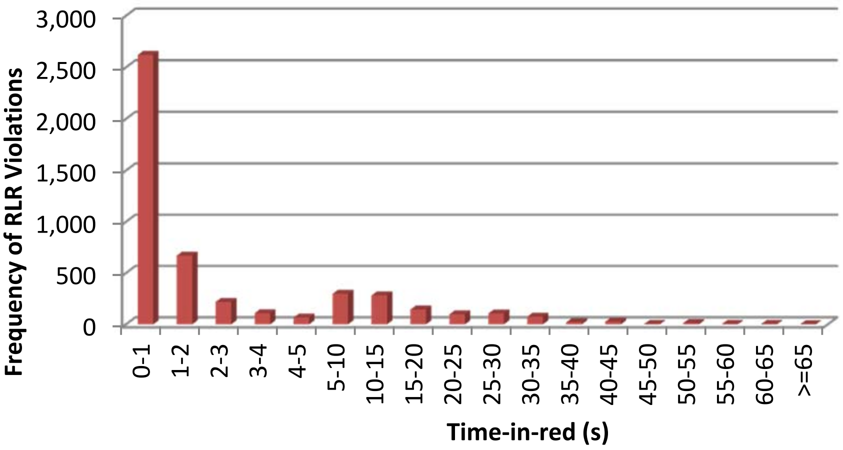

FIGURE 2 Red light violation distribution by time-in-red.

The results from the distribution of RLR violations by approaching speeds showed that half of the violations in the after period (2010) occurred with speeds of less than 20 mph. It would be reasonable to believe that RLR violations that occur with approach speeds of 20 mph or less are those vehicles beginning to make right or left turn movements. Since turning vehicles display slower approach speeds due to the characteristics of vehicle kinetics involved with turns, slower approach speed would be expected.

Since approximately 2,000 RLR violations (42%) occurred with vehicle speeds being less than 10 mph, it would also be reasonable to hypothesize that drivers violated the red signal while performing turning movements. However, approximately 1,000 RLR violations (21%) occurred within the speed range of 30 to 40 mph. While there is evidence that suggests a large majority of drivers run red signals at slower speeds, many travel at faster speeds, which is more indicative of straight travel paths. Figure 3 illustrates the frequency of RLR violations according to vehicle approach speeds.

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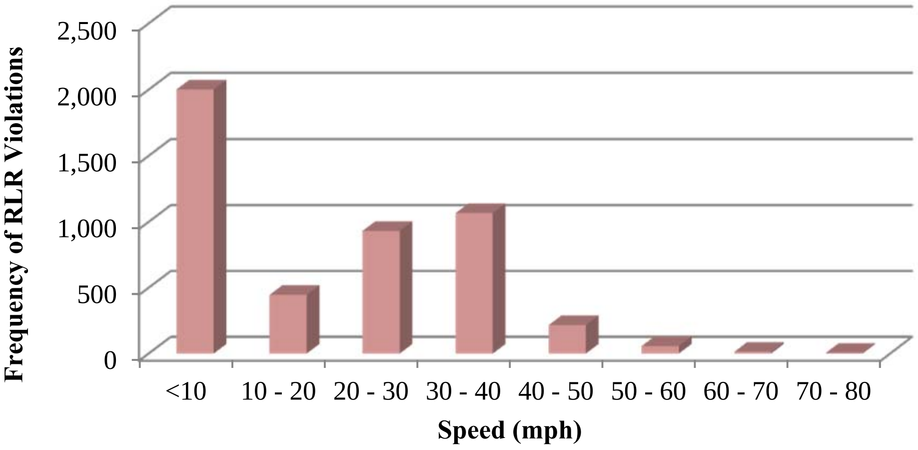

FIGURE 3 Red light violation distribution by approach speeds.

Wilcoxon Match-Pairs Signed Ranks Test

The Wilcoxon Match-Pairs Signed Ranks Test was used to compare two paired samples, such as before and after treatment, when small sample size does not guarantee a normal assumption (*12*). Using the Wilcoxon test proved differences in the number of RLR violations between before and after removal. Significance was based upon the null hypothesis: "*The treatment does not make any significant difference in the number of RLR violation at the selected intersection.*" The Wilcoxon Match-Pairs Signed Ranks Test represents the statistical relevance regarding differences in the frequency of RLR violations among the study year periods between 2008, 2009, and 2010.

Comparison between the first year (2008) and second year (2009) with treatment showed significant differences at two intersections: E/B Harvey Rd. @ Munson Ave. and N/B Texas Ave. @ Walton Ave. Interestingly, the number of RLR violations significantly decreased in the second-year intersections with the treatment in place. For the comparison years (2008 and 2009), with the treatment being active, the Wilcoxon test results showed a significant difference in RLR violations at all intersections while the treatment was in place.

As expected, removal of the treatment (2010) resulted in a significant increase in the number of RLR violations as compared to 2008 and 2009. Table 10 provides the comparative differences between RLR violations between study year periods with and without the treatment being active.

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TABLE 10 Results from Wilcoxon Match-Pairs Signed Ranks Test

Intersection		2008 VS. 2009	2008 VS. 2010	2009 VS. 2010
W/B HARVEY RD @ G. BUSH EAST	test	-1.826	-2.201	-2.207
	Sig.	0.068	0.027*	0.027*
N/B WELLBORN RD @ G. BUSH DR	test	-0.406	-2.371	-2.524
	Sig.	0.684	0.018*	0.012*
E/B HARVEY RD @ MUNSON AVE	test	-2.201	-2.383	-2.201
	Sig.	0.028*	0.017*	0.028*
N/B TEXAS AVE @ WALTON AVE	test	-2.240	-2.521	-2.521
	Sig.	0.025*	0.012*	0.012*

Note : * $p < .05$

Interrupted Time-Series Analysis

Interrupted time series analysis measures whether the treatment affects any subsequent observations. The advantage of this type of analysis is a trend assessment on the long term effect of the treatment, as well as the immediate effect. TTI researchers used the number of RLR violations per weekly period at each intersection. The interrupted time series analysis represents how the removal of automated traffic enforcement systems made a difference on the number of RLR violations at the intersections during subsequent before and after time periods. The interrupted time series analysis represents the change of RLR violations and provides support for the results from previous analyses.

Results of this analysis showed that the number of RLR violations per period decreased from 2,445 (2008) to 1,738 (2009) but then increased to 4,755 in the after period (2010). As was observed in the previous analysis, the number of RLR violations greatly increased after the treatment was removed. This strongly suggests that results from the comparisons of RLR violations before and after the treatments were removed is consistent. Both methods, Wilcoxon and Interrupted Time Series Analysis, verified dramatic rises in the number of RLR violations at the intersections when automated traffic enforcement activity ceased. Figure 4 provides an illustration of the change in RLR violation differences during and after treatment use.

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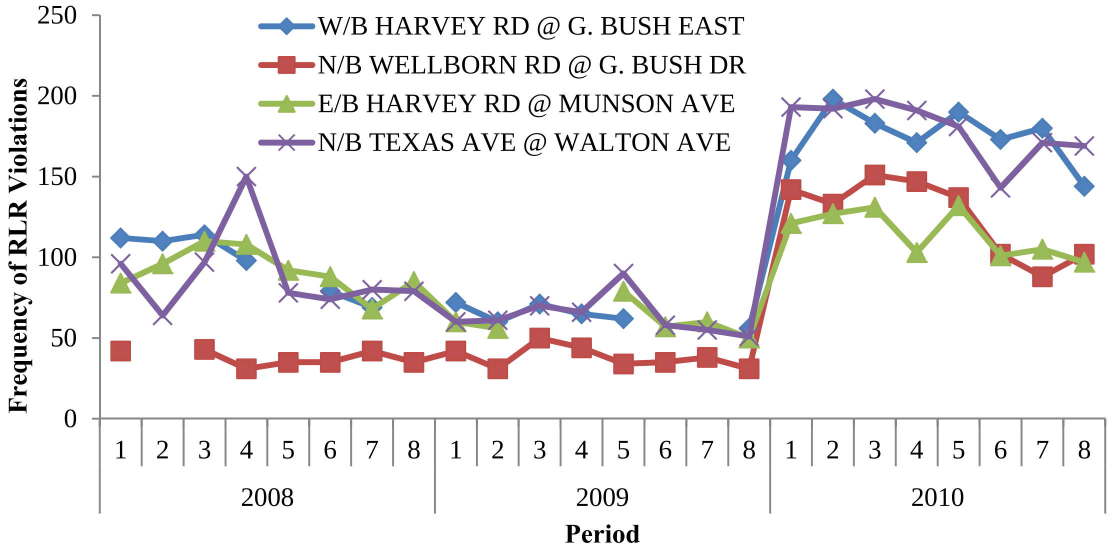

FIGURE 4 Time-series analysis for RLR violations.

Conclusion

The results of this analysis showed that driver behavior was influenced by the presence of automated traffic enforcement systems. Both positive and negative influences were observed based upon whether or not the treatment cameras were in place. There was clear evidence that shows reductions in RLR violation while the treatments are active and increases in RLR violations when the treatments were removed.

As expected there were fewer crashes that occurred in the second year than the first. First year intersections totaled 2,445 RLR violations, where year two intersections decreased to 1,738. As a result there were 707 fewer RLR violations that occurred between year one (2008) and year two (2009) while treatments were active. When year two (2009) was compared against year three (2010-no treatment) there was an increase of 3,017 RLR violations observed.

Across weekdays and weekend observation periods, data sets showed decreases in RLR violations between year one and two, and increases in RLR violation in the year after the treatments were removed. On weekday periods when the treatments were active, RLR violations were concentrated and more likely to occur in the afternoon hours (12 PM and 3 PM) just before peak traffic flow. During weekday periods when the treatments were not active, RLR violations were scattered but more likely to occur between 8 AM and 10AM and 4 PM and 6 PM.

During weekend periods while the treatments were active, RLR violations remained consistent with those experienced on the weekday periods, with a majority occurring in the afternoon hours between 1 PM and 4 PM. During weekend periods when the treatments were not present, RLR violations were evenly distributed between 8 AM and

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7 PM, meaning that RLR violators were more prone to run red signals at all times of the day as opposed to certain times of peak traffic flow.

In closing, the findings discovered in these analysis supports the hypothesis that automated traffic enforcement systems not only produce significant reductions in RLR violations, they also appear to change driver behavior regarding red light running risk taking during most hours of the day.

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