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Evaluation of Low-Cost Intersection Countermeasures to Reduce Red Light Running Violations: Retro-Reflective Signal Back Plates

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16. Abstract

Red light running has become a serious safety issue at signalized intersections throughout the United States. One objective of this study was to identify the characteristics of red-light-running (RLR) crashes and the drivers involved in those crashes. Driver characteristics, time and day of the crash, occupancy of the vehicle, and environmental factors were tested against any relationship with the RLR crashes and other signalized intersection (non-RLR) crashes. The other objective was to evaluate the effectiveness of retro-reflective signal backplates in reducing red light running as a low cost countermeasure. Crashes that happened in the State of Kansas were analyzed as a case study. Contingency table analysis was used to identify whether a particular factor is related to the crash type, i.e. RLR vs non-ROR. Two methods were used to evaluate the effectiveness of reflective backplates: cross-sectional analysis using an intersection with reflective backplates and an intersection without reflective backplates, and a before-and-after study using four intersections. According to the results of contingency table analysis, the driver age and safety equipment usage, injury severity of the driver, crash severity, time and day of crash, adverse weather conditions, and surface condition were related to crash type. Variables such as gender of the driver, light condition, and presence of passengers were not related to the crash type. The cross-sectional analysis found that reflective backplates are effective in reducing red light violations in the through and left turning traffic flows. The before-and-after study showed a significant reduction in red light violations in one of the two treatment sites, according to paired-t-test statistics. The reduction of red light violations was not significant in the other. Both analyses could not prove a significant impact on red light violations among the right turning vehicles.

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Disclaimer

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Abstract

Red light running has become a serious safety issue at signalized intersections throughout the United States. One objective of this study was to identify the characteristics of red-light-running (RLR) crashes and the drivers involved in those crashes. Driver characteristics, time and day of the crash, occupancy of the vehicle, and environmental factors were tested against any relationship with the RLR crashes and other signalized intersection (non-RLR) crashes. The other objective was to evaluate the effectiveness of retro-reflective signal backplates in reducing red light running as a low cost countermeasure. Crashes that happened in the State of Kansas were analyzed as a case study. Contingency table analysis was used to identify whether a particular factor is related to the crash type, i.e. RLR vs non-ROR. Two methods were used to evaluate the effectiveness of reflective backplates: cross-sectional analysis using an intersection with reflective backplates and an intersection without reflective backplates, and a before-and-after study using four intersections. According to the results of contingency table analysis, the driver age and safety equipment usage, injury severity of the driver, crash severity, time and day of crash, adverse weather conditions, and surface condition were related to crash type. Variables such as gender of the driver, light condition, and presence of passengers were not related to the crash type. The cross-sectional analysis found that reflective backplates are effective in reducing red light violations in the through and left turning traffic flows. The before-and-after study showed a significant reduction in red light violations in one of the two treatment sites, according to paired-t-test statistics. The reduction of red light violations was not significant in the other. Both analyses could not prove a significant impact on red light violations among the right turning vehicles.

Chapter 1 Introduction

A red light violation occurs when a motorist enters an intersection after the onset of a red signal light indication. For many years, crashes due to red light violators have been a serious threat to road safety at signalized intersections. At intersections where right a turn on red is allowed, a vehicle turning right on red without coming to a complete stop is also considered as red-light-running (RLR) or a red-light violation. According to the National Highway Traffic Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS) database, RLR crashes caused 676 fatalities in 2009 (FHWA, 2010). From 2000 to 2009, RLR crashes resulted in a total of 8,845 fatalities. A red-light-running brochure from Federal Highway Administration (FHWA) asserts that vehicle operator disregard of red lights or other traffic controls is the most common cause of all urban vehicle crashes. Moreover, an estimated 165,000 motorists, cyclists, and pedestrians were injured annually by red-light-running drivers (Shaw, 2013). According to a study carried out by the AAA Foundation for Traffic Safety (AAA Foundation for Traffic Safety, 2010), 93% of drivers believe that violating a red light is unacceptable behavior; however, one out of three drivers admitted to running a red light in the past 30 days.

Concern about the crashes due to red-light violations in the state of Kansas is similar to those at the national level. Because of this important safety issue, in 2009 “Red Light Running” was added as a separate factor under “Driver Contributing Circumstances” in the Kansas Crash Analysis and Reporting System (KCARS) database. According to KCARS database, 1,097 drivers violated a red light during 2012, resulting in 468 injury-crashes and three fatal crashes. However, little research has been conducted to identify factors affecting RLR crashes or characteristics of red-light-running drivers. One of the objectives of this study was to identify the characteristics of RLR crashes. Several driver factors, road conditions, and environmental conditions that are related to RLR crashes are discussed in this report.

Currently, methods such as engineering measures and automated and manual enforcement are practiced throughout the United States to prevent red light violations. Red-light-running cameras, confirmation lights, an increased yellow-time interval, and retro-reflective backplates are common red-light-running countermeasures. Retro-reflective borders frame the backplates so that the traffic signal lights are more visible. This is effective in daytime and nighttime conditions and therefore intended to reduce unintentional red-light-running crashes. The other objective of this study is to evaluate the effectiveness of retro-reflective signal backplates as a low cost countermeasure to reduce RLR violations. A before-and-after study and a cross sectional study were conducted in order to evaluate the effectiveness of the retro-reflective backplates, and the methodologies and its results are discussed in this paper.

Due to the sheer number of signalized intersections prevalent in any urban area of the United States, low cost countermeasures are needed to improve intersection safety by reducing red-light violations. One such countermeasure is the application of retro-reflective signal backplates. The Manual of Uniform Traffic Control Devices (MUTCD) states that traffic signal backplates enhance the contrast between the traffic signal indications and their surroundings (Federal Highway Administration, 2009). A yellow retro-reflective strip is mentioned as an option to prevent confusion due to distracting features in the background during both day and night conditions. Accordingly, one of the objectives of this study was to evaluate the effectiveness of those retro-reflective backplates in reducing red-light violations. Two methods of evaluating retro-reflective backplates were carried out in this study: a cross sectional study and a before-and-after study. Two intersections in Topeka, Kansas and four intersections in Manhattan, Kansas were used primarily for data collection.

Chapter 2 Literature Review

2.1 Characteristics of Red-Light-Running Crashes

According to Martinez and Porter (Martinez & Porter, 2006), drivers under 26 years of age are more likely to violate red lights than drivers of 26 years and older, and red light violators are less likely to wear seat belts as well. Their research also revealed that red light running is positively correlated with traffic volume; increased traffic volume per cycle results in an increased number of red light violations. Porter and Berry (Porter & Berry, 1999) also found that a typical red-light-running driver is younger (age below 26 years), unemployed or employed in a blue-collar position, hurrying to work or school during morning hours on weekdays, and often alone in the vehicle when a red light violation is committed.

In a study of the role of race and ethnicity in regards to fatal RLR crashes (Romano, et al., 2005), results indicated that red light runners are predominantly Hispanic or white, compared to African-Americans. Also, logistic regression models have revealed that the prevalence of red light running is not significantly different between Hispanics and whites, even after adjustments were made for possible relevant factors such as age, gender, and the presence of alcohol. However, Martinez and Porter (Martinez & Porter, 2006) have failed to identify a significant difference between whites and non-whites among red light runners.

According to Retting and Williams (Retting & Williams, 1996), 67% of red light violators wear shoulder harnesses and 74% among compliers wear shoulder harnesses. In addition, no gender difference has been observed between violators and compliers, for which 71% of drivers were male in both groups. Other findings of this study include: (1) violators were younger drivers compared with compliers, (2) 14% of violators have multiple speeding convictions on their driving records, whereas only 4% of compliers have convictions, and (3) no relationship has been found between red light running and prior crash involvement.

Among likely factors that affect the rate of red light running, the time of crash has been considered in many studies. According to a study carried out by the University of Florida in 2004 (Washburn & Courage, 2004), red-light-running rates were found to be generally higher during mid-day and afternoon peak periods than during the morning peak period (Washburn & Courage, 2004).

In a nationwide survey of self-reported red light running (Porter & Berry, 2001), one of the five characteristics discussed was the occupancy of the vehicles and it stated that the presence of passengers in the vehicle reduced driver tendency to run red lights (Porter & Berry, 2001). The survey also stated that a 26% probability of running a red light exists when a driver is alone, 16% when one adult passenger is in the vehicle, and only 5% when a child is present in the vehicle.

In their study of large-truck crashes, Kotikalapudi and Dissanayake (Kotikalapudi & Dissanayake, 2013) pointed out that driver-related contributory causes are more common than any other contributory cause for truck-crashes. An attempt to recognize such trend regarding RLR crashes, additional intersection factors, such as signal type and number of turning lanes, could not be analyzed due to lack of available data. Hence, majority of factors discussed in this paper are driver-related.

2.2 Retro-Reflective Backplates

According to Hallmark et. al., three types of engineering countermeasures are prevalent in reducing red-light violations: signal operations, motorist information, and physical improvements (Hallmark, et al., 2012). Introducing reflective backplates is considered one of the treatments that falls under motorist information. Reflective backplates can help both distracted and undistracted drivers who do not observe the traffic signal lights. In order to identify the effectiveness of retro-reflective backplates, the crash modification factor could be used.

The crash modification factor (CMF) is a multiplicative factor used to estimate the expected number of crashes after the implementation of a countermeasure at a specific site. Three studies that tested retro-reflective bordered backplates observed a 19.7%-38.9% reduction of all vehicle crashes and a 31.8%-76.8% reduction for injury crashes. The CMF Clearinghouse has stated a CMF of 0.85 for all crashes for this countermeasure, including the advantages of low cost and potential effectiveness in many applications (Sayed, et al., 2005). The disadvantages of introducing backplates to traffic signal heads were identified as additional items to maintain, signal heads being prone to more movement during high winds, and the possible requirement of additional loading on support poles due to wind loading.

Backplates improve visibility of the illuminated signal face by introducing a controlled-contrast background (Shaw, et al., 2013). Retro-reflective border frames the backplates so that the traffic signal lights become more conspicuous. This is expected to be effective in both daytime and nighttime conditions and therefore intended to reduce unintentional RLR crashes. A study carried out by the Insurance Corporation of British Columbia and the Canadian National Committee on Uniform Traffic Control has concluded that reflective backplates are effective at reducing crashes. In addition, the FHWA encourages this treatment as a human-factor-enhancement of traffic signal visibility and conspicuity for older and colorblind drivers. According to the CMF Clearinghouse, the use of backplates with retro-reflective borders may result in a 15% reduction in all crashes at urban, signalized intersections (CMF Clearinghouse, 2005). Adding a retro-reflective border with strips of retro-reflective sheeting to an existing backplate is a low-cost safety treatment for existing traffic signals that lack standard backplates. The addition of backplates with a retro-reflective border can also be carried out (after structural capacity of the supports are tested). Shaw et. al also state that, in terms of color and size, implementation of backplates and retro-reflective borders must be consistent with the latest edition of the MUTCD (Shaw, et al., 2013).

Chapter 3 Methodology and Data

3.1 Characteristics of Red-Light-Running Crashes

Certain characteristics of RLR crashes might distinguish them from other crash types. For example, a particular age group of drivers may tend to run red lights more frequently than drivers of other ages. Consequently, crash data can be used to identify characteristics of these red-light violations. Subjected to data availability, characteristics evaluated in this study include driver characteristics, time distribution of RLR crash occurrence, crash severity, occupancy, road surface condition, and environmental factors.

This study relies on the Kansas Crash Analysis and Reporting System (KCARS) database, which includes all police-reported crashes in Kansas above a certain threshold. One variable recorded in the crash database is the contributing circumstances leading to the crashes. Identified driver contributing circumstances (driver CCs) reported in the crash database under three sub categories are: driver condition at the time of crash, distracted driver, and driver action at the time of the crash. A RLR crash is identified when driver action at the time of the crash is noted as "Red Light Running" (disregarded traffic signal). The list of contributing circumstances changed at the beginning of 2009 and law enforcement has taken the entire year to switch to the new crash reporting system. Accordingly, crash data from 2010, 2011, and 2012 were used for this study because the 2009 data may not be as complete as the later data.

From the entire crash dataset, intersection crashes were identified by crash location. Intersection crashes, intersection-related crashes, and crashes occurring within access to a parking lot/driveway were filtered out. Signalized intersections in which the traffic control type was a properly functioning traffic signal were then filtered. Crashes at the following intersection types were omitted: roundabouts, traffic circles, sections of interchange, and unknown intersection types. RLR crashes that occurred in interchange areas, crossovers and toll plazas, and roundabouts or traffic circles were not subjected to further analysis. From the filtered dataset, RLR crashes were identified and the rest were used as the control sample.

The contingency table analysis tests whether or not a relationship exists between two discrete parameters.

H_0: Null hypothesis: two variables are independent of each other;

H_1: Alternative hypothesis: H_0 is not true.

$$\text{If the Chi-Square } (\aleph^2)_{\text{critical}} \begin{cases} > \aleph^2_{\text{estimated}}\text{; } H_0 \text{ is rejected;} \\ < \aleph^2_{\text{estimated}}\text{; No sufficient evidence to accept } H_0 \end{cases}$$

This simple statistical analysis was used to identify whether or not a relationship exists between a signalized intersection crash being a red-light-running crash and the parameters mentioned. Confidence interval was taken as 95% for all analyses.

3.2 Effectiveness of Retro-Reflective Backplates

3.2.1 Cross-Sectional Study

Cross-sectional studies identify the red-light violations at intersections with and without reflective signal backplates and then accredit the safety differences to reflective signal backplates. Conclusions are made by comparing average violation frequencies. In order to obtain reliable results, all intersections must be as similar to each other as possible in all factors that may possibly affect red-light violations.

The intersection at 21st St. and Washburn Ave. in Topeka, KS (see Figure 0.1**)** has retro-reflective backplates on all four approaches. Vehicle detection cameras located at five intersections in Topeka could be remotely accessed. A screen shot of the live video stream from the vehicle detection cameras at one of those intersections are shown in

Figure **0.3**.

The five intersections with vehicle detection cameras are shown in Figure 0.4. Among these intersections, the intersection at 21st St. and Fairlawn Rd.21st St. was recognized as an appropriate control site, considering the traffic volume, lane configuration, and signal configuration. Since retro-reflective backplates were installed before the current research study began, a before-and-after study of RLR violations was not possible at the location mentioned. Additionally, the latest crash data available is for the year 2012, and the installation of retro reflective backplates took place in August 2012, so a before-and-after study of RLR crashes could not be conducted. The next suitable option to identify any difference in RLR violations was to conduct a with-and-without study in which the rate of RLR violations at the intersection containing reflective tape is compared with intersections with no reflective tape.

Figure 0.1 Reflective tape at 21st and Washburn

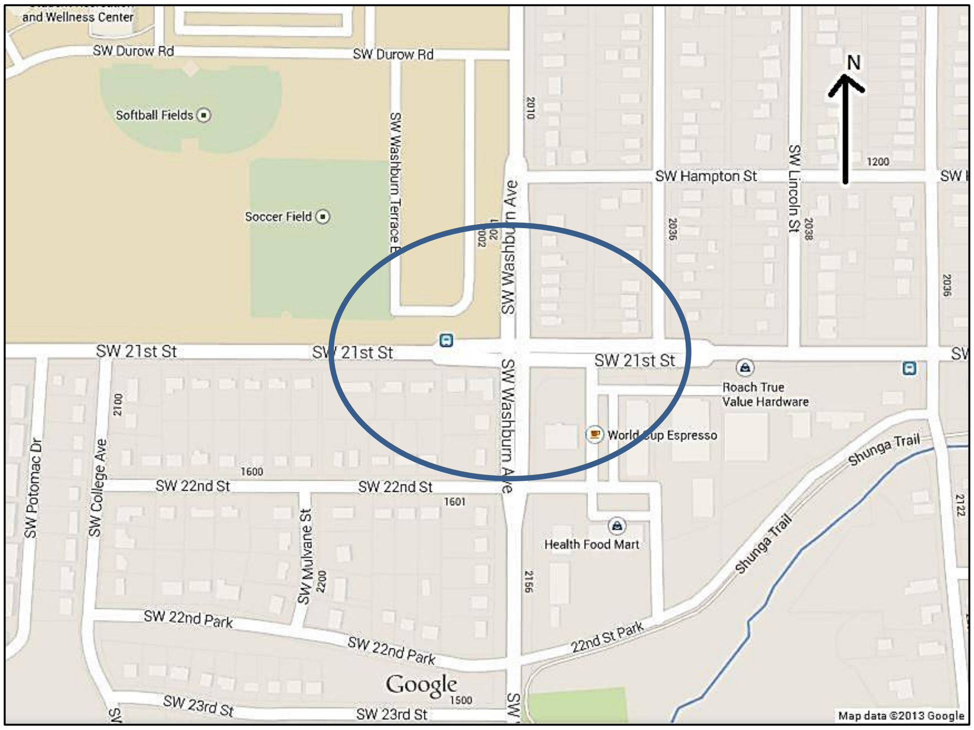


Figure 0.2 Intersection of Washburn Ave. and 21st St.

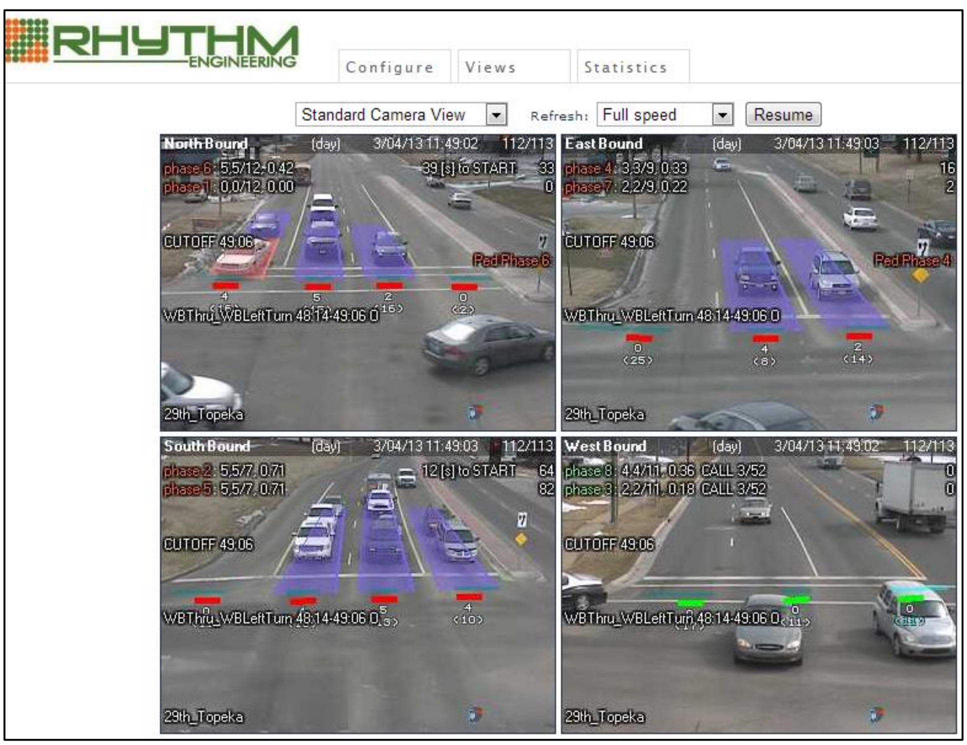


Figure 0.3 Screenshot of live video stream from vehicle detection cameras

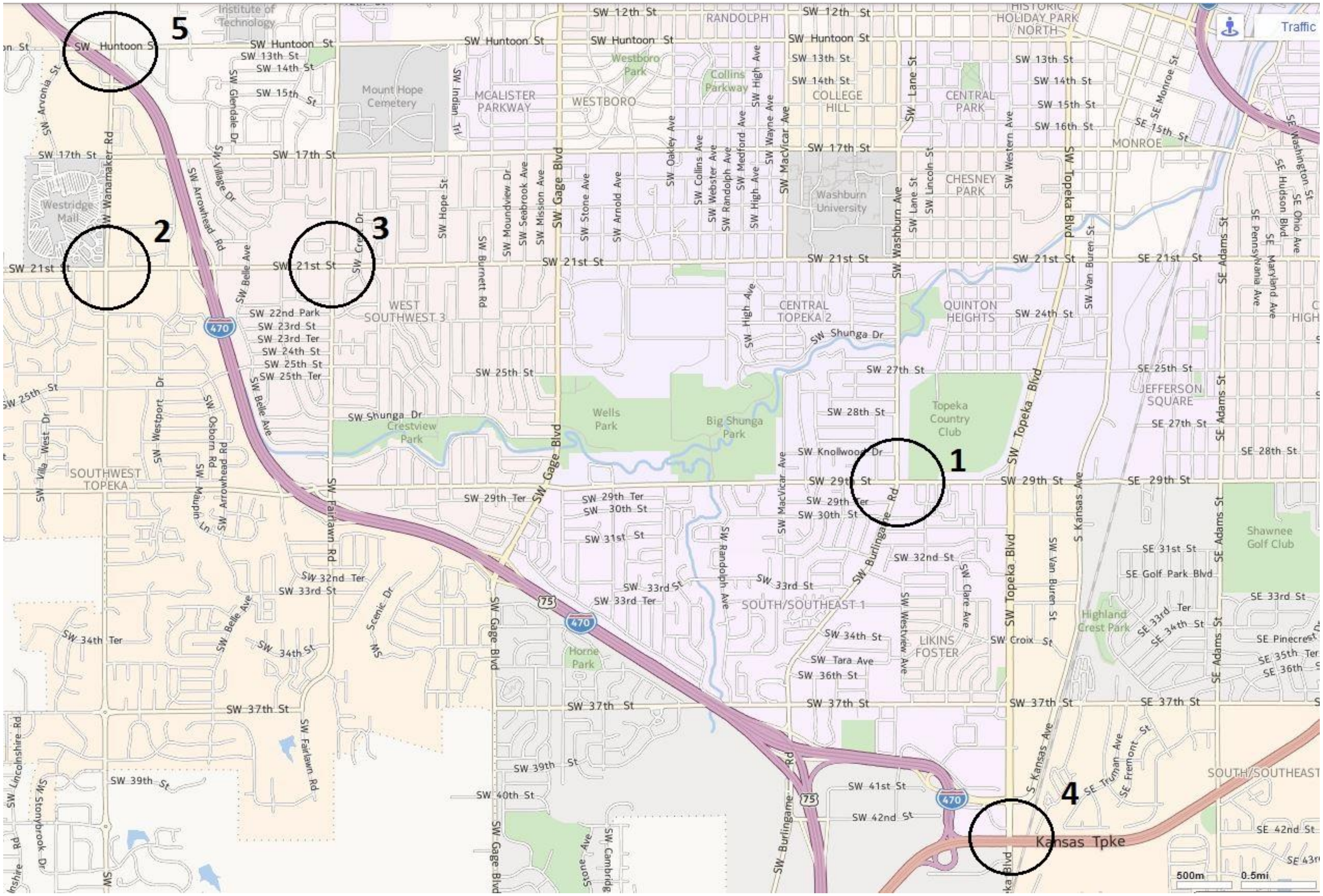


Figure 0.4 Intersections with accessible vehicle detection cameras - Topeka, KS

Traffic counts of each traffic movement and RLR violations were recorded using digital traffic counting devices while watching the videos. Live video streams from vehicle detection cameras at 21st St. and Fairlawn Rd. in Topeka, KS were accessible remotely for data collection. The intersection of Washburn Ave. at 21st St. is a busy intersection with approximately 17,000 Annual Daily Traffic (ADT) (City of Topeka, 2011) along each road. In order to evaluate treatment effectiveness, southbound and eastbound traffic on 21st St. were video recorded during morning and evening peak periods in order to detect red-light violations.

The observed data is analyzed using two-sample-t-test. The null hypothesis for a 2-sample t-test is:

$$H_0: \mu_1 - \mu_2 = \delta_0 \tag{3.1}$$

Where:

- μ_1 = the mean for the first population
- μ_2 = the mean for the second population
- δ_0 = the hypothesized difference between population means

The alternative hypothesis:

$$H_1: \mu_1 - \mu_2 > \delta_0 \text{ (One-tailed test)} \tag{3.2}$$

3.2.2 Before-and-After Study

The effectiveness of retro-reflective backplates can also be evaluated by observing RLR violations before and after introducing the retro-reflective tape to an intersection. As the first step, similar intersections were identified, and treatment sites and comparison sites were selected among them. Intersection similarities include intersection geometry, lane configuration, traffic flow, land use, and phases of traffic signal lights at the intersections to theextent it is practically possible.

Seven intersections in Manhattan, Kansas were initially selected and data collection was carried out to observe traffic counts and traffic violations. Traffic counts were taken in 15-minute intervals, where through and turning movements were counted separately. The set of intersections was selected based on large traffic volumes. Two hours of the morning peak period, 7:30 a.m. to 9:30 a.m., and two hours of the evening peak period, 4:30 p.m. to 6:30 p.m., were video recorded. Only one approach at each intersection was observed. The intersections observed were:

1. Eastbound on Anderson Ave. at Manhattan Ave.
2. Westbound on Anderson Ave. at 14^{th} St.
3. Eastbound on Bluemont Ave. at 11^{th} St.
4. Westbound on Poyntz Ave. at 11^{th} St.
5. Southbound on Seth Child Rd. at Southwind Pl.
6. Northbound on Seth Child Rd. at Claflin Rd. (see figure 0.5)
7. Northbound on Seth Child Rd. at Amherst Ave.

Figure 0.5 Video recording of northbound traffic on Seth Child Rd. at Claflin Rd.

Due to lower percentages of red-light-running and scheduled renovations of Bluemont Ave., these seven intersections could not continue be used for this study. Therefore, four other intersections were selected in order to continue the before-and-after study.

Second set of data collection

The second set of intersections were as follows:

1. Treatment site 1: Eastbound and westbound on Anderson Ave. at Sunset Ave.
2. Control site 1:Eastbound and westbound on Anderson Ave. at 17th St.
3. Treatment site 2: Northbound and southbound on Denison Ave. at Claflin Rd.
4. Control site 2:Northbound and southbound on Denison Ave. at Jardine Dr.

As indicated above, two approaches were observed at each intersection. Each treatment site was 0.3 miles apart from the control site along the same road.

The FHWA has mentioned a method to check the suitability of selected comparison sites when calculating CMFs, and identical methods and equations were adopted for this study to test the suitability of comparison sites. According to FHWA, a comparison site is suitable when ratios of expected crash counts in the after-period to expected crash counts in the before-period are equal to the comparison group and treatment group. These formulae were derived to match violation data instead of crash data. The derived equations are given below.

$$\text{Sample odds ratio} = \frac{(\text{Treatment}_{\text{before}}\text{Comparison}_{\text{after}})/(\text{Treatment}_{\text{after}}\text{Comparison}_{\text{before}})}{1 + \frac{1}{(\text{Treatment}_{\text{after}}} + \frac{1}{\text{Comparison}_{\text{before}}}}$$

(3.1)

Where,

$\text{Treatment}_{\text{before}}$= total red light violations for the treatment site in the before time period

$\text{Treatment}_{\text{after}}$ = total red light violations for the treatment site in the after time period

$\text{Comparison}_{\text{before}}$= total red light violations for the comparison site in the before time period

$\text{Comparison}_{\text{after}}$= total red light violations for the comparison site in the after time period

If the sample odds ratio is sufficiently close to 1.0, then the candidate reference site is deemed suitable for the study.

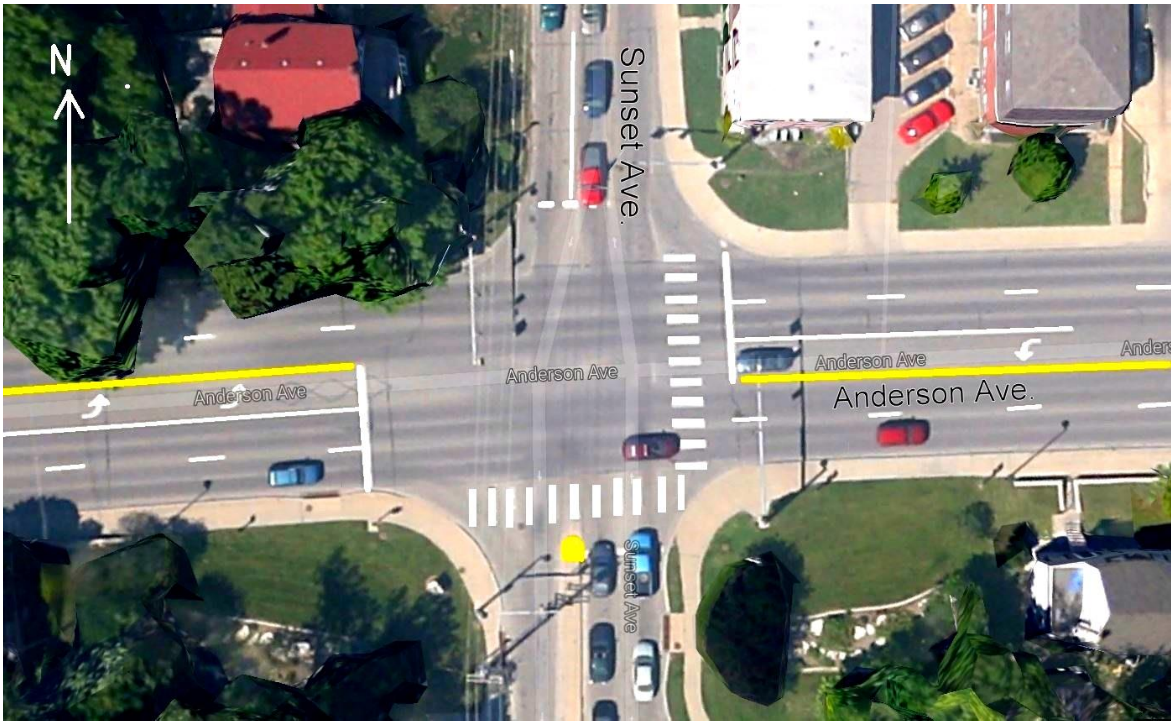


Figure 0.6 Lane configuration at Anderson/Sunset intersection

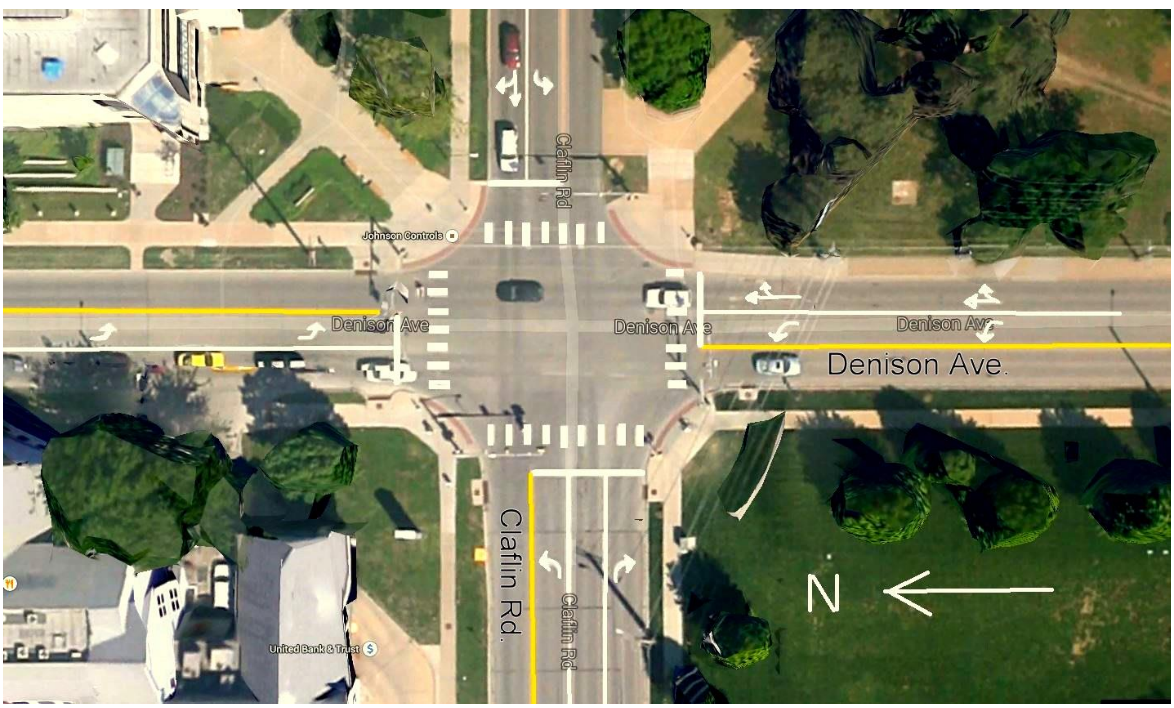


Figure 0.7 Lane configuration at Denison/Claflin intersection

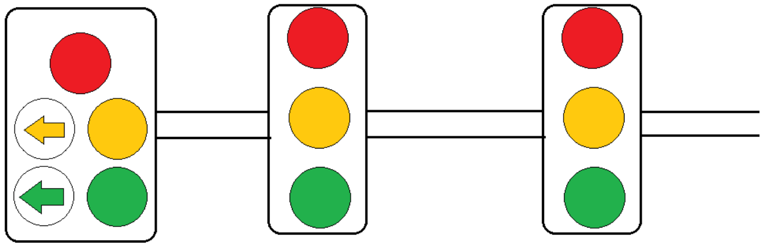


Figure 0.8 Layout of signal heads at the intersections

In order to obtain a larger sample size for higher reliability, data collections were carried out for longer time periods for this second set of intersections. These intersections were observed from 7:30 a.m. to 7:30 p.m., and the observation of these 12 hours was staggered throughout several days. Video recordings of traffic flows was the primary method of data collection. Video recordings were conducted so that the traffic stream at the stop line and the corresponding signal indication were captured in the same screen. A screen shot of a video recording is shown in Figure 0.9, and Figure 0.10 is a photo of video recording in progress at Anderson Ave. /17th St.

Figure 0.9 Screen shot of westbound traffic at Anderson/17th St.

Figure 0.10 Video recording at Anderson Ave. /17th St.

Installation of Reflective Backplates

According to the MUTCD (2009), Section 4D.12 – paragraph 21, the reflective strip should be a minimum width of 1 inch and a maximum width of 3 inches. The retro-reflective tape utilized in this study was a two-inch wide fluorescent yellow tape pasted on the backplate and leaving a one-inch border around the outer perimeter of the signal backplate. Two intersections were selected for the application of retro-reflective tape, and two approaches per intersection were treated with the tape. At the intersection at Anderson Ave. and Sunset Ave., retro-reflective tape was added to the signal heads facing westbound and eastbound traffic flows. At the intersection of Denison Ave. and Claflin Rd., the signal heads subjected to treatment were for northbound and southbound traffic flows. Since both these intersections already had backplates, pasting reflective tape was the only treatment that had to be carried out. Data for the before-study were collected during September 2013, and the retro-reflective tape was applied at both intersections on October 9, 2013. Less than one hour was required for the application of tape at one intersection. Data for the after-study was collected during October and November.

Signal lights at Treatment Site 1 with the reflective tape is shown in Figure 0.11. Figure 0.12 shows the traffic signal mast arm facing northbound traffic at Treatment Site 2 before and after retro-reflective tape was introduced. Figure 0.13 and Figure 0.14 are photos taken when the tape was applied on signal backplates facing southbound traffic along Denison Ave. at Claflin Rd. The same mast arm with retro-reflective tape is shown in Figure 0.15 and Figure 0.16.

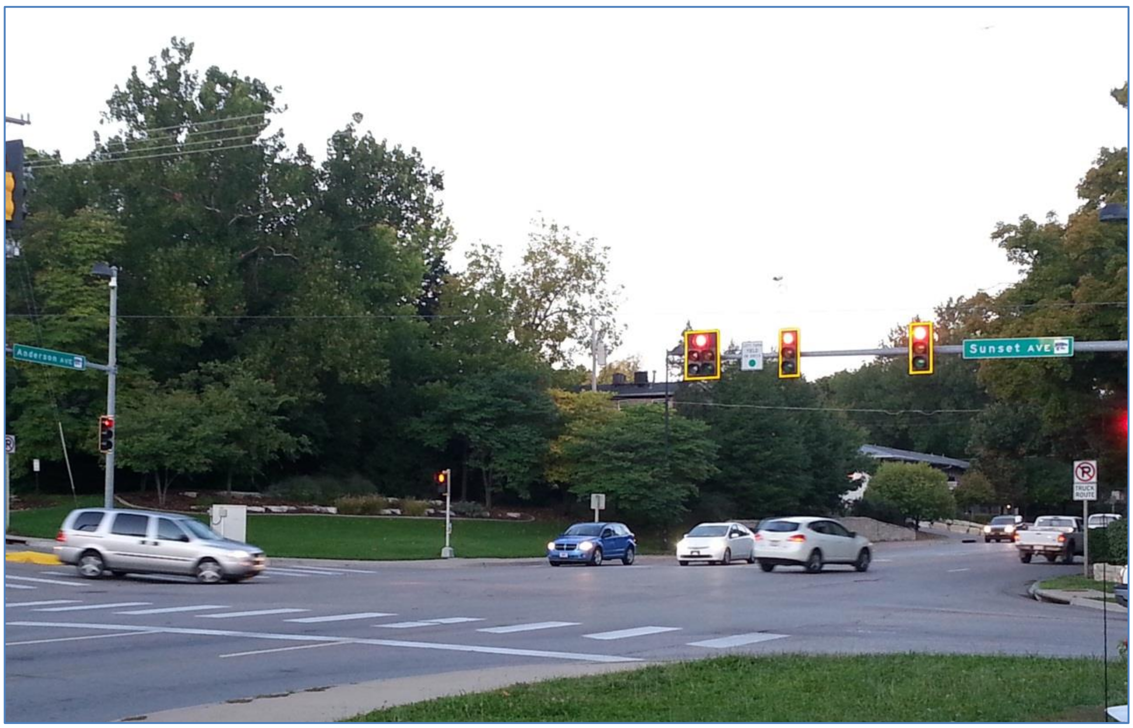


Figure 0.11 Signal backplates at Treatment site – 1 (Anderson/Sunset) after adding reflective tape

Figure 0.12 Signal backplates at treatment site – 2 before adding reflective tape

Figure 0.13 Installation of reflective tape – treatment site – 2

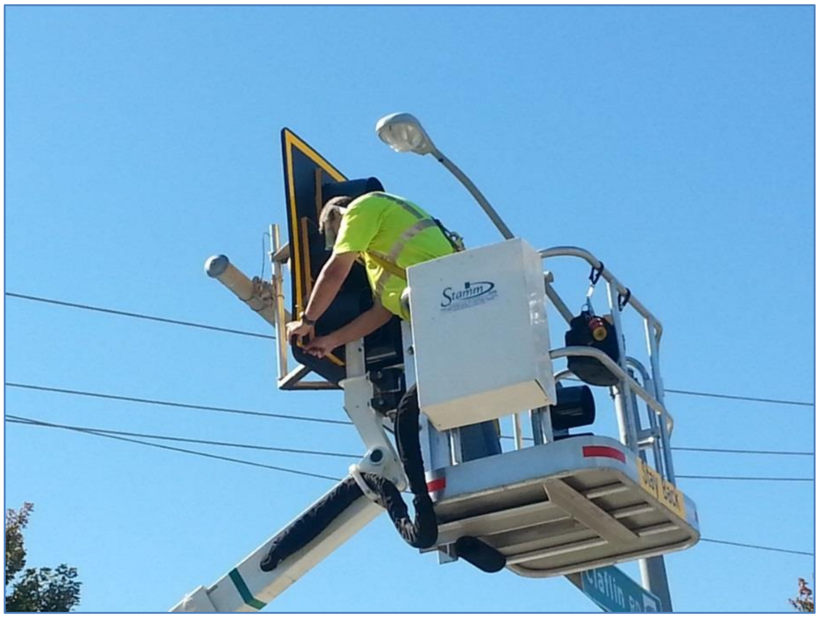


Figure 0.14 Treatment site – 2: Denison Ave. at Claflin Rd.

Figure 0.15 Signal backplates at Treatment site – 2 (Denison/Claflin) after adding reflective tape

Figure 0.16 Signal backplates at Treatment site – 2 (Denison/Claflin) after adding reflective tape

Equations derived using CMF Clearinghouse guidelines (Gross, et al., 2010) to calculate violation modification factors (VMFs) for different scenarios are given below:

$$N_{expected,T,A} = N_{observed,T,B} \left({N_{observed,C,A}} / {N_{observed,C,B}} \right) \tag{3.2}$$

$$\mathrm{Var}(\mathrm{N}_{\mathrm{expected,T,A}}) = \mathrm{N}_{\mathrm{expected,T,A}}{}^{2} ({1}/{\mathrm{N}_{\mathrm{observed,T,B}}} + {1}/{\mathrm{N}_{\mathrm{observed,C,B}}} + {1}/{\mathrm{N}_{\mathrm{observed,C,A}}}) \tag{3.3}$$

$$VMF = \frac{(\mathrm{N}_{\mathrm{observed,T,A}} / \mathrm{N}_{\mathrm{expected,T,A}})}{1 + {\mathrm{Var}(\mathrm{N}_{\mathrm{expected,T,A}})} / {\mathrm{N}_{\mathrm{expected,T,A}}{}^{2}}} \tag{3.4}$$

$$\mathrm{Variance(VMF)} = \frac{\mathrm{VMF}^{2} [(1/\mathrm{N}_{\mathrm{expected,T,A}}) + (\mathrm{Var}(\mathrm{N}_{\mathrm{expected,T,A}}) / \mathrm{N}_{\mathrm{expected,T,A}}{}^{2})]}{[1 + \mathrm{Var}(\mathrm{N}_{\mathrm{expected,T,A}}) / \mathrm{N}_{\mathrm{expected,T,A}}{}^{2}]^{2}} \tag{3.5}$$

Where,

$N_{observed,\ T,\ B}$ = the observed number of violations in the before-period for the treatment site

$N_{observed,\ T,\ A}$ = the observed number of violations in the after-period for the treatment site

$N_{observed,\ C,\ B}$ = the observed number of violations in the before-period in the comparison site

$N_{observed, C, A}$ = the observed number of violations in the after-period in the comparison site

$N_{expected, T, A}$ = the expected number of violations in the after-period in the treatment site

$Var(N_{expected, T, A})$ = Variance of $N_{expected, T, A}$

A paired t test is more appropriate to determine the difference in a before-and-after study. The null hypothesis for the *paired t-test* is:

H_0: Two population means are similar; $\mu_d = \mu_0$ (two-tailed test) (3.6)

Where:

- μ_d = the population mean of the differences
- μ_0 = the hypothesized mean of the differences

Alternative hypothese, H_1: Two samples are different; $\mu_d \neq \mu_0$ (3.7)

Chapter 4 Results and Discussion

4.1 Characteristics of Red-Light-Running Crashes

Summarized data for the total number of signalized intersection crashes and red-light-running (RLR) crashes are given in Table 0.1.

Table 0.1 Summary of all signalized intersection crashes and drivers involved by crash type

Year	RLR crashes		Non-RLR crashes		All signalized intersection crashes
	Frequency	%	Frequency	%	Frequency
2010	966	13%	6,510	87%	7,476
2011	939	12%	6,667	88%	7,606
2012	959	13%	6,434	87%	7,393
3-yr Total	2,864	13%	19,611	87%	22,475
Year	RLR drivers		Drivers involved in non-RLR crashes		All drivers involved in signalized intersection crashes
	Frequency	%	Frequency	%	Frequency
2010	1,018	7%	14,576	93%	15,594
2011	943	6%	14,648	94%	15,591
2012	980	6%	14,287	94%	15,267
3-yr Total	2,941	6%	43,511	94%	46,452

Null hypothesis says that the relationship between the tested parameter and the number of RLR crashes is similar to the relationship between the tested parameter and non- RLR crashes. All the non-RLR crashes considered in this study are signalized intersection crashes in which none of the drivers involved in the crash were running a red light. The alternative hypothesis says these relationships are different (i.e., the null hypothesis is not true), which implies that there is an effect on the RLR crashes from the tested parameter.

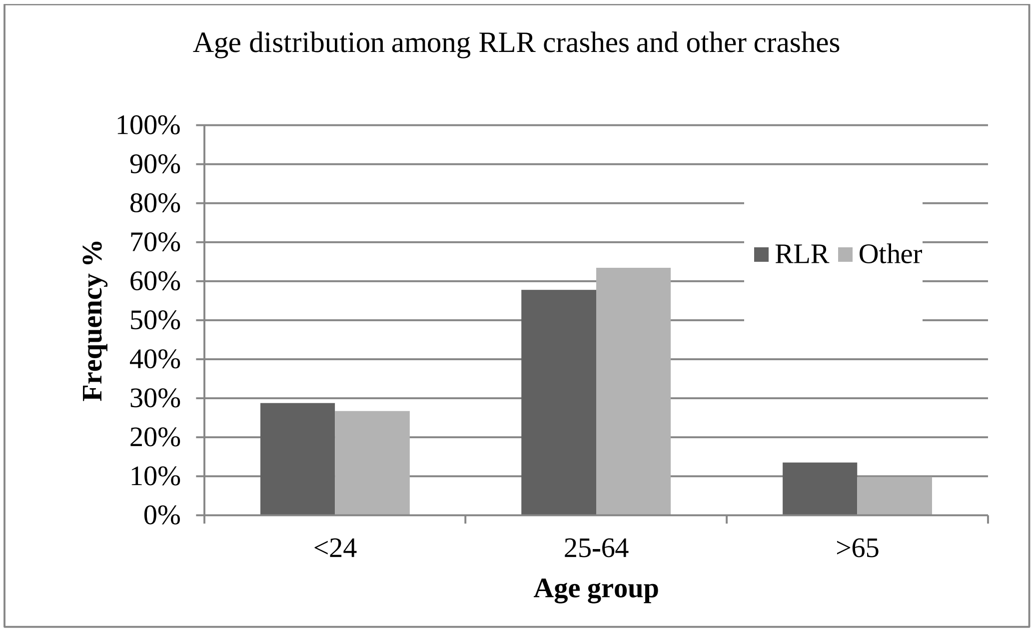
According to the contingency table analysis, RLR crashes and non-RLR crashes depend on driver age (see Table 0.2). Figure 4.1(a) shows that the percentage of RLR crashes by younger drivers (age < 24 yrs.) and older drivers (age > 65 yrs.) is overly represented. According to Table 0.2, injury severity of the driver depends on the crash type. Figure 4.1(b) reveals the likelihood that a red-light-running driver is injured or severely injured more often than non-RLR drivers.

Table 0.2 Relationship of driver characteristics to RLR crashes

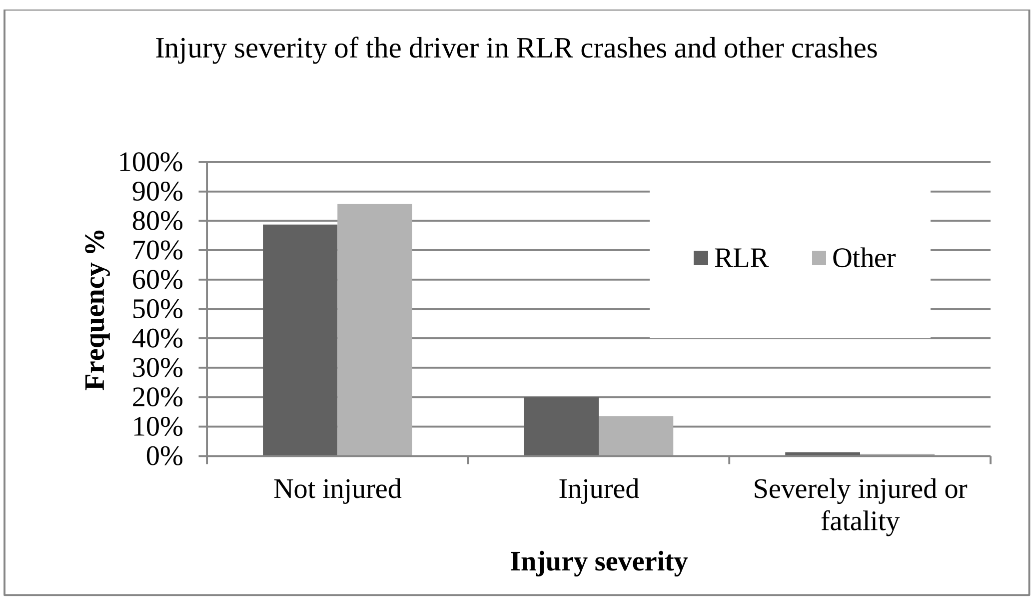
Independent variable	Crash type	Observed frequency	Expected frequency	d.f.*.	$\chi 2$ crit.	$\chi 2$ est.	Status of H_0)
Age							
<24	RLR	764	714	2	5.99	50.61	Rejected**
	Non-RLR	11,252	11,302				
25-64	RLR	1,536	1,679				
	Non-RLR	26,729	26,586				
>65	RLR	359	267				
	Non-RLR	4,132	4,224				
Injury severity of the driver							
Not injured	RLR	2,083	2,256	2	5.99	96.71	Rejected**
	Non-RLR	35,851	35,678				
Injured	RLR	530	370				
	Non-RLR	5,691	5,851				
Severely injured or fatality	RLR	33	20				
	Non-RLR	303	316				
Gender							
Male	RLR	1,359	1,387	1	3.84	1.25	Failed to reject***
	Non-RLR	21,887	21,859				
Female	RLR	1,342	1,314				
	Non-RLR	20,677	20,705				
Safety equipment usage							
Used	RLR	2,485	2,509	1	3.84	13.16	Rejected**
	Non-RLR	40,205	40,181				

Not used	RLR	69	45				
	Non-RLR	705	729				

*d.f. = Degrees of freedom
** Rejected = Parameters tested are related
*** Failed to reject = No evidence for a relationship between the parameters



(a) Age Group

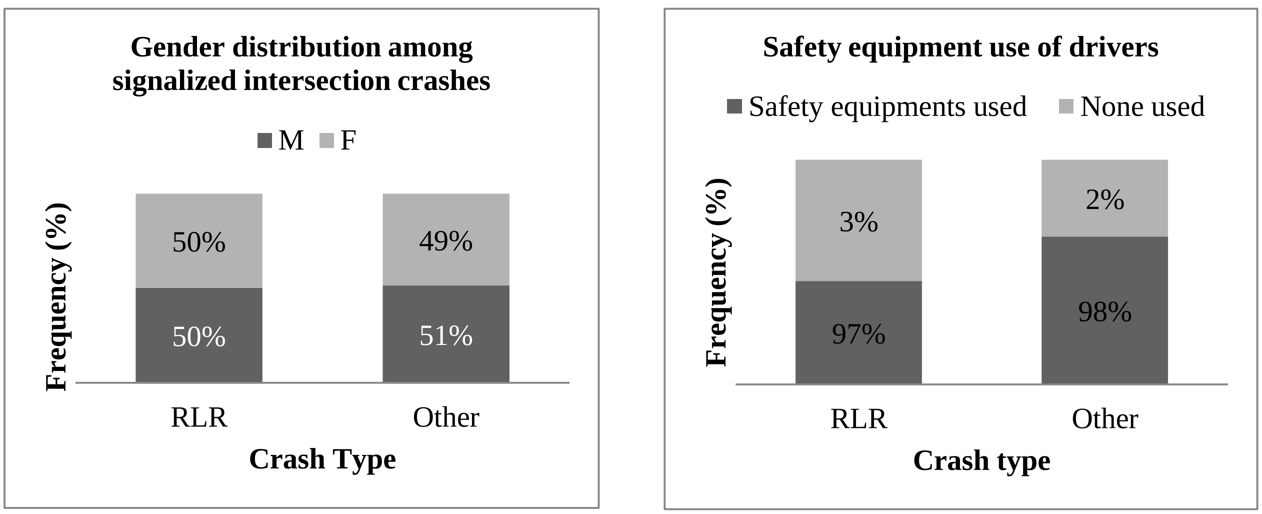


(b) Injury severity of the driver

Figure 0.1 Illustration of age distribution (a) and injury severity of drivers (b) related to signalized intersection crashes

Previous literature suggesting no difference in gender contribution in red-light-running crashes (Retting & Williams, 1996) was confirmed by results of this study, as demonstrated in

Figure **0.2** (a). This study found that there is a similar likelihood that a signalized intersection crash, either RLR or non-RLR, is caused by a male driver or a female driver.



(a) Gender distribution (b) Safety equipment use

Figure 0.2 Illustration of gender distribution (a) and safety equipment use of drivers involved in signalized intersection crashes (b)

In the Kansas crash database, categories in "at least one type of safety equipment was used" included driver records coded as either shoulder & lap belt, shoulder belt only, lap belt only, airbag deployed - shoulder & lap belt, or airbag deployed - shoulder belt only, airbag deployed - lap belt only, both motorcyclist helmet & eye protection, botorcyclist eye protection, or botorcyclist helmet. Categories in "none was used" include airbag deployed only (Passive system), and none used. A contingency table analysis revealed that safety equipment usage of the driver is related to type of the crash, as in whether the crash was a RLR crash or not. However, almost all drivers (97.5%) involved in all signalized intersection crashes used at least one type of safety equipment [see

Figure **0.2**(b)].

According to the contingency table analysis shown in Table 0.3, crash type and time of crash are related. The percentage of RLR crashes occurring in the morning peak period (6 a.m. - 9 a.m.) is approximately equal to the percentage of non-RLR crashes during this period. During the evening peak period (4 p.m. – 7 p.m.), only a slight probability exists (9%) that an intersection crash is an RLR crash. According to the distribution of RLR crashes, the probability of an RLR crash occurrence is above average in off-peak hours (7 p.m. – 6 a.m. and 9 a.m. – 11a.m.), as shown in Figure 0.3 and Table 0.3.

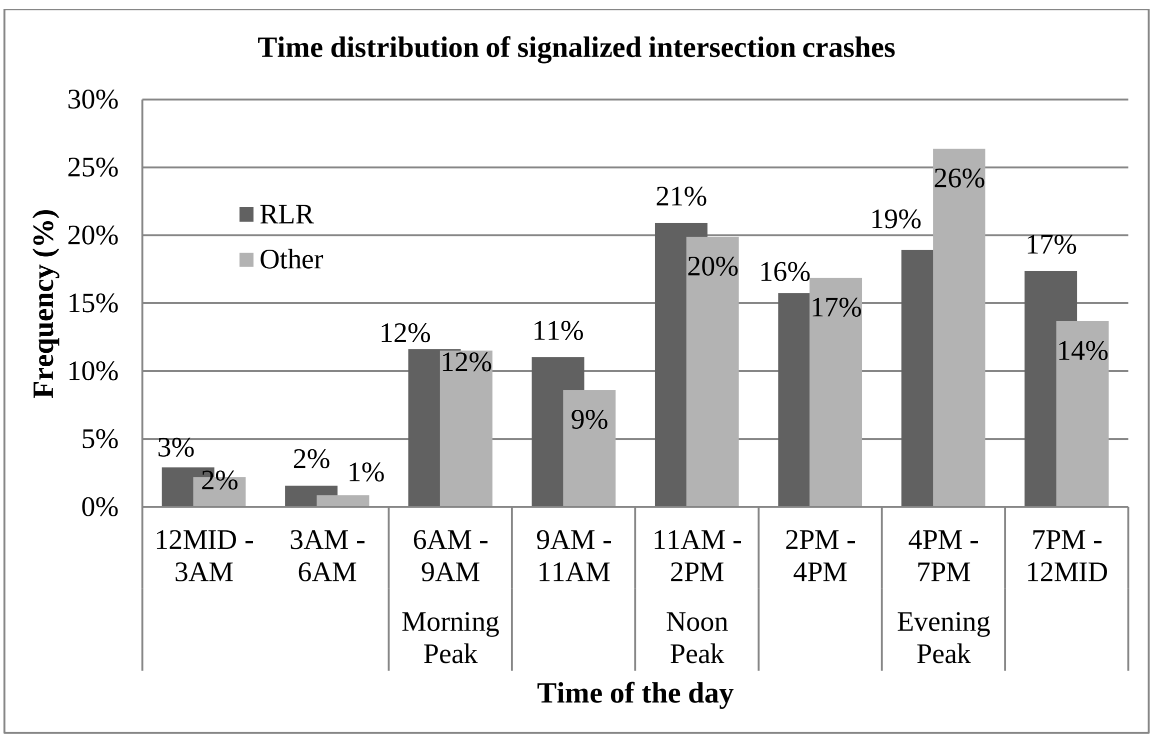


Figure 0.3 Time distribution of signalized intersections

As shown in Table 0.3, the contingency table analysis reveals that crash type and day of the crash are also related. Probability of occurrence of a RLR crash at a signalized intersection averages 12.0% for a weekday and 16.5% on weekends. Percentage comparison is shown in Table 0.4.

Table 0.3 Relationship of time and day of week with red-light-running crashes

Independent variable	Crash type	Observed Frequency	Expected frequency	d.f.*	χ2 critical	χ2 estimated	Status of the Null Hypothesis
Time of the crash							
12am – 3am	RLR	59	47	7	14.07	82.86	Rejected
	Non-RLR	15	327				
3am – 6am	RLR	32	19				
	Non-RLR	122	135				
6am - 9am	RLR	236	234				
	Non-RLR	1,638	1,640				
9am - 11am	RLR	224	181				
	Non-RLR	1,225	1,268				
11am - 2pm	RLR	425	407				
	Non-RLR	2,828	2,846				
2pm - 4pm	RLR	320	340				
	Non-RLR	2,399	2,379				
4pm - 7pm	RLR	385	518				
	Non-RLR	3,752	3,619				
7pm – 12am	RLR	353	288				
	Non-RLR	1,946	2,011				
Day of the crash							
Monday	RLR	394	420	6	12.59	80.91	Rejected
	Non-RLR	2,901	2,875				
Tuesday	RLR	423	431				
	Non-RLR	2,961	2,953				
Wednesday	RLR	406	456				
	Non-RLR	3,173	3,123				
Thursday	RLR	422	458				
	Non-RLR	3,176	3,140				
Friday	RLR	474	509				
	Non-RLR	3,521	3,486				
Saturday	RLR	393	350				
	Non-RLR	2,353	2,396				
Sunday	RLR	351	239				
	Non-RLR	1,523	1,635				

Table 0.4 Frequency distribution of RLR and other crashes based on day and time of crash

		RLR		Non-RLR	
Time of the crash					
Time		*Frequency*	%	*Frequency*	%
	12MID - 3AM	59	16%	315	84%
	3AM - 6AM	32	21%	122	79%
Morning Peak	6AM - 9AM	236	13%	1,638	87%
	9AM - 11AM	224	15%	1,225	85%
Noon Peak	11AM - 2PM	425	13%	2,828	87%
	2PM - 4PM	320	12%	2,399	88%
Evening Peak	4PM - 7PM	385	9%	3,752	91%
	7PM - 12MID	353	15%	1,946	85%
Day of the week					
Day		*Frequency*	%	*Frequency*	%
Weekday	Mo	394	12%	2,901	88%
	Tu	423	13%	2,961	88%
	We	406	11%	3,173	89%
	Th	422	12%	3,176	88%
	Fr	474	12%	3,521	88%
Weekend	Sa	393	14%	2,353	86%
	Su	351	19%	1,523	81%

*Highlighted cells are above average among its own set of data

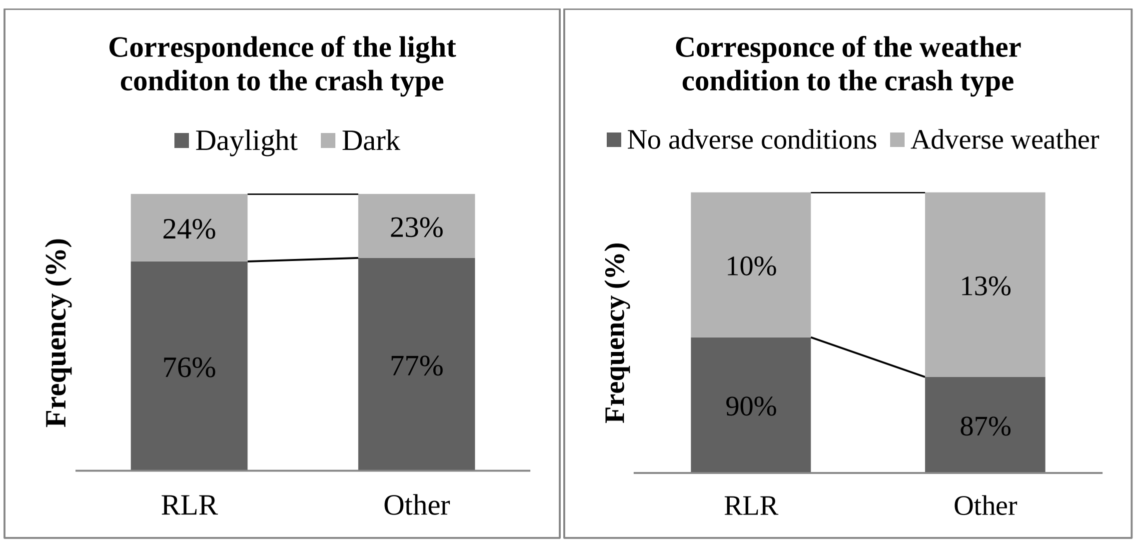
Similar to injury severity of the driver, analysis of crash severity revealed that crash type is related to the reported severity of the crash (see Table 0.5). Moreover, approximately 18% of injury and fatal intersection crashes are RLR crashes, whereas only 11% of Property Damage Only (PDO) crashes are RLR crashes. A higher probability exists that an RLR crash could be an injury or a fatal crash compared to non-RLR crashes, as shown in Figure 0.1 (b). Similar to the injury severity of the driver, results on crash severity also revealed that crash type is related to the severity of the crash.

Table 0.5 Relationship of light condition, weather condition, crash severity, and presence of passengers with red-light-running crashes

Independent variable	Crash type	Observed Frequency	Expected frequency	d.f.	α	χ2 critical	χ2 est	Status of the Null Hypothesis
Light condition								
Daylight	RLR	2,165	2,195	1	0.05	3.84	1.99	Failed to reject
	Non-RLR	15,048	15,018					
Dark	RLR	698	668					
	Non-RLR	4,542	4,572					
Weather condition								
No adverse conditions	RLR	2,564	2,493	1	0.05	3.84	18.10	Rejected
	Non-RLR	16,985	17,056					
Adverse weather	RLR	295	366					
	Non-RLR	2,575	2,504					
Crash Severity								
Property damage Only	RLR	1,665	2,008	2	0.05	5.99	224.3	Rejected
	Non-RLR	14,090	13,747					
Injury	RLR	1,192	852					
	Non-RLR	5,492	5,832					
Fatal	RLR	7	5					
	Non-RLR	29	31					
Presence of passengers								
Only the driver	RLR	2,143	2,106	1	0.05	3.84	2.44	Failed to reject
	Non-RLR	30,808	30,845					
One or more passengers present	RLR	797	834					
	Non-RLR	12,251	12,214					

Table 0.6 Relationship of the surface condition with red-light-running crashes

Independent variable	Crash type	Observed Frequency	Expected frequency	d.f.	α	χ2 critical	χ2 est	Status of the Null Hypothesis
Surface condition								
Dry	RLR	2,454	406	1	0.05	3.84	23.72	Rejected
	Non-RLR	16,032	3,494					
Wet	RLR	2,362	498					
	Non-RLR	16,124	3,402					



(a) Light condition (b) Weather condition

Figure 0.4 Illustration of environmental conditions related to signalized intersection crashes

The correspondence of environmental factors, light condition, and weather condition is evaluated in Table 0.5; it shows there was no relationship between crash type and light condition at the time of the crash. As shown in Figure 0.4 (a), in both RLR and non-RLR crashes, approximately 77% of crashes occurred in daylight conditions.

The contingency analysis found a relationship between road surface conditions and crash type in Table 0.6. Considering the percentages, only 14% of RLR crashes occurred on wet road surfaces, whereas 18% of non-RLR crashes happened in wet weather. The last parameter tested against the crash type was the presence of passengers. Results of this study showed that there is about 72.5% probability of a driver being alone when the vehicle faced a signalized intersection crash. This characteristic was found to be similar in both RLR and non-RLR crashes and it was also statistically proven that the behavior of the two crash types is not significantly different.

In summary, all the variables that were tested against any association with the crash types are listed in Table 0.7 as the final output of the first half of the study.

Table 0.7 Association of various factors with the RLR crashes and non-RLR crashes

Factors related to crash type	Factors **not related** to crash type
Driver related Factors	
Age	Gender
Injury Severity	
Safety equipment usage	
Environmental related factors	
Weather condition	Light condition
Other	
Crash Severity	Presence of passengers
Time of the crash	
Day of the crash	
Road surface condition	

4.2 Effectiveness of Retro-Reflective Signal Backplates

4.2.1 Cross-sectional study

For the cross-sectional study, a sample of data is defined as observed red-light violations per 15-minute intervals.

Traffic counts and the observed traffic violations are given in Appendix A.

At the intersection with reflective tape (21st & Washburn – Topeka, KS) there were 15 of such samples from eastbound and southbound combined. For the intersection without reflective tape (21st & Fairlawn – Topeka, KS) there were eight samples in total from northbound and eastbound combined. No RLR violations were detected in the southbound traffic along Washburn Ave. during the morning peak period, 7:30 a.m. to 9:30 a.m. However, there were four RLR violation in the eastbound traffic along 21st St. during the morning peak period, 7:45 a.m. to 9:30 a.m. There were 22 RLR violations during 8:15 a.m. to 9:15 a.m. at 21st and Fairlawn from eastbound and northbound combined.

Table 0.8 Summary statistics for cross-section study (*two-sample-t-test)*

Movements:	Presence of reflective tape	Statistics			
		Average number of red light violations per 15 minutes	Standard Dev.	p-value	Significance
Morning peak period					
Through and left turns	With	0.200	0.414	0.019	Significant reduction
	Without	2.750	2.820		
Right turns only	With	0.067		-	-
	Without	0.000			
Noon peak period					
Through and left turns	With	0.125	0.342	0.041	Significant reduction
	Without	0.860	0.900		
Right turns only	With	0.375	0.619	0.438	Not Sig.
	Without	0.429	0.787		

Two-sample-t-test statistics were used to identify the change of red-light violations due to the retro-reflective signal backplates.

Table 0.10 summarizes *two-sample-t-test* statistic for the cross-sectional study in which each sample contained the number of RLR violations per 15-minute intervals.

According to the *two-sample-t-test* statistic, the 15-minute-average number of RLR violations at the intersection with reflective tape is significantly less compared to the intersection without reflective tape when considering the entire traffic stream (through + right turns + left turns). Significance could not be tested statistically for the through movement alone, as there were no RLR violations in the control group for the through movement, and similar issues occurred for right turning movements. During the noon peak period, the 15-minute-average of the number of RLR violations in the through movements and left turns at the intersection with reflective tape was significantly less compared to the intersection without reflective tape. This difference was not observed when all three movements were combined.

4.2.2 Before-and-after study

Suitability of comparison sites was tested first; the calculations and results are shown in Table 0.9.

Table 0.9 Validation of selection of the comparison sites

	Before	After
Comparing intersections on Anderson Ave. at Sunset Ave. and 17th St.		
Treatment Site	53	42
Comparison Site	65	45
Comparing intersections on Denison Ave. at Claflin Rd. and Jardine Dr.		
	Before	After
Treatment Site	67	49
Comparison Site	77	82

For intersections on Anderson Ave. at Sunset Ave. and 17th St.:

$$\text{Sample odds ratio} = \frac{(53\times45)/(42\times65)}{1+\frac{1}{42}+\frac{1}{65}} = 0.84 \cong 1$$

For intersections on Anderson Ave. at Sunset Ave. and 17th St.:

$$\text{Sample odds ratio} = \frac{(67\times 82)/(49\times 77)}{1+\frac{1}{49}+\frac{1}{65}} = 1.41$$

Because the sample odds ratios are sufficiently close to 1.0, the selected comparison sites can be considered suitable.

Table 0.10 contains the summary of paired *t*-test statistics for significance of reduction in violations is included. Hourly frequencies of violations were calculated for each scenario and then the average 12-hour violations and their standard deviations were used in paired *t*-test to evaluate significance.

According to Table 0.10, a significant reduction in red light running occurred at Treatment Site 2 for through and left-turning vehicles. Control Site 2 did not indicate such a significant difference. However, after the treatment, no significant effects on right-turns-on-red at any intersection were noted. Although no reduction in the average hourly frequencies of RLR or RTOR violation occurred at Treatment Site 1, a reduction in the total number of violations for the 12 hours of observation time was observed, as shown in Table 0.11.

Table 0.10 Summary statistics for before-and-after study

Period		12-hour average violations		Significant reduction?	
		Through and left turn	RTOR	Through and left turn	RTOR
Treatment Site 1					
Before	Mean	2	2	Not significant	Not significant
	Std. Dev.	1	2		
After	Mean	1	2		
	Std. Dev.	2	2		
p value		0.067	0.426		
Control Site 1					
Before	Mean	3	2	Not significant	Not significant
	Std. Dev.	3	2		
After	Mean	2	2		
	Std. Dev.	1	1		
p value		0.206	0.133		
Treatment Site 2					
Before	Mean	4	2	Significant reduction	Not significant
	Std. Dev.	2	2		
After	Mean	2	2		
	Std. Dev.	2	2		
p value		0.029	0.367		
Control Site 2					
Before	Mean	5	2	Not significant	Not significant
	Std. Dev.	2	2		
After	Mean	6	1		
	Std. Dev.	4	2		
p value		0.738	0.154		

Where,

Mean = 12-hour average violations

Std. Dev.= Standard deviation of the mean

RTOR = Right turning on red without coming to a stop

Table 0.11 Violation modification factors using total number of violations during 12 hours

Movements included*	Total red light violations during 12 hours				Violation modification factor	95% confidence interval		90% confidence interval	
	Treatment Site		Comparison Site						
	Before	After	Before	After		Lower	Upper	Lower	Upper
Treatment Site 1/ Control Site 1									
1	53	42	65	45	1.083	0.514	1.653	0.605	1.561
2	23	14	33	20	0.894	0.205	1.582	0.316	1.472
3	28	10	5	7	0.185	0.003	0.367	0.032	0.338
4	51	24	38	27	0.612	0.221	1.002	0.284	0.940
5	28	26	27	18	1.234	0.359	2.110	0.499	1.969
Treatment Site 2/ Control Site 2									
1	33.5	25	77	82	0.651	0.277	1.025	0.337	0.965
2	27	18	38	51	0.459	0.150	0.768	0.199	0.718
3	15	9	17	15	0.570	0.054	1.087	0.137	1.004
4	42	27	55	66	0.507	0.218	0.795	0.265	0.749
5	25	22	22	16	1.054	0.263	1.846	0.390	1.718
Both intersections									
1	146	99	65	127	0.337	0.208	0.465	0.229	0.445
2	50	32	33	71	0.279	0.120	0.439	0.146	0.413
3	43	19	5	22	0.079	0.010	0.148	0.021	0.137
4	93	51	65	127	0.271	0.152	0.391	0.171	0.371
5	53	48	27	34	0.663	0.273	1.053	0.335	0.990

*Movements included	Movements included
1	Total traffic flow
2	Through traffic only
3	Left turns only
4	Through and left turning traffic
5	Right turns only

Chapter 5 Conclusion

5.1 Characteristics of Red-Light-Running

Red-light-running has had the attention of relevant authorities for many years due to the significant number of red-light-running-related crashes and resulting fatalities. Approximately 9,000 fatalities have been attributed to red light running from 2000 to 2009. While the U.S. Department of Transportation and other research groups have identified and tested red-light-running countermeasures, characteristic identification of red light running has also been carried out by few researches. This paper has considered signalized intersection crashes that occurred in Kansas from 2010 to 2012 to identify various factors related to red-light-running crashes.

Driver-related factors tested in this study included age, gender, and use of safety equipment. According to the contingency table analysis, age and use of safety equipment related to the crash type, whether the crash was red-light-running or another signalized intersection crash. Sufficient evidence was lacking to indicate any relationship with the gender of the driver and the crash type. An increased likelihood exists that a younger driver (age <24 years) or an old driver (age >64 years) will violate a red light compared to a middle-aged driver. Safety equipment usage was slightly less among red-light-running drivers than drivers involved in other signalized intersection crashes.

Injury severity and crash severity have both shown a relationship to crash type. A driver is more likely to be injured or die in RLR crashes compared to the control set. In addition, the reported severity of a crash is more likely to be an injury crash or a fatal crash rather than another type of signalized intersection crash (42% compared to 28%).

According to the contingency table analysis, the time of the crash and day of the week are related to crash type. Above-average red-light-running crashes were reported in off-peak hours compared to peak periods of the day. In addition, the observation was made that red-running-crash occurances are higher in percentage during weekends than the weekdays, proving that red light runners are not always the drivers who are late to work or school during the weekdays.

The effect of the presence of passengers on red light violations failed to be proven from the contingency table analysis. In both types of intersection crashes (RLR and other), more than 70% of drivers were alone in the vehicle when the crash occurred. A relationship between light condition and crash type was not observed from testing environmental factors in this study. More than 76% of crashes occurred in the daylight for both types of crashes, however, weather condition showed a relationship with crash type. Results showed that the possibility of an RLR crash occurring in adverse weather is less than the expected frequency. Among the many possible road conditions likely to affect red light running, only road surface condition was tested and it was found to relate to crash type.

5.2 Effectiveness of Retro-Reflective Signal Backplates

5.2.1 Cross-Sectional Study

Considering analyzed data for both morning and noon periods, it can be concluded that RLR violations related to through and left turning traffic movement are significantly less at the intersection with reflective tape. For all three movements, through, left turns and right turns, RLR violations were significantly less with reflective tape during the morning peak period. The difference was not significant for the noon peak period, yet lesser than the intersection without reflective tape. A conclusion could not be drawn for the right turning vehicles, as it shows different results for morning and noon data groups. One RLR violation was detected among the right turning vehicles along eastbound at the 21st St. and Washburn Ave. intersection (with-reflective tape) during 7:45 a.m. to 9:30 a.m., and there were no RLR violations among the right turns at 21st St. and Fairlawn Rd. intersection (without reflective tape; eastbound and northbound) during that time period. During the noon time period, RLR violations were less with the reflective tape, yet not statistically significant.

5.2.2 Before-and-After Study

A statistically significant reduction of RLR violations due to the addition of reflective tape was observed at one site out of the two tested sites. This does not provide strong evidence about the effectiveness of the reflective tape toward reducing RLR violations. However, violation modification factors developed for the combined through traffic flow and left turns was 0.271 with a 95% confidence interval ranging from 0.15 to 0.40. Considering only the right turns, the violation modification factor was 0.66, which shows lesser, but still positive, impact on RLR violations in the right turning vehicles.

Considering both the cross-sectional analysis and the before-and-after analysis, it can be concluded that adding retro-reflective signal backplates is effective in reducing red light violation in the through and left turning traffic, but it is not very effective in reducing the RLR violation in right turning vehicles.

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Appendix A

Detailed data collection for the with-and-without study is included here.

Table A.1 Counts for the morning session at 21st St. – Washburn Ave. intersection (with reflective tape)

Time (Morning)	Traffic counts			Violation counts					
				RT		Through		LT	
	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
Eastbound on 21st									
7.45 - 8.00 AM	34	180	23	1	2	1	12	0	3
8.00 - 8.15 AM	24	184	30	0	0	1	10	0	0
8.15 - 8.30 AM	28	111	22	0	0	0	6	0	1
8.30 - 8.45 AM	18	114	31	0	2	0	2	1	2
8.45 - 9.00 AM	18	78	22	0	0	0	4	0	1
9.00 - 9.15 AM	13	84	28	0	1	0	3	0	2
9.15 - 9.30 AM	17	66	9	0	0	0	0	0	0
Southbound on Washburn									
7.30 - 7.45 AM	21	85	9	0	0	0	3	0	0
7.45 - 8.00 AM	28	85	13	0	1	0	2	0	0
8.00 - 8.15 AM	27	82	5	0	0	0	2	0	1
8.15 - 8.30 AM	21	61	13	0	0	0	3	0	0
8.30 - 8.45 AM	21	64	5	0	3	0	2	0	0
8.45 - 9.00 AM	14	52	14	0	0	0	3	0	0
9.00 - 9.15 AM	15	72	15	0	0	0	2	0	0
9.15 - 9.30 AM	15	55	12	0	2	0	3	0	0

Table A.2 Counts for the morning session at 21st St. – Fairlawn Rd. intersection (without reflective tape)

Time (Morning)	Traffic counts			Violation counts					
				RT		Through		LT	
	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
Eastbound on 21st									
8.15 - 8.30 AM	15	88	23	0	1	0	2	0	5
8.30 - 8.45 AM	14	84	18	0	0	0	5	1	0
8.45 - 9.00 AM	23	92	25	0	1	0	2	0	0
9.00 - 9.15 AM	8	98	22	0	0	0	0	1	1
Northbound in Fairlawn									
8.15 - 8.30 AM	46	70	2	0	0	0	4	8	1
8.30 - 8.45 AM	34	44	14	0	4	0	2	5	1
8.45 - 9.00 AM	43	59	4	0	2	0	2	3	0
9.00 - 9.15 AM	33	68	16	0	1	0	4	4	1

Table A.3 Counts for the midday session at 21st St. – Washburn Ave. intersection (with reflective tape)

Time (Mid-day)	Traffic counts			Violation counts					
				RT		Through		LT	
	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
Eastbound on 21st									
11.30 - 11.45 AM	18	106	13	0	0	0	0	0	0
11.45 - 12.00 N	21	82	16	0	0	0	4	0	0
12.00 - 12.15 PM	25	96	11	1	0	0	6	0	0
12.15 - 12.30 PM	36	111	26	2	0	0	3	0	2
12.30 - 12.45 PM	33	101	14	0	0	0	5	0	0
12.45 - 1.00 PM	23	108	17	0	0	0	1	0	0
1.00 - 1.15 PM	19	99	17	1	1	0	1	0	0
1.15 - 1.30 PM	27	139	13	1	0	0	2	0	0
1.30 - 1.45 PM	26	109	18	0	0	0	3	0	0
Southbound on Washburn									
11.45 - 12.00 N	18	81	11	1	0	0	1	0	0
12.00 - 12.15 PM	19	85	15	0	0	0	0	0	0
12.15 - 12.30 PM	21	98	13	0	0	1	1	0	0
12.30 - 12.45 PM	17	106	19	0	1	0	6	0	0
12.45 - 1.00 PM	17	81	9	0	0	0	2	0	1
1.00 - 1.15 PM	26	91	12	0	0	0	4	0	0
1.15 - 1.30 PM	19	76	17	0	0	0	1	0	0

Table A.4 Counts for the midday session at 21st St. – Fairlawn Rd. intersection (without reflective tape)

Time (Midday)	Traffic counts			Violation counts					
				RT		Through		LT	
	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
Eastbound on 21st									
11.30 - 11.45 AM	33	112	10	0	2	0	2	0	0
11.45 - 12.00 N	30	136	20	2	6	0	1	2	0
12.00 - 12.15 PM	33	130	18	0	1	0	3	0	0
12.15 - 12.30 PM	23	117	18	0	1	0	1	1	0
12.30 - 12.45 PM	22	138	19	0	0	0	5	1	3
12.45 - 1.00 PM	38	147	22	0	3	0	2	0	1
1.00 - 1.15 PM	42	136	16	1	7	0	9	2	0

Appendix B

Data from the before-and-after study at the second stage is presented in detail in this appendix.

Table B.1 Before data for Anderson at Sunset - Eastbound

Traffic flow on Anderson Ave. at Sunset Ave.				Violation counts					
Eastbound	Traffic counts			RT		Through		LT	
Time	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
7.30 - 8.30 AM	77	329	22	2	2	0	4	0	0
8.30 - 9.30 AM	54	454	26	0	2	1	13	0	1
9.30 - 10.30 Am	52	365	12	1	0	0	18	0	0
10.30 - 11.30 AM	59	462	18	2	0	1	20	0	2
11.30 AM - 12.30 PM	107	557	16	0	2	1	18	0	1
12.30 - 1.30 PM	104	505	15	5	0	0	14	0	1
1.30 - 2.30 PM	72	420	11	0	3	0	9	0	0
2.30 - 3.30 PM	64	447	13	2	4	1	13	0	0
3.30 - 4.30 PM	103	455	9	1	1	1	16	0	0
4.30 - 5.30 PM	146	554	25	3	3	1	13	0	1
5.30 - 6.30 PM	106	522	12	0	2	1	16	0	0
6.30 - 7.30 PM	87	427	21	0	0	0	8	0	0
Total	1,031	5,497	200	16	19	7	162	0	6

Table B.2 Before data for Anderson at Sunset - Westbound

Traffic flow on Anderson Ave. at Sunset Ave.				Violation counts					
Westbound	Traffic counts			RT		Through		LT	
Time	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
7.30 - 8.30 AM	76	313	30	1	1	1	4	0	0
8.30 - 9.30 AM	107	291	18	4	4	2	17	0	2
9.30 - 10.30 Am	71	275	16	0	7	1	17	0	1
10.30 - 11.30 AM	115	334	29	1	3	1	16	0	3
11.30 AM - 12.30 PM	129	424	36	0	1	1	24	0	2
12.30 - 1.30 PM	144	527	51	3	11	4	28	1	5
1.30 - 2.30 PM	144	462	36	1	6	2	33	0	1
2.30 - 3.30 PM	148	523	36	1	5	2	18	1	1
3.30 - 4.30 PM	111	467	21	1	9	0	20	0	2
4.30 - 5.30 PM	150	647	48	0	6	0	13	0	3
5.30 - 6.30 PM	107	496	50	0	8	0	22	0	1
6.30 - 7.30 PM	303	458	42	0	5	2	14	0	1
Total	1,605	5,217	413	12	66	16	226	2	22

Table B.3 After data for Anderson at Sunset - Eastbound

Traffic flow on Anderson Ave. at Sunset Ave.				Violation counts					
Eastbound	Traffic counts			RT		Through		LT	
Time	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
7.30 - 8.30 AM	98	553	30	0	1	0	14	0	3
8.30 - 9.30 AM	64	445	26	1	1	0	23	0	1
9.30 - 10.30 Am	41	349	18	1	2	1	14	0	2
10.30 - 11.30 AM	54	360	8	3	2	0	11	0	0
11.30 AM - 12.30 PM	97	457	18	1	6	0	15	0	0
12.30 - 1.30 PM	106	461	22	1	5	2	15	1	1
1.30 - 2.30 PM	57	404	26	1	1	2	10	0	3
2.30 - 3.30 PM	72	439	13	0	4	0	16	1	0
3.30 - 4.30 PM	107	487	23	0	3	0	17	0	0
4.30 - 5.30 PM	145	560	26	0	2	0	8	0	0
5.30 - 6.30 PM	119	518	20	5	5	0	12	0	0
6.30 - 7.30 PM	83	455	13	2	0	1	26	0	0
Total	1,043	5,488	243	15	32	6	181	2	10

Table B.4 After data for Anderson at Sunset - Westbound

Traffic flow on Anderson Ave. at Sunset Ave.				Violation counts					
Westbound	Traffic counts			RT		Through		LT	
Time	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
7.30 - 8.30 AM	88	280	10	2	2	0	4	0	0
8.30 - 9.30 AM	95	299	20	4	10	1	29	0	1
9.30 - 10.30 Am	84	258	21	0	3	1	12	0	0
10.30 - 11.30 AM	111	373	33	1	6	0	12	0	1
11.30 AM - 12.30 PM	126	414	37	0	3	0	26	0	0
12.30 - 1.30 PM	120	470	33	1	9	1	25	0	1
1.30 - 2.30 PM	121	421	37	0	4	3	19	0	0
2.30 - 3.30 PM	120	506	34	0	4	0	27	0	2
3.30 - 4.30 PM	143	501	43	1	6	0	14	0	5
4.30 - 5.30 PM	106	591	49	0	1	0	13	0	2
5.30 - 6.30 PM	115	491	62	0	4	1	17	0	2
6.30 - 7.30 PM	101	441	50	2	4	1	24	0	0
Total	1,330	5,045	429	11	56	8	222	0	14

Table B.5 Before data for Anderson at 17th - Eastbound

Traffic Flow on Anderson at 17th St.				Violation counts					
Eastbound	Traffic counts			RT		Through		LT	
Time	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
7.30 - 8.30 AM	123	494	116	0	0	1	14	0	6
8.30 - 9.30 AM	101	454	69	1	2	0	18	0	1
9.30 - 10.30 Am	91	425	81	4	4	0	9	0	3
10.30 - 11.30 AM	110	596	64	0	6	0	13	0	0
11.30 AM - 12.30 PM	149	695	52	0	1	1	14	0	1
12.30 - 1.30 PM	142	696	41	6	2	5	14	1	1
1.30 - 2.30 PM	130	633	46	2	2	1	6	0	4
2.30 - 3.30 PM	158	664	38	1	3	3	17	0	2
3.30 - 4.30 PM	149	690	50	3	13	2	20	2	0
4.30 - 5.30 PM	200	791	21	2	5	2	13	0	0
5.30 - 6.30 PM	116	711	11	3	5	1	18	0	0
6.30 - 7.30 PM	92	635	10	0	2	0	20	0	2
Total	1,561	7,484	599	22	45	16	176	3	20

Table B.6 Before data for Anderson at 17th - Westbound

Traffic Flow on Anderson at 17th St.				Violation counts					
Westbound	Traffic counts			RT		Through		LT	
Time	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
7.30 - 8.30 AM	92	344	25	0	2	1	14	0	3
8.30 - 9.30 AM	62	344	19	0	3	0	15	0	0
9.30 - 10.30 Am	44	344	13	0	2	1	9	0	0
10.30 - 11.30 AM	59	480	31	2	3	0	16	0	3
11.30 AM - 12.30 PM	50	534	33	0	1	0	19	0	0
12.30 - 1.30 PM	80	491	58	0	1	5	11	0	0
1.30 - 2.30 PM	72	543	31	0	2	1	5	0	0
2.30 - 3.30 PM	56	566	54	0	0	2	19	0	1
3.30 - 4.30 PM	49	570	39	1	1	2	17	1	0
4.30 - 5.30 PM	55	663	66	0	3	2	33	0	2
5.30 - 6.30 PM	56	600	57	1	3	0	19	0	4
6.30 - 7.30 PM	43	580	42	1	1	3	39	1	1
Total	718	6,059	468	5	22	17	216	2	14

Table B.7 After data for Anderson at 17th - Eastbound

Traffic Flow on Anderson at 17th St.				Violation counts					
Eastbound	Traffic counts			RT		Through		LT	
Time	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
7.30 - 8.30 AM	113	450	103	0	3	0	6	0	4
8.30 - 9.30 AM	105	444	53	0	2	2	21	0	3
9.30 - 10.30 Am	100	435	47	3	2	0	7	1	3
10.30 - 11.30 AM	106	525	49	0	5	0	13	0	0
11.30 AM - 12.30 PM	150	781	79	3	3	0	22	0	0
12.30 - 1.30 PM	151	671	68	3	5	2	17	0	3
1.30 - 2.30 PM	104	628	55	0	2	1	19	0	0
2.30 - 3.30 PM	159	601	31	1	2	1	19	1	3
3.30 - 4.30 PM	167	669	46	1	10	0	21	0	0
4.30 - 5.30 PM	168	758	59	1	4	0	13	1	1
5.30 - 6.30 PM	151	788	20	0	6	2	24	1	0
6.30 - 7.30 PM	124	608	46	1	4	0	14	0	2
Total	1,598	7,358	656	13	48	8	196	4	19

Table B.8 After data for Anderson at 17th - Westbound

Traffic Flow on Anderson at 17th St.				Violation counts					
Eastbound	Traffic counts			RT		Through		LT	
Time	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
7.30 - 8.30 AM	96	307	35	3	3	2	7	0	1
8.30 - 9.30 AM	51	371	9	0	1	3	13	0	0
9.30 - 10.30 Am	36	330	25	1	0	1	17	0	2
10.30 - 11.30 AM	63	465	23	0	1	1	10	0	0
11.30 AM - 12.30 PM	53	455	36	0	6	1	12	0	5
12.30 - 1.30 PM	56	543	36	0	1	0	14	0	1
1.30 - 2.30 PM	69	481	26	0	1	0	11	0	1
2.30 - 3.30 PM	33	488	49	0	1	0	13	1	1
3.30 - 4.30 PM	46	586	53	0	0	1	8	0	3
4.30 - 5.30 PM	30	608	63	1	1	1	34	1	3
5.30 - 6.30 PM	47	584	37	0	4	1	33	0	1
6.30 - 7.30 PM	49	579	47	0	4	1	14	1	0
Total	629	5,797	439	5	23	12	186	3	18

Table B.9 Before data for Denison at Claflin - Southbound

Traffic Flow on Denison at Claflin				Violation counts					
Southbound	Traffic counts			RT		Through		LT	
Time	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
7.30 - 8.30 AM	57	249	90	0	1	3	10	0	6
8.30 - 9.30 AM	52	188	57	0	0	0	6	1	2
9.30 - 10.30 Am	47	172	46	0	0	3	2	0	0
10.30 - 11.30 AM	88	134	38	2	2	1	6	0	0
11.30 AM - 12.30 PM	75	157	59	0	3	0	3	0	1
12.30 - 1.30 PM	111	171	55	0	3	0	6	0	0
1.30 - 2.30 PM	56	218	74	0	2	1	2	1	0
2.30 - 3.30 PM	88	231	78	1	0	0	3	1	4
3.30 - 4.30 PM	118	213	55	2	2	1	9	0	2
4.30 - 5.30 PM	110	220	65	1	4	1	11	0	2
5.30 - 6.30 PM	93	193	62	3	3	0	9	0	0
6.30 - 7.30 PM	86	147	29	2	4	2	2	0	1
Total	981	2,293	708	11	24	12	69	3	18

Table B.10 Before data for Denison at Claflin - Northbound

Traffic Flow on Denison at Claflin				Violation counts					
Northbound	Traffic counts			RT		Through		LT	
Time	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
7.30 - 8.30 AM	64	133	28	2	0	0	4	2	3
8.30 - 9.30 AM	46	131	33	0	0	0	0	0	0
9.30 - 10.30 Am	40	94	42	1	0	1	1	0	1
10.30 - 11.30 AM	36	97	37	1	1	1	1	0	0
11.30 AM - 12.30 PM	49	177	74	1	0	0	1	1	2
12.30 - 1.30 PM	47	170	79	1	0	1	2	0	4
1.30 - 2.30 PM	36	248	128	1	0	2	9	1	6
2.30 - 3.30 PM	36	235	126	2	2	1	3	0	2
3.30 - 4.30 PM	43	203	109	1	0	1	7	1	3
4.30 - 5.30 PM	45	261	137	0	3	2	2	2	7
5.30 - 6.30 PM	43	205	101	1	1	5	7	1	4
6.30 - 7.30 PM	49	200	89	3	5	1	7	4	44
Total	534	2,154	983	14	12	15	44	12	76

Table B.11 After data for Denison at Claflin - Southbound

Traffic Flow on Denison at Claflin				Violation counts					
Southbound	Traffic counts			RT		Through		LT	
Time	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
7.30 - 8.30 AM	75	212	83	3	1	1	4	1	3
8.30 - 9.30 AM	71	160	49	1	1	0	3	0	0
9.30 - 10.30 Am	53	136	42	1	2	0	1	1	0
10.30 - 11.30 AM	63	153	50	0	2	1	3	0	3
11.30 AM - 12.30 PM	119	167	55	3	7	0	0	0	0
12.30 - 1.30 PM	89	165	57	2	2	0	7	0	1
1.30 - 2.30 PM	86	186	74	2	2	2	4	0	2
2.30 - 3.30 PM	117	158	54	3	2	1	6	0	0
3.30 - 4.30 PM	150	246	74	1	3	3	12	1	3
4.30 - 5.30 PM	127	238	100	0	5	2	8	3	3
5.30 - 6.30 PM	111	244	98	0	5	3	10	2	4
6.30 - 7.30 PM	81	250	91	0	1	1	3	0	1
Total	1,142	2,315	827	16	33	14	61	8	20

Table B.12 After data for Denison at Claflin - Northbound

Traffic Flow on Denison at Claflin				Violation counts					
Northbound	Traffic counts			RT		Through		LT	
Time	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
7.30 - 8.30 AM	39	111	37	1	0	0	0	0	0
8.30 - 9.30 AM	46	101	37	0	0	0	0	0	0
9.30 - 10.30 Am	29	117	25	0	0	0	2	0	0
10.30 - 11.30 AM	24	94	24	0	0	2	1	0	0
11.30 AM - 12.30 PM	45	96	51	1	0	0	2	0	1
12.30 - 1.30 PM	54	176	74	0	0	1	1	0	0
1.30 - 2.30 PM	51	186	81	2	0	0	3	1	1
2.30 - 3.30 PM	41	206	88	0	0	0	2	0	1
3.30 - 4.30 PM	52	196	80	0	0	0	0	0	0
4.30 - 5.30 PM	52	262	126	1	4	1	7	0	5
5.30 - 6.30 PM	49	250	97	0	1	0	6	0	5
6.30 - 7.30 PM	67	193	106	1	0	0	2	0	1
Total	549	1,988	826	6	5	4	26	1	14

Table B.13 Before data for Anderson at Jardine - Southbound

Traffic Flow on Denison at Jardine				Violation counts					
Southbound	Traffic counts			RT		Through		LT	
Time	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
7.30 - 8.30 AM	25	394	256	5	4	0	0	0	0
8.30 - 9.30 AM	13	287	113	3	1	4	6	0	0
9.30 - 10.30 Am	12	198	70	0	2	3	6	1	3
10.30 - 11.30 AM	7	196	68	0	0	0	7	2	1
11.30 AM - 12.30 PM	5	252	52	1	1	2	20	2	3
12.30 - 1.30 PM	30	272	102	2	0	2	5	1	4
1.30 - 2.30 PM	18	212	68	2	0	2	8	0	0
2.30 - 3.30 PM	18	205	65	0	0	2	5	1	5
3.30 - 4.30 PM	22	244	71	0	0	0	10	1	10
4.30 - 5.30 PM	19	261	92	0	3	2	10	0	12
5.30 - 6.30 PM	22	287	100	0	0	1	10	0	5
6.30 - 7.30 PM	23	320	118	1	1	3	9	0	3
Total	214	3,128	1,175	14	12	21	96	8	46

Table B.14 Before data for Anderson at Jardine - Northbound

Traffic Flow on Denison at Jardine				Violation counts					
Northbound	Traffic counts			RT		Through		LT	
Time	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
7.30 - 8.30 AM	52	149	13	0	0	1	0	0	0
8.30 - 9.30 AM	25	146	18	0	0	0	0	0	0
9.30 - 10.30 Am	12	198	70	0	2	3	6	1	3
10.30 - 11.30 AM	7	196	68	0	0	0	7	2	1
11.30 AM - 12.30 PM	14	231	55	2	0	2	16	2	3
12.30 - 1.30 PM	27	216	20	1	0	1	5	0	0
1.30 - 2.30 PM	45	275	25	1	0	2	12	1	1
2.30 - 3.30 PM	46	308	30	1	0	0	16	1	3
3.30 - 4.30 PM	26	288	23	1	1	1	13	0	2
4.30 - 5.30 PM	46	367	30	1	3	1	7	2	3
5.30 - 6.30 PM	25	232	15	1	1	2	2	0	2
6.30 - 7.30 PM	12	240	35	0	1	4	11	0	2
Total	337	2,846	402	8	8	17	95	9	20

Table B.15 After data for Anderson at Jardine - Southbound

Traffic Flow on Denison at Jardine				Violation counts					
Southbound	Traffic counts			RT		Through		LT	
Time	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
7.30 - 8.30 AM	26	396	272	6	4	0	0	0	0
8.30 - 9.30 AM	11	266	124	1	1	2	8	1	1
9.30 - 10.30 Am	23	202	94	1	0	1	7	1	0
10.30 - 11.30 AM	18	192	68	0	0	2	4	1	2
11.30 AM - 12.30 PM	25	222	80	1	0	1	8	0	4
12.30 - 1.30 PM	21	248	124	0	0	1	7	0	5
1.30 - 2.30 PM	9	182	71	0	0	0	5	0	1
2.30 - 3.30 PM	11	214	77	2	0	3	2	0	4
3.30 - 4.30 PM	32	284	125	0	1	5	4	5	8
4.30 - 5.30 PM	35	303	154	0	0	6	14	1	10
5.30 - 6.30 PM	23	280	95	0	0	2	8	0	2
6.30 - 7.30 PM	16	280	80	1	0	3	8	4	4
Total	250	3,069	1,364	12	6	26	75	13	41

Table B.16 After data for Anderson at Jardine - Northbound

Traffic Flow on Denison at Jardine				Violation counts					
Northbound	Traffic counts			RT		Through		LT	
Time	RT	Through	LT	Red	Amber	Red	Amber	Red	Amber
7.30 - 8.30 AM	53	149	15	1	0	0	1	0	0
8.30 - 9.30 AM	48	151	22	1	0	1	1	0	0
9.30 - 10.30 Am	34	139	13	0	0	1	0	0	0
10.30 - 11.30 AM	34	189	13	1	0	1	3	0	0
11.30 AM - 12.30 PM	25	255	25	0	0	0	1	0	0
12.30 - 1.30 PM	33	262	16	0	2	1	2	0	0
1.30 - 2.30 PM	42	259	18	0	1	4	6	0	0
2.30 - 3.30 PM	53	243	13	0	1	5	2	2	0
3.30 - 4.30 PM	35	324	23	0	0	2	4	0	0
4.30 - 5.30 PM	33	356	32	1	1	3	7	0	0
5.30 - 6.30 PM	14	277	37	0	0	6	2	0	0
6.30 - 7.30 PM	8	228	27	0	0	1	4	0	0
Total	412	2,832	254	4	5	25	33	2	0